Amyloid–Chitosan Aerogels for Efficient Removal of Pharmaceutical Contaminants and Heavy Metals

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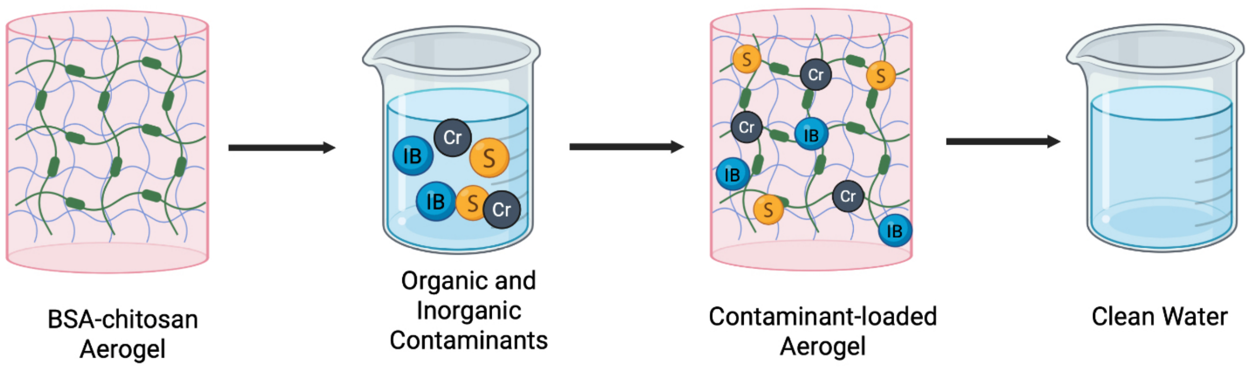
Water contamination by pharmaceutical residues and heavy metals remains a persistent global challenge, driven by the limited efficiency of conventional treatment processes. Contaminants, such as hexavalent chromium (Cr^{VI}) [1] released from metal finishing or textile, and widely used pharmaceuticals, including ibuprofen (IBF) and sulfamethoxazole (SMX) [2], are frequently detected in aquatic systems at concerning levels, which highlight the urgent need for sustainable and high-performance adsorbents.

Herein, we present a class of protein–polysaccharide composite aerogels constructed from bovine serum albumin (BSA) amyloid fibrils and chitosan as multifunctional adsorbents for the removal of both inorganic and organic contaminants. Amyloid fibrils were prepared via acid-induced self-assembly and used as building blocks for aerogel fabrication. Chitosan was added post-fibrillation at tunable ratios, followed by crosslinking and freeze drying to yield mechanically durable, highly porous aerogel networks. To the best of our knowledge, this is the first study to integrate BSA amyloid fibrils with chitosan in an aerogel platform for the simultaneous removal of pharmaceutical pollutants and toxic heavy metals.

Comprehensive characterization (SEM, BET, FTIR, XPS, zeta potential, swelling, and mechanical testing) revealed that the chitosan incorporation enhances surface charge density, functional group availability, and structural stability, which collectively enable efficient contaminant capture. Chitosan incorporation significantly improved the physicochemical properties of the aerogels, increasing young modulus from ~300 kPa for BSA-only systems to ~770 kPa in hybrid structures. All samples reached swelling equilibrium within the first 30 minutes, with higher chitosan content leading to increased water uptake due to the presence of additional hydrophilic functional groups. Furthermore, the BET surface area increased from ~117 to 130 $m^2\ g^{-1}$, accompanied by a rise in pore volume from 0.0456 to 0.0856 $cm^3\ g^{-1}$. As a result of these structural and surface enhancements, the aerogels exhibit outstanding adsorption performance, achieving >97% removal of Cr(VI) and >90% removal of IBF and SMX under the same conditions, with optimal pharmaceutical removal observed at pH 6 and pH 3 for Cr(VI).

Mechanistically, the adsorption process is governed by a synergistic interplay of electrostatic interaction, hydrogen bonding, and hydrophobic effects. This work underscores the potential of BSA-chitosan bio-derived, structurally engineered aerogels as sustainable platforms for advanced water purification systems.

Keywords:
Amyloid fibrils; Chitosan; Composite aerogels; Cr(VI); Pharmaceutical pollutants; Emerging contaminants



Amyloid–Chitosan Aerogels for Dual Removal of Heavy Metals and Pharmaceutical Contaminants

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