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Optimization, Characterization and Modeling of Functionalized Macadamia Nutshell Derived-Biochar for Drinking Water Defluoridation

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Abstract

Fluoride contamination in drinking water is a serious global environmental concern owing to its irreversible health effects. This study synthesized Zr(IV)-impregnated macadamia nutshell biochar (Zr-MNSB) by the surface modification of macadamia nutshell biochar (MNSB) and investigated its fluoride removal efficiency and biosorption capacity. Surface modification significantly enhanced the specific surface area and pore size. FE-SEM results exhibited increased porosity with Zr(IV)-impregnation and EDX confirmed Zr(IV) existence on the MNSB surface which enhanced fluoride removal performance. The effect of pH, co-existing ions, biosorbent dosage, contact time, and initial fluoride concentration were investigated using batch experiments. Zr-MNSB showed stable and excellent fluoride removal efficiency (78–99%) with initial fluoride concentration of 10 mg L^{-1} at a pH range of 2–8 compared to MNSB with 77.78% removal efficiency at pH 2 which declined significantly with pH increase. Zr-MNSB defluorinated naturally contaminated water below the WHO standard (1.5 mg L^{-1}). The Langmuir isotherm fitted well the experimental results with high R^2 (0.98) compared to the investigated isotherms and it exhibited maximum fluoride biosorption capacity of 11.97 mg g^{-1}. The pseudo-second-order kinetic model best suited the experimental results with high R^2 (≈1.0). The thermodynamic parameters viz., $\Delta H°$, $\Delta S°$ and $\Delta G°$ revealed that the fluoride removal process was endothermic, irreversible, random, spontaneous, rapid, and chemisorption in nature. Regenerated Zr-MNSB exhibited stable removal efficiency of 72–89% for three cycles but dropped significantly to 47% after the 4th cycle. Thus, this study developed a simple, affordable and efficient biosorbent that's potential for drinking water treatment.

Keywords: Agro-waste, Macadamia nutshell waste, Defluoridation, Biochar, Biosorption, Adsorption isotherms