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Pilot scale application of nanosized iron oxides as electron acceptors for bioremediation

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Microbial reduction of ferric iron is a major biogeochemical process in groundwater aquifer ecosystems and often associated with the degradation of organic contaminants, as bacteria couple iron reduction to the oxidation reduced carbon like e.g. BTEX. Yet in general the low bioavailability of natural iron oxides limits microbial reduction rates. However, nanosized iron oxides have an unequally enhanced bioavailability and reactivity compared to their respective bulk, macro-sized, and more crystalline materials. At the same time, nanosized iron oxides can be produced in stable colloidal suspensions, permitting efficient injections into contaminated aquifers.
We examined the reactivity of nanosized synthetic colloidal iron oxides in microbial iron reduction. Application of colloidal nanoparticles led to a strong and sustainable enhancement of microbial reaction rates in batch experiments and sediment columns. Toluene oxidation was increased five-fold as compared to bulk, non-colloidal ferrihydrite as electron acceptor. Furthermore, we developed a unique approach for custom-tailoring the subsurface mobility of these particles after being injected into a contaminant plume.
In a field pilot application, we injected 18 m3 of an iron oxide nanoparticle solution into a BTEX contaminated aquifer with a maximum excess pressure as low as 0.2 bar. The applied suspension showed a superior subsurface mobility, creating a reactive zone of 4 m height (corresponding to the height of the confined aquifer) and 6 m in diameter. Subsequent monitoring of BTEX, microbial BTEX degradation metabolites, ferrous iron generation, stable isotopes fractionation, microbial populations, and methanogenesis demonstrated the strong impact of our approach. Mathematic processed X-ray diffractograms and FTIR spectra provided a semi-quantitatively estimate of the long-term fate of the iron oxide colloids in the aquifer. Potential environmental risks of the injection itself were monitored with ecotoxicological investigations.
Our data suggest that the injection of ferric iron nanoparticles as electron acceptors into contaminated aquifers for the enhancement of microbial contaminant degradation might develop into a novel bioremediation strategy.