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Field-scale demonstration of induced biogeochemical reductive dechlorination at Dover Air Force Base, Dover, Delaware

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Abstract

Biogeochemical reductive dechlorination (BiRD) is a new remediation approach for chlorinated aliphatic hydrocarbons (CAHs). The approach stimulates common sulfate-reducing soil bacteria, facilitating the geochemical conversion of native iron minerals into iron sulfides. Iron sulfides have the ability to chemically reduce many common CAH compounds including PCE, TCE, DCE, similar to zero valent iron (Fe^0). Results of a field test at Dover Air Force Base, Dover, Delaware, are given in this paper. BiRD was stimulated by direct injection of Epson salt ($MgSO_4 \cdot 7H_2O$) and sodium (L) lactate ($NaC_3H_5O_3$) in five injection wells. Sediment was sampled before and 8 months after injection. Significant iron sulfide minerals developed in the sandy aquifer matrix. From ground water analyses, treatment began a few weeks after injection with up to 95% reduction in PCE, TCE, and cDCE in less than 1 year. More complete CAH treatment is likely at a larger scale than this demonstration.

Keywords: Biogeochemical reductive dechlorination; TCE; FeS; Reduced minerals

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1. Introduction

The bioremediation of chlorinated aliphatic hydrocarbons (CAHs), including perchloroethylene (PCE), trichloroethylene (TCE), trichloroethane (TCA), has generally focused on direct microbially facilitated oxidation/reduction reactions (Bouwer, 1994; Wiedemeier et al., 1998). Both natural and enhanced bioremediation of CAH compounds normally requires the presence of labile organics and special chlororespiring bacteria, which facilitate the oxidation of the organic through the complimentary reductive dechlorination of the targeted CAH. The bioremediation of CAH compounds is typically stepwise with highly chlorinated compounds (e.g., PCE or TCE) biotransformed to intermediate, less chlorinated, daughter products (e.g., DCE or VC). Active CAH bioremediation is often recognized by the generation of these daughter products. In some instances, if these are not further biodegraded, they can persist in the environment.

Biogeochemical reductive dechlorination (BiRD) is a new approach to CAH treatment (Kennedy, 2005). Under certain natural or stimulated conditions, native sulfate-reducing soil bacteria have the ability to significantly modify the mineralogical composition of their environment, inducing the rapid authigenic formation of mineral iron sulfides. FeS minerals are strongly reduced and facilitate the autoreduction of CAH compounds similar to exposure to elemental iron. Synthetic FeS has been documented to dechlorinate a wide range of chlorinated compounds including PCE, TCE, PCA, CT, PCA, and others (Butler and Hayes, 1998, 1999, 2000; Gander et al., 2002). Lee and Batchelor (2002) also found good dechlorination rates for PCE, cDCE, and VC by reaction with pyrite (FeS_2).

FeS forms in many natural subsurface environments and has also been documented to occur in sediment contaminated with labile organics, including landfill leachate and fuel hydrocarbons (Howarth and Jorgensen, 1984; Morse et al., 1987; Kennedy et al., 1998a,b; Kennedy et al., in press). By stimulation, high concentrations of FeS and FeS_2 have been developed in just a few weeks under controlled conditions simulating natural aquifers in typical sediment (Kennedy and Everett, 2001). BiRD can be stimulated through the addition of sulfate and a labile organic in the presence of natural or supplemented Fe (typically mineral).

There are several theoretical advantages to BiRD. Sulfate bacteria are ubiquitous and sulfate reduction is simple and rapid to stimulate. The formation of iron sulfide minerals during sulfate reduction is almost instantaneous. Reaction half-lives for dechlorination by iron sulfides range from only hours to weeks. CAH treatment via BiRD results in the generation of comparatively little daughter products. BiRD is also inexpensive, requiring only the addition of sulfate salts, manufactured for agricultural purposes, and any of a number of organic materials, such as lactate or plant mulch.

The demonstration project presented here is the first to stimulate the formation of FeS under field conditions for the purpose of CAH remediation. The project was located in a chlorinated solvent plume at Dover Air Force Base, Dover, Delaware (DAFB). DAFB is a National Test Site, and multiple treatment technologies have been evaluated there. The BiRD treatment area is located 160 ft cross-hydraulic gradient to a bioremediation test site performed as a separate effort (Lee, 2002) so that CAH treatment response could be compared. Both field tests were conducted as part of the Air Force Center for Environmental Excellence (Brooks City-Base, San Antonio, Texas) Enhanced In Situ Bioremediation (EISB) Initiative.

2. BiRD background

BiRD can be divided into three parts: (1) biological sulfate reduction, (2) geochemical mineral formation, and (3) dechlorination. To facilitate the biological phase, a soluble labile organic (e.g.,