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Design and Construction of Biochar Materials for Sustainable Remediation of Heavy Metal Contaminated Soil

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ABSTRACT

Soil contamination by heavy metals represents a critical environmental risk. Innovative and sustainable remediation strategies are urgently needed to address this global challenge. Biochar, derived from biomass pyrolysis, has gained attention as an eco-friendly material for heavy metal adsorption. However, its adsorption performance is highly dependent on the pyrolysis conditions and can be further enhanced through functionalization. In this study, wheat straw biochar was functionalized by incorporating metal-organic framework (MOF) MIL-100(Fe) based on Fe^{3+} ions bound by trimesic acid to create a high-performance nanocomposite. The specific surface area (SSA) of biochar from wheat straw was 36.6 m^2/g with a total pore volume of 0.046 cm^3/g. To obtain biochar, wheat straw was pyrolyzed in a nitrogen gas flow (50 ml/min) at 700°C for 45 minutes and a heating rate of 10°C/min. MIL-100(Fe) was obtained by hydrothermal synthesis in a Berghof BR-200 Teflon autoclave at 120°C for 20 minutes. Coating biochar with MIL-100(Fe) increased its surface area sixfold, achieving 419 m^2/g, and doubled its sorption capacity for heavy metals in soil. Mechanistic insights into heavy metal adsorption were gained through a combination of XRD, SEM, EDX, and synchrotron EXAFS analyses, revealing two main interaction mechanisms: complexation and cation exchange. Thus, the findings highlight the potential of the biochar materials as an effective amendment for reducing heavy metal toxicity in soils.

Keywords: biochar, metal-organic framework, synthesis, nanocomposite, soil, contamination, adsorption

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