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Nano-enabled phosphates for wide-range of environmental applications

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This study demonstrates exceptional utility of various Phosphate-based nanostructures in water purification, bioremediation, and recovery of rare-earth elements. For example- Hydroxyapatite, calcium based nano-phosphate has been utilized for the removal of various toxic metals. We observed that Induction of non-stoichiometry in nano-hydroxyapatite (nSt-HAP) enhances its efficacy in ultra-fast sequestration of uranyl ions from water. Mechanisms characterized by X-ray absorption spectroscopy (XAS), reveals specific sites within nSt-HAP where U(VI) is preferentially trapped, elucidating an enhanced sequestration mechanism. This unique capability positions nSt-HAP as a promising candidate for rapid uranium removal below permissible limits.

In parallel, a novel nano-Farringtonite (ns-FAR), magnesium based nano-phosphate demonstrates remarkable sorption and continuous filtration capabilities for heavy metals and radionuclides. Extended X-ray absorption fine structure (EXAFS) spectroscopy confirms ion exchange and crystal incorporation as dominant removal mechanisms, showcasing ns-FAR's potential for permanent contaminant incorporation. Its ability to achieve high contaminant removal capacities positions ns-FAR as an efficient and sustainable solution for water treatment.

Further expanding the applications, oleic-acid functionalized mesoporous silica nanoparticles with a hydroxyapatite core (OA–nHAP@MSN) are engineered for targeted binding at oil–water interfaces. This design enhances the growth of hydrocarbon-degrading bacteria at the interface, providing a strategic approach for augmenting oil-spill bioremediation through nutrient supply.

Similarly, Dittmarite, ammonium-magnesium nano-phosphate has been magnetized and incorporated on sponges to achieve efficient REEs extraction from complex water matrices. In addition, Dittmarite-iron-ZIF67 nanocomposites showed its potential in water purification, mineralization and agricultural soil fertilization.

In summary, these investigations collectively underscore the broad and impactful environmental applications of phosphate-based nanostructures, offering a comprehensive toolkit for addressing diverse challenges in water management, pollution control, and sustainable resource utilization.