

Removal of TCE from Clay Lenses by Multi-Phase Diffusion during Electrical Resistance Heating

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Extended Abstract

In-Situ Thermal Treatment (ISTT) is a group of technologies used to treat soil and groundwater in source zones containing volatile or semi-volatile organic compounds, including trichloroethene (TCE) and other chlorinated solvents. Heterogeneous geologies that contain clay lenses are a challenge for in-situ treatment using injection-based technologies because low-permeability zones are inaccessible and can have high concentrations of dissolved organic compounds. Incomplete remediation of clay lenses is a potential cause of persisting contaminant plumes. Therefore, mass removal in the interiors is key to avoiding rebound effects. A promising technique for clay geologies is electrical resistance heating (ERH) and related technologies such as ET-DSPTM. Laboratory experiments have demonstrated preferential heating in clay materials and preferential phase change at interfaces with soils with lower displacement pressures [1]. Other experiments have quantified gas production in the interior of clay lenses, which may exist as an unconnected phase within the low permeability clay [2]. The objective of this study was to experimentally quantify dissolved-phase TCE concentrations in 4-cm high consolidated clay (kaolin) lenses before and after ISTT using a two-dimensional soil cell. Gas production in the lens interiors was quantified by electrical resistance measurements to estimate gas saturations (S_g^{WS}). TCE concentration data were compared to analytical model results to determine the dominant mass transfer mechanism in each scenario. Low, moderate and high power levels were applied to produce either no gas, a disconnected gas phase, or a connected gas phase, for a duration of either 24 or 72 hours. Low power heating for 24 hours had a mean TCE concentration in the clay, expressed as C/C_o of 1.06 ± 0.23 , with no quantifiable gas presence. Moderate power heating had C/C_o values of 0.05 ± 0.01 and 0.04 ± 0.01 , and gas saturations of $S_g^{WS} = 0.17 \pm 0.03$ and $S_g^{WS} = 0.13 \pm 0.02$ for 72 and 24 hours of heating, respectively. High power heating reduced concentrations below detection limits and a connected gas phase of $S_g^{WS} = 0.52 \pm 0.07$. A diffusion model that considers changes in diffusivity with gas saturation was used to simulate TCE removal from the clay lenses. TCE concentration data were used to constrain fitting parameters, independent of the resistance measurements, and fit estimates of gas saturation (S_g^D). Gas saturation values fit to TCE concentrations were $S_g^D = 0.03 \pm 0.025$ for low power heating, and $S_g^D = 0.08 \pm 0.02$ and $S_g^D = 0.14 \pm 0.02$ for moderate power over 72 and 24 hours, respectively. High power treatment was estimated to achieve TCE reductions below detectable limits where $S_g^D \geq 0.22$. Good agreement between S_g^{WS} and S_g^D demonstrated the low power experiment was consistent with liquid phase diffusion; the high power experiment likely formed continuous gas channels. Rapid removal of TCE in the moderate power experiments was consistent with multi-phase (gas and water) diffusive transport and high gas saturations at the lens exterior. Diffusion effects are expected to increase nonlinearly with gas saturations for disconnected gas. A clay lens in a coarser medium may achieve faster-than-expected mass removal by multi-phase diffusion during treatment by electrical resistance heating.

References

- [1] E. J. Martin, K. G. Mumford and B. H. Kueper, "Electrical Resistance Heating of Clay Layers in Water-Saturated Sand," *Groundwater Monitoring & Remediation*, vol. 36, no. 1, pp. 54-61, 2016.
- [2] E. J. Martin, K. G. Mumford, B. H. Kueper and G. A. Siemens, "Gas formation in sand and clay during electrical resistance heating," *International Journal of Heat and Mass Transfer*, vol. 110, pp. 855-862, 2017.