# Sulfate, Magnetite, Sheep, and Chlorinated Solvent Bioremediation: Biodegradation of TCE in a High Sulfate Fractured Bedrock Environment

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**Background/Objectives:** Bioremediation of chlorinated solvents in high sulfate groundwater is challenging because the electron donors added to provide energy for the anaerobic bacteria are also used by sulfate reducing bacteria, resulting in the production of hydrogen sulfide. At elevated concentrations, the sulfide is toxic to the bacteria that support reductive dechlorination and can shut down the desired biodegradation process. Laboratory microcosm studies performed at General Electric Company's Global Research Center for an industrial site in Upstate New York showed that the introduction of magnetite into the system led to the precipitation of sulfide as iron-sulfide minerals and alleviated the toxicity issue (Matis et al*.*, 2015). Additional laboratory column studies further demonstrated that excess vitamin B12 and other nutrients were also critical to support the complete reductive dechlorination of trichloroethene (TCE) to ethene in this environment (Harkness et al*.*, 2017).

The challenge in taking these concepts into the field was to produce an injectable form of magnetite and a source of vitamin B12 that would persist in the subsurface. The first issue was addressed by teaming with EOS Remediation to develop an injectable form of magnetite. The second issue was addressed based on a literature search that identified a slow-release source of vitamin B12 consisting of biodegradable, vitamin-B12 impregnated microspheres used to treat vitamin deficiency in New Zealand sheep.

**Approach/Activities:** The concept was tested in a field pilot performed in May 2018 at the same industrial site with high sulfate concentrations in the deep groundwater. The site sits on fractured bedrock consisting of multiple layers of carbonate rock overlying a deeper, highly conductive, gypsum-rich unit (called the "D3" unit) that occurs more than 38 meters (m) below grade. TCE and sulfate concentrations in D3 groundwater often exceed 200 and 600 mg/L, respectively. Two injection wells were installed into the D3 bedrock 12.3 meters (m) apart. Amendments were added in two groups, the first consisting of colloidal magnetite (CMAG) and slow-release nutrients, and the second consisting of emulsified vegetable oil (EVO), lactate, nutrients, and the slow-release vitamin B12 microspheres. Including the chase water, a total of 154 $m^3$ (40,000 gallons) was added continuously to each well over a 72-hour period.

**Results/Lessons Learned:** Both downhole probe and laboratory data were used to assess the distribution of the amendments in the subsurface. All the amendments were successfully injected. Amendment break though in monitoring wells located downgradient from the injection wells was observed in real time by changes in pH, oxidation-reduction potential (ORP), and conductivity, and verified that the 12.3 m injection well spacing was adequate. The observed changes were supported by laboratory data measuring total organic carbon (TOC), iron, potassium (from the lactate) and cobalt (from the vitamin B12), as well as bromide tracer. TCE concentrations in the downgradient monitoring wells were reduced by 95 to 99% within two months of implementation and the performance monitoring is on-going. The pilot test is currently being expanded with the installation of eight additional injection wells.

Harkness, M.R., Matis, H., Hare, P., Uruskyj, J., 2017. Role of Iron and Vitamin B12 Amendments in Stimulating Reductive Dechlorination of TCE in High Sulfate Groundwater, in *Proceedings of the Fourth International Symposium on Bioremediation and Sustainable Environmental Technologies*, Battelle Memorial Institute, Columbus, OH.

Matis, H., Harkness, M., Hare, P., Morse, R., and J. Uruskyj. 2015. Laboratory Study of Iron Amendments Used to Facilitate Reductive Dechlorination of TCE in High Sulfate Groundwater, in *Proceedings of the Third International Symposium on Bioremediation and Sustainable Environmental Technologies*, Battelle Memorial Institute, Columbus, OH.