

ABSTRACT

Food waste generation has become a critical environmental challenge due to rapid urbanization, inefficient waste management systems, and increasing global food demand. Converting food waste into valuable materials aligns with circular economy principles and offers a sustainable pathway for mitigating pollution. Hydrothermal carbonization (HTC) is an emerging thermochemical process that transforms wet biomass into hydrochar without the need for energy-intensive drying. This dissertation investigates the sustainable production of hydrochar from food waste using two HTC pathways, pressure-reactor HTC and microwave-assisted HTC, and evaluates their performance for heavy metal adsorption. The study integrates process optimization, comprehensive physicochemical characterization, and adsorption modeling to establish hydrochar as an efficient, low-cost adsorbent for the removal of cadmium (Cd^{2+}), copper (Cu^{2+}), and nickel (Ni^{2+}) from aqueous systems.

Hydrochar was produced under varying temperatures, residence times, and feedstock-to-water ratios. A Minitab-based factorial design was employed to optimize HTC parameters to maximize hydrochar yield and achieve desirable surface properties. The resulting hydrochar was characterized using X-ray diffraction (XRD), X-ray fluorescence (XRF), Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), Brunauer-Emmett-Teller (BET) surface area analysis, and thermogravimetric analysis (TGA). These techniques provided insight into crystallinity, elemental composition, functional groups, morphology, porosity, and thermal stability. Activated hydrochar produced via the pressure-reactor method exhibited enhanced surface area and functional group development compared to non-activated microwave-derived hydrochar.

Batch adsorption experiments were conducted to evaluate the removal efficiency of Cd^{2+} , Cu^{2+} , and Ni^{2+} under varying pH, contact time, initial concentration, and temperature. Adsorption kinetics were modeled using pseudo-first-order and pseudo-second-order equations, while equilibrium behavior was assessed using Langmuir, Freundlich, and Temkin isotherms. Thermodynamic parameters (ΔG° , ΔH° , ΔS°) were calculated to assess spontaneity, enthalpy change, and entropy change associated with adsorption. The results demonstrated that adsorption was spontaneous and endothermic for all metals, with activated hydrochar showing superior uptake capacity. Langmuir isotherm behavior indicated monolayer adsorption, while pseudo-second-order kinetics suggested chemisorption as the dominant mechanism.

Overall, this research establishes food-waste-derived hydrochar as a sustainable and effective adsorbent for heavy metal remediation. The integration of HTC optimization, detailed characterization, and adsorption modeling provides a comprehensive understanding of hydrochar performance and mechanisms. The findings contribute to the development of environmentally responsible waste-valorization strategies and offer practical implications for wastewater treatment applications. This work advances the field of sustainable materials and demonstrates the potential of hydrochar as a viable solution for mitigating heavy metal pollution in aquatic environments.