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# Development of Sulfur and Bromine Co-Doped Bentonite-Chitosan Hydrogels for Adsorption of Cobalt and Strontium Radionuclides

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This study explores the synthesis of sulfur- and bromine-co-doped bentonite and its three-dimensional chitosan composite hydrogels (S/Br-B-CB-x) for the effective and selective removal of radiotoxic contaminants, particularly the radionuclides $^{60}$Co and $^{85,90}$Sr. The physicochemical properties of the synthesized materials were analyzed using comprehensive characterization techniques. Batch adsorption studies were conducted to evaluate the effects of various parameters, including contact time, pH, adsorbent dosage, temperature, and co-existing anions, on the adsorption performance. Response surface methodology (RSM) was used to optimize these parameters, providing valuable insight into their combined effects on removal efficiency. The adsorption behavior followed pseudo-second-order kinetics. Isothermal analysis revealed that the adsorption of $^{60}$Co was best described by the Langmuir model, suggesting monolayer chemisorption, while the adsorption of $^{85,90}$Sr followed the Freundlich model, suggesting multilayer adsorption on heterogeneous surfaces. Mechanistic studies showed that electrostatic interactions, ion exchange, surface complexation and hard-soft acid-base (HSAB) principles contributed significantly to the adsorption performance. Furthermore, regeneration experiments showed that S/Br-B-CB-50 maintained excellent removal efficiency for $^{60}$Co and $^{85,90}$Sr over five consecutive cycles, demonstrating its high stability and reusability. The integration of RSM with adsorption experiments provided a robust framework for process optimization, ensuring maximum efficiency under practical conditions. These results confirm that S/Br-B-CB-50 is a highly effective and sustainable adsorbent for liquid radioactive waste remediation and offers a promising solution for the removal of hazardous radionuclides.