

# Cellulose-Polyphenol Bioadsorbents for Sustainable Water Pollutant Removal

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## Abstract

Sustainable water treatment solutions are critical to managing natural resources and minimizing environmental pollution, especially in regions facing industrial wastewater challenges and freshwater scarcity. This study presents a bio-based adsorbent developed from cellulose functionalized with two natural polyphenols, tannic acid (TA) and lignin (LN), for the simultaneous removal of heavy metals and phenol. To enhance water stability and reduce leaching, TA and LN were polymerized via laccase-mediated oxidation and further stabilized through epichlorohydrin crosslinking, forming a robust polyphenol network on the cellulose surface. The resulting composite showed high adsorption capacities: 2.52 mmol/g for Cu<sup>2+</sup>, 0.74 mmol/g for Pb<sup>2+</sup>, and 0.44 mmol/g for phenol at pH 4.0, with equilibrium behavior well-described by the Langmuir isotherm model. FTIR, SEM, and UV-vis spectroscopy confirmed successful polymerization and surface functionalization. The proposed adsorption mechanisms include chelation, ion exchange, electrostatic attraction, and  $\pi$ - $\pi$  interactions. Reusability tests showed that over 90% of Cu<sup>2+</sup> and Pb<sup>2+</sup> could still be adsorbed after three cycles, demonstrating excellent material durability and regeneration potential. These results highlight the potential of cellulose-polyphenol composites as green, low-cost, and reusable materials for sustainable water purification, promoting the circular use of lignocellulosic biomass and natural polyphenols in environmental remediation and industrial wastewater treatment.