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Abstract

As part of the first modification strategy, a two-step modification pathway of the material was developed and optimized. The use of a central composite design enabled the process to be described by a mathematical model and allowed for the determination of optimal reaction parameters. Characterization of the material using Fourier-transform infrared spectroscopy (FTIR) confirmed the effectiveness of the modification process by showing an increased intensity of bands corresponding to carboxyl group vibrations, as well as the appearance of new signals in the spectrum suggesting the incorporation of amino groups as a result of the reaction with the ammonia solution. The influence of solution pH on metal sorption was determined, which, due to the ionic nature of the surface, represents a key parameter in selecting the optimal sorption conditions. Sorption equilibrium studies demonstrated that the best fit was achieved with the Sips and Toth models, indicating a heterogeneous surface character of the sorbent. The material effectively bound Cr(III), Fe(III), and Cu(II) ions, while showing no efficient adsorption toward anionic As(V) species. Evaluation of the material's durability and regeneration capacity demonstrated high sorption stability during long-term operation. After 50 sorption–desorption cycles, the material retained 87–91% of its initial sorption capacity.

Within the second modification strategy, the focus was placed on the deposition of iron(III) oxide onto the surface of the material, which is known for its high affinity toward arsenic. The application of a four-factor central composite design enabled the determination of optimal conditions under which the material surface was highly covered with iron(III) oxide. Adsorption equilibrium studies of As(III) and As(V) revealed the best fit to the Sips and Toth models, confirming surface heterogeneity, whereas the kinetic data were best described by an irreversible pseudo-second-order reaction model.

The developed modification methods and obtained sorbent materials possess multiple advantages, including the ability to precisely tailor the geometry of 3D-printed structures, simplicity of modification procedures, accessibility of the base polymer, high sorption efficiency toward selected heavy metals, and regeneration capability. The application of 3D printing technology provides a simple and cost-effective approach to producing sorbent materials tailored to specific needs.