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Remediation of vinyl chloride-contaminated groundwater by granular ZVI-biochar

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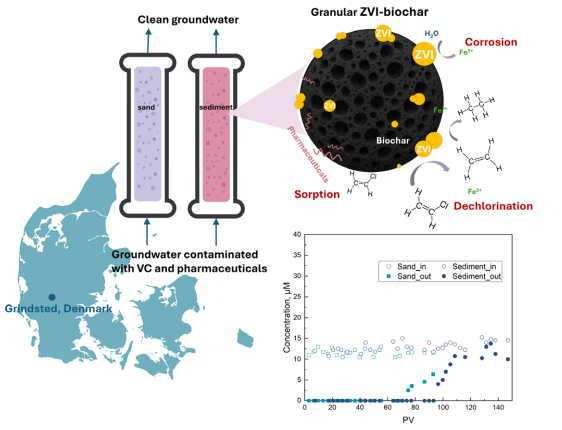

Chlorinated solvent plumes remain challenging to remediate, and vinyl chloride (VC) is particularly problematic due to its persistence, volatility and toxicity. We developed an effective granular biochar-supported zero-valent iron (ZVI-biochar) material for remediation of chlorinated solvent contaminated groundwater. The biochar matrix provides pre-concentration capacity, while the ZVI enables subsequent reductive dechlorination. The ZVI-biochar is synthesized via a one-step carbothermal reduction, in which Fe(III)-impregnated wood chips are pyrolyzed under oxygen-free conditions, reducing Fe(III) to Fe(0) through syngas generated during biochar formation. Iron-based permeable reactive barriers are widely used for the remediation of chlorinated solvents, yet formulation as ZVI-biochar and its performance under advective groundwater flow remain uncertain, in particular the competing effects of complex groundwater matrices on sorption and reduction processes.

Here, continuous-flow column experiments were conducted using contaminated groundwater and sediment from a sandy aquifer in Grindsted, Denmark, where an extensive groundwater plume contaminated with VC and pharmaceuticals discharges into a nearby stream. Columns were amended with 1.4% (w/w) ZVI-biochar granules and operated at a flow rate of ~4×10^{-6} m s^{-1}. Complete VC removal was achieved under realistic groundwater and sediment conditions, outperforming the non-amended control columns. Breakthrough of transformation products (ethylene/ethane) indicated coupled sorption and reductive dechlorination, while apparent dechlorination kinetics differed between sediment-packed and quartz sand-packed columns. Mass-balance analysis and reactive-transport modelling reaffirmed considerable VC dechlorination and further showed that groundwater chemistry (acidity and dissolved inorganic carbon/CO_2; pH 5.7) strongly influenced ZVI reactivity under flow-through conditions. In addition to VC removal, the composite simultaneously sorbed co-occurring pharmaceuticals including sulphonamides and barbiturates. These results not only demonstrate the potential of granular ZVI-biochar for simultaneous removal of VC and pharmaceuticals in contaminated groundwater but also highlight that mitigating acidity (and associated CO_2-driven corrosion) is critical to preserve ZVI reactivity and enable durable field-scale reactive barriers.