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Separation of Methylparaben from Environmental Waters Using Invasive Plant Species-Derived Carbon Material under varying geochemical conditions

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Parabens are extensively used as preservatives in pharmaceutical and personal care products due to high consumption they are continuously discharged into wastewater and subsequently enter in the aquatic systems. Parabens are alkyl esters of p-hydroxybenzoic acid, which are not effectively removed by WWTP, resulting in ubiquitous occurrences in aquatic environment. Globally, methylparaben (MP) has been frequently detected in various environmental compartments, with particularly high concentrations reported in surface waters and wastewater treatment plant (WWTP) influents (>100 μg L^{-1}), groundwater (>200 μg L^{-1}), and drinking water (up to 6 μg L^{-1}). They pose harmful effects on ecological systems as well as human health due to their pseudo-persistent nature and characteristics as endocrine disruptors, and they also show carcinogenic potential at high exposure levels.

This study explores the efficacy of pyrolytic carbon materials derived from the biomass of invasive plant species, both raw and with acid modification, as an adsorbent for MP. The batch experiments were carried out to know adsorption isotherm and kinetics to understand the behavior of the MP with the materials.

The unmodified carbon material was transformed into a more efficient adsorbent through a stepwise design approach involving temperature-controlled pyrolysis at four different temperatures 350, 450, 600, and 900°C, followed by acid functionalization. This treatment resulted in significantly improved adsorption capacity and percentage removal efficiency across different water matrices. These acid-modified materials achieved effective MP removal efficiencies of ~99% at low concentrations and remain above 87% even at 150 mg L^{-1}. The adsorption capacity increased progressively from 10 mg g^{-1}, with increasing pollutant loading. The highest adsorption capacities were obtained at other water matrices, which were more than distilled water (51 mg g^{-1}), demonstrating the effectiveness of the materials under realistic environmental conditions. Experiments were further conducted to test the effectiveness of optimized material in different geochemically complex water matrices and under varying environmental conditions (pH, T, organic matter). These findings highlight the strong potential of invasive-plant-derived carbon materials as efficient, sustainable, and cost-effective adsorbents for methylparaben removal from aquatic systems.