Ordered mesoporous silica SBA-15 functionalized with phosphonic acid groups for strontium removal from radioactive contaminated wastewater

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The effective removal of strontium radionuclides from contaminated water remains a critical challenge, particularly in the context of nuclear power plant operation and environmental remediation. Strontium-90, a fission product of uranium and plutonium, has a long half-life of 28.8 years, high biological toxicity, and significant mobility in aquatic environments, posing a serious risk of contamination to groundwater and surface waters. Modern nuclear power plants and facilities involved in the processing and storage of radioactive waste generate liquid waste streams containing strontium, which require efficient purification before release into the environment. Effective and selective adsorbents can significantly improve the remediation of radionuclide-contaminated water, reducing the need for costly and energy-intensive chemical or physical treatments. For this reason, materials with high affinity for Sr²⁺ ions, resistant to radiation and the presence of interfering ions, are being actively developed and for use in future purification systems in nuclear power plants, waste storage sites and emergency situations, such as contamination following an accident [1].

Various forms of silica-based strontium adsorbents have been tested to date, proving that the search for the ideal adsorbent for waste water remediation among silica-based materials is a valid approach [2, 3]. This research focuses on the development and evaluation of mesoporous silica-based adsorbents, with a particular emphasis on SBA-15. A comparative analysis with structurally related materials such as SBA-16 and MCM-41 highlights the superior properties of SBA-15, including its large, uniform mesopores, high surface area, and thick pore walls, which together ensure enhanced chemical stability and adsorption performance.

Solutions based on functionalized silica nanostructure are considered very and currently, ongoing research is being conducted to determine the best form of functionalisation leading to selective strontium adsorption [1]. Our research aimed to investigate the effectiveness and selectivity of phosphonic acid functional groups placed in the ordered mesoporous structure of SBA-15 silica. The synthesis of SBA-15 was followed by surface functionalization with phosphonic acid groups capable of binding divalent metal ions. The success of the functionalization process was confirmed using energy-dispersive X-ray spectroscopy (EDS) and Raman spectroscopy. Adsorption experiments were conducted using strontium-containing aqueous solutions, and the extent of strontium uptake was quantitatively evaluated via EDS. The results demonstrate the high potential of phosphonic acid functionalized SBA-15 as an efficient adsorbent for strontium ions, with significant advantages over other mesoporous silica frameworks. Moreover, its versatility allows for fabrication in powder, pellet, or thin-film forms, enabling adaptation to various application scenarios. These findings support the continued development of SBA-15-based materials for advanced water purification systems in nuclear and environmental applications.

1. Zhang, Shichang, et al. "Phosphination of amino-modified mesoporous silica for the selective separation of strontium." *Journal of Hazardous Materials* 467 (2024): 133741.
2. Chen, Zi, et al. "Selective removal of Sr2+ by cation exchange using silica-based titanate adsorbents." *Journal of Solid State Chemistry* 312 (2022): 123247.
3. Chen, Z., et al. "Preparation of silica-based titanate adsorbents and application for strontium removal from radioactive contaminated wastewater." *Journal of Radioanalytical and Nuclear Chemistry* 307.2 (2016): 931-940.