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Hydrothermal synthesis and optimization of rice husk-based hydroxyapatite composites for copper removal in aquatic systems

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Heavy metal contamination in soil and aquatic environments, originating from both anthropogenic activities and natural sources, poses significant risks to ecosystems and human health due to its high toxicity and persistence. Among these pollutants, copper (Cu) is widely distributed in sediments and water systems, necessitating effective immobilization technologies. Hydroxyapatite (HAP) has attracted attention as an eco-friendly adsorbent due to its low toxicity, chemical stability, and ability to immobilize divalent heavy metals via ion exchange with Ca^{2+} and surface reactions involving OH^- or PO_4^{3-} groups. Additionally, rice husk (RH), an abundant agricultural byproduct, can serve as a cost-effective biomass support that enhances economic viability through waste recycling. In this study, RH-HAP composite adsorbents were synthesized via a hydrothermal method, and the conditions were optimized by varying temperature (120℃-210℃) and pH (pH9–12). Structural properties and Cu adsorption tests were evaluated using XRD, BET, FT-IR, ICP-OES analyses. XRD results showed that the RH-HAP sample synthesized at 120℃ exhibited low crystallinity, while the sample at 210℃ contained calcite impurities. Therefore, 180℃ was determined as the optimal temperature. Under this optimal temperature, varying pH conditions revealed that while crystallinity decreased at pH 12, the specific surface area reached its maximum (98.88 m^2/g). FT-IR analysis revealed carbonate-related bands at 1417 and 891 cm^{-1} under strongly alkaline conditions, indicating carbonate incorporation into the RH-HAP structure. Cu adsorption capacities (q_e) at pH 9, 10, 11, 12 were 26.2, 33.1, 23.4, and 41.7 mg/g, respectively, with the highest performance observed at pH 12. The enhanced adsorption at high alkalinity is attributed to increased supersaturation, which promotes nucleation-dominated crystallization. This mechanism facilitates the formation of nanoparticles with high specific surface areas, thereby enhancing Cu adsorption. The developed RH-HAP composites demonstrate significant potential for immobilizing various divalent heavy metals, including Pb, Zn, and Co, in contaminated environments.