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Biogenic carbon matrix with dual-mode adsorption capability: synthesis, characterization and mechanistic insights

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Highlights

- CBCM synthesized from waste prawn shell biomass.
- CBCM adsorption modeled for MG and CR dye removal.
- Higer adsorption capacity for MG (714.27 mg/g) than CR (476.19 mg/g).
- Predicted maximum MG adsorption capacity of 1132 mg/g.
- MG and CR removal followed chemisorption and pore diffusion.

Abstract

The transformation of biowaste into high-performance functional materials presents a promising strategy for sustainable environmental technologies. In this study, a novel biogenic carbon-based catalytic matrix (CBCM) was synthesized from prawn shell waste, integrating chitin-derived carbon and in-situ formed calcite to yield a hybrid material with distinctive structural and surface characteristics. Comprehensive characterization using X-ray diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR) revealed a composite architecture featuring both organic (Chitin) and inorganic (Calcite) crystalline domains, along with abundant surface oxygenated functional groups (O—H, C=O, CO-NH, and C—O). These structural attributes underpin the CBCM's dual-mode adsorption capability, enabling simultaneous and efficient uptake of both cationic (Malachite green) and anionic (Congo red) dyes. Kinetic and isotherm analyses highlighted the dominant roles of hydrogen bonding and π-π interactions, directly linked to the material's functional groups and porous surface morphology. Response surface modeling confirmed strong agreement between predicted and experimental adsorption capacities (R^2=0.978), underscoring the reliability of the structure-function correlation. This work demonstrates how rational design and valorization of marine biowaste can yield multifunctional materials, with the CBCM serving as a proof-of-concept platform for pollutant capture and broader environmental applications.

Graphical abstract