Dual-Function Biochar-Alginate Beads for Heavy Metal Removal and as a Slow Release Fertilizer

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Access to safe drinking water remains a pressing global challenge, with millions exposed to heavy-metal contamination each year. At the same time, fertilizer runoff degrades water quality through harmful algal blooms, linking both issues to unsustainable water management. While effective treatments exist, they are often expensive or pollutive, making them inaccessible to low-income communities. Therefore, there is an urgent need for solutions that address both water and nutrient management in an affordable and sustainable way. Recent studies on biochar, a carbon-rich material derived from biomass, have shown its ability to absorb metal ions due to its porous structure. However, its powdered form limits recovery and reuse. To address this, this research incorporates biochar into cross-linked alginate beads to investigate effectiveness in adsorbing $Cu^{2?}$, $Pb^{2?}$, and $Zn^{2?}$ while enabling slow phosphorus release. Beads were formed in a calcium chloride bath and placed into 100 ppm metal solutions. Metal removal was measured over 48 hours using iodometric and EDTA titration, while phosphorus release kinetics were evaluated using water-extractable and Mehlich III tests. Results showed biochar–alginate beads removed more ions than alginate beads, reaching 87.3% for $Cu^{2?}$, 86.2% for $Pb^{2?}$, and 86.2% for $Zn^{2?}$. A paired t-test confirmed significance ($t = 3.26, 4.00, 3.08$; $t > 2.776$). A one-way ANOVA showed no difference between metals ($F = 0.176 < 3.89$), indicating consistent performance. Phosphorus release showed a stable trend, suggesting controlled release. Since alginate and biochar are biodegradable and low-cost, these results support biochar-alginate beads as an accessible, sustainable solution for heavy-metal removal with controlled nutrient release.

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