

Editorial

Iron-Based Nanoparticles for Water and Soil Treatment

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In the face of growing global water and soil pollution, scientists and engineers are turning to nanotechnology for innovative solutions, which has emerged as an essential tool with considerable potential benefits for environmental remediation [1]. Among the most promising tools in this field are iron-based nanoparticles [2]. Due to their small size, these particles present exceptional properties such as high surface area, reactivity, and mobility, which make them ideal candidates for water and soil treatment, particularly in removing toxic pollutants from groundwater and industrial wastewater, including the injection into contaminated aquifers. Recent reviews are available, offering a different approach: synthesis, manufacture, applications, enhancement of reactivity, stability, subsurface mobility, and use in remediation, etc. (e.g., [3-10]).

There are three main types of iron-based nanoparticles used in water and soil remediation [11]: zerovalent iron nanoparticles (nZVI), iron oxide nanoparticles (nFeO_x), and nanoparticles prepared by green chemistry from iron salts and extracts of plants (g-FeNPs). Reports for the removal of a wide range of pollutants with these materials are available: halogenated organics, nitroaromatics, pesticides, dyes, antibiotics, phenolic compounds, PCBs, nitrate, phosphates, heavy metals and metalloids (e.g., As, Cr, Hg, Pb, Cu, Ni, Zn, Cd, and Ag); works include activity against Gram-positive and Gram-negative bacteria (e.g., [12-17]). Remediation processes typically involve reduction reactions, adsorption or catalysis (e.g., use in Fenton-like reactions). nZVI are low-cost materials, with high reactivity; in some cases, noble metals (e.g., Pd, Pt, Cu, Ni) can be added to form



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nZVI/bimetallic materials, which increases the reduction rate. n-FeO_x are more stable towards oxidation or more efficient for the removal of certain pollutants, e.g., As, compared with nZVI. At the same time, g-FeNPs present a straightforward and cheap preparation and good activity.

Environmental applications of Fe-based nanomaterials have been significantly accepted by users and regulatory agencies, due to the low costs and the apparent absence of toxicity. The technology is rapid, highly effective, and becomes a low-cost alternative to conventional remediation technologies. However, some remaining problems must be solved for a wide application, such as increasing the stability of free nanoparticles to avoid agglomeration or aggregation, or resolving the difficulties for their injection into the soil. Polymers and other coatings have been used to stabilize nZVI [8, 18], leading to nanoparticles of greater reactivity.

The technology is an effective and versatile tool for the remediation of waters and soils, with removal rates of contaminants at much greater reaction rates than other reagents, the materials being highly efficient and affordable. The actual number of applications of Fe-based nanoparticles in contaminated sites and effluents is constantly growing. Applications vary from small-scale (household point-of-use treatments), *in-situ* methods, and much larger batch or flow-through applications. Moreover, the application of these nanoparticles in environmental remediation decreases the costs of large-scale installations and the duration of the processes. The materials present some advantages compared with others: a high efficiency, rapid reaction rates, and broad-spectrum pollutant removal. Their enhanced mobility allows for direct injection into contaminated aquifers. Compared to traditional methods, nanoparticle-based treatments can be more economical in the long term. Researchers are actively exploring surface modifications, coatings, and hybrid materials to overcome these limitations and enhance performance.

The integration of iron-based nanoparticles into water treatment systems is advancing rapidly. With ongoing research into safer formulations and scalable deployment strategies, these nanomaterials could become a cornerstone of sustainable water management. Their ability to target specific pollutants with precision and efficiency makes them a powerful partner in the fight against water and soil contamination.

Author Contributions

The author did all the research work for this study.

Competing Interests

The author declares no conflict of interest.

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