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LIGNIN-DERIVED SORBENTS FOR THE REMOVAL OF CONTAMINANTS FROM WATER

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Background: Lignin, a highly abundant by-product of pulp- and biorefinery operations, often constitutes up to 40 % of the dry mass of lignocellulosic feedstocks. Its under-utilisation represents both a waste challenge and an opportunity for valorisation. Heavy metal ions (e.g., Fe^{3+}, Cu^{2+}, Zn^{2+}, Cr(VI)) are persistent water-borne contaminants arising from industrial processes, and their removal remains a major challenge in water treatment. The aromatic, three-dimensional polymeric nature of lignin, enriched with hydroxyl and carboxyl functional groups, suggests potential as a low-cost sorbent for heavy metal remediation.

Methods: Different technical lignins were investigated: Kraft lignins derived from spruce and eucalyptus (both in native and methacrylated form), Organosolv spruce lignin, and a commercial alkali lignin. Comprehensive structural characterisation included elemental analysis, ^31P NMR quantification of OH and COOH groups, and gel permeation chromatography for molecular weight distribution. Batch adsorption experiments were conducted for Fe(III), Cu(II), Zn(II), and Cr(VI) ions under varying pH, contact time and initial concentration. Adsorption isotherms were analysed via the Langmuir model to assess sorption capacity and binding affinities.

Results: Under optimal conditions, removal efficiencies of up to ~93 % were achieved for chromate, copper, zinc and ferric ions. The sorption capacity correlated not only with the content of polar functional groups but also with the supramolecular structure of lignin—its mesh-like three-dimensional network and polydispersity. Methacrylated Kraft lignins exhibited enhanced sorption compared to unmodified samples, likely due to improved accessibility of active sites and modified hydrophilicity. Organosolv lignin also showed strong performance, attributable to its lower molecular weight and higher phenolic hydroxyl concentration. Kinetic studies indicated rapid initial uptake, with adsorption reaching equilibrium in a relatively short time. The optimal pH range was slightly acidic to neutral, correlating with favourable ion-speciation and lignin functional group ionisation.

Conclusions: Lignin-derived materials present a sustainable and cost-effective alternative to conventional synthetic sorbents for heavy metal removal from aqueous streams. Their structural tunability and abundance render them promising candidates for integration into water-treatment processes. Future work will focus on regeneration performance, composite sorbent design and the extension of this approach to other contaminant classes.