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Electromagnetic induction of nanoscale zerovalent iron particles accelerates the degradation of chlorinated dense non-aqueous phase liquid: Proof of concept

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ABSTRACT

In this study, a novel electromagnetically enhanced treatment concept is proposed for in situ remediation of a source zone of chlorinated dense non-aqueous phase liquid (DNAPL) that is slowly dissolved, causing contaminated groundwater for centuries. Here, we used polystyrene sulfonate (PSS)-modified nanoscale zerovalent iron (NZVI) particles (ferromagnetic) in combination with a low frequency (LF) (150 kHz) AC electromagnetic field (EMF) to accelerate the degradation of the DNAPLs via enhanced dissolution and reductive dechlorination. Trichloroethylene (TCE) and tetrachloroethylene (PCE) were used in a bench-scaled evaluation. The PSS-modified NZVI successfully targeted the DNAPL/water interface, as evidenced by the Pickering emulsion formation. Dechlorination of TCE- and PCE-DNAPL was measured by quantifying the by-product formation (acetylene, ethene, and ethane). Without magnetic induction heating (MIH) by LF EMF, PSS-modified NZVI transformed TCE- and PCE-DNAPL to ethene and ethane at the rate constants of 12.19×10^{-3} and 1.00×10^{-3} μmol/h/m^2, respectively, following pseudo zero-order reactions. However, four MIH cycles of PSS-NZVI increased the temperature up to 87 °C and increased the rate constants of TCE-DNAPL and PCE-DNAPL up to 14.58 and 58.01 times, respectively, in comparison to the dechlorination rate without MIH. Theoretical analysis suggested that the MIH of the PSS-modified NZVI enhanced the dechlorination of TCE- and PCE-DNAPL via the combination of the enhanced thermal dissolution of DNAPL, the effect of increasing the temperature on the rate constant (the Arrhenius equation), and the accelerated NZVI corrosion. Nevertheless, the effect of the Arrhenius equation was dominant. For the first time, this proof-of-concept study reveals the potential for using polyelectrolyte-modified NZVI coupled with LF EMF as a combined remediation technique for increasing the rate and completeness of in situ chlorinated DNAPL source remediation.

1. Introduction

Chlorinated dense non-aqueous phase liquids (DNAPLs) entrapped in the subsurface as a result of either an accidental or intentional spill slowly dissolve, generating a toxic plume of contaminated groundwater. In addition, the DNAPLs persist as a long-term source of groundwater contamination, making the restoration costly and technically challenging and making it difficult to meet the cleanup targets in a reasonable amount of time through conventional remediation techniques (Fagerlund et al., 2007; Illangasekare et al., 1995; ITRC, 2002; Leeson et al., 2003; US.EPA, 2003). Nanoscale zerovalent iron (NZVI) particles are capable of the reductive transformation of chlorinated organics into

Abbreviations: AC, Alternate Current; CVOCs, Chlorinated Volatile Organic Compounds; EMF, Electromagnetic Field; EMFG, Electromagnetic Field Generator; ERH, Electrical Resistance Heating; IR, Infrared; LF, Low Frequency; DNAPL, Dense Non-aqueous Phase Liquid; MIH, Magnetic Induction Heating; MWH, Microwave Heating; NZVI, Nanoscale Zerovalent Iron; PCE, Tetrachloroethylene; PSS, Polystyrene Sulfonate; RFH, Radio Frequency Heating; RNIP, Reactive Nano Iron Particle; TCE, Trichloroethylene; TEM, Transmission Electron Microscope; VSM, Vibrational Sample Magnetometer.

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