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Engineering Biochar for Environmental Adsorbents: Unveiling the Role of Bimetal and Nitrogen Doping

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The effectiveness of pyrolysis products of lignocellulosic biomass as environmental adsorbents is often limited by their relatively low adsorption capacity, primarily due to a restricted number of adsorption sites and low selectivity for target micropollutants. To address these challenges, various engineering techniques, including metal and nitrogen doping, have been employed to enhance the specific surface area (SSA) and introduce adsorption sites with high selectivity for specific micropollutant groups. Recent studies have shown that co-doping with two metals, a metal and nitrogen, or a combination of two metals and nitrogen is a promising approach. However, most of these focus on optimizing the engineering techniques to improve the adsorption capacity for specific micropollutants, providing limited insights into how these techniques influence the material characteristics. This study aims to advance the understanding of how metal and nitrogen doping affect the physicochemical characteristics of biochars derived from lignocellulosic biomass.

Pyrolysis of pinecone at 500 ^{o}C produced a biochar with 84% surface carbon content, an SSA of less than 1 m^2/g, and an average pore size of 59.5 nm. Introducing cobalt, iron, and nitrogen precursors to the pinecone biochar followed by heating at 700 ^{o}C effectively developed micropores, increasing SSA to 431.5 m^2/g and reducing the average pore size to 1.58 nm. Two key factors were critical for micropore formation: a sufficiently high temperature (≥ 600 ^{o}C) and the presence of metal precursors. Without these conditions, SSA remained below 10 m^2/g. Nitrogen doping, iron doping, and lower heating temperatures were found to decrease the graphitization degree of the carbon network. Interestingly, cobalt doping mitigated the disruptive effect of iron on graphitic structure. At 500 ^{o}C, cobalt and iron precursors primarily formed oxide phases, whereas at 700 ^{o}C, a significant portion transformed into alloy structures, which serve as effective adsorption sites for electrophilic micropollutants. Overall, this study provides valuable insights into how different engineering strategies influence the structural and chemical properties of lignocellulose-derived biochars, offering guidance for optimizing their performance as environmental adsorbents.