

Challenges and solutions of using magnetite nanoparticles for metal(loid) remediation

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The release of toxic heavy metals and metalloids into the environment is a global issue, affecting the health of millions around the world. Several strategies exist for removing contaminants from drinking water including filtration, biological remediation or adsorption by synthetic Fe(III) minerals such as ferrihydrite. Alternatively magnetite (Fe_3O_4) potentially yields greater performance due to its mixed valent nature (i.e. contains both Fe(II) and Fe(III)) and magnetic properties. The method of formation affects magnetite properties, including particle size, and concentration of surface bound Fe(II). These properties can be tailored to increase the reactivity towards environmental pollutants such as chromium. Fe(II) promotes Cr(VI) removal from suboxic and anoxic waters and soils via reduction to poorly soluble Cr(III) which precipitate as Cr(III) solids. For treating these pollutants, it is thus desirable to produce magnetite with high Fe(II) content, and a high surface area to volume ratio, i.e. nanoparticles ($d \sim 12$ nm). The application of these nanoparticles in flow through systems, e.g. column filters is impractical due their small particle size, which results in transportation of the magnetite, and hence pollutant, through the column. Furthermore, the fast reactions of magnetite with metal pollutants make complete characterization of the reactivity of the material challenging using conventional geochemical analytical techniques. Ultimately, this lack of understanding inhibits the potential to design optimal remediation strategies for environmental pollutants.

To overcome these challenges, we developed new methods to precipitate magnetite directly onto coarse and fine sand grains. We prepared both biogenic and abiogenic magnetite coated sand grains, with significant differences in the surface coverage achievable via each method. The magnetite still behaves as the nanoparticles, but by precipitation onto a sand matrix we have overcome transport issues. Coating onto sand also enabled us to use quick X-ray absorption (QXAS) to probe changes in the oxidation state of both Fe and Cr in very short time-intervals (~ 2 min), enabling a detailed analysis of the reactions as they take place (i.e. in-situ).

Overall, our results show the potential applications of magnetic nanoparticles coated onto a sand substrate to treat environmental pollutants.