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Quantifying chlorinated ethene degradation during reductive dechlorination at Kelly AFB using stable carbon isotopes

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Abstract

Stable isotope analysis of chlorinated ethene contaminants was carried out during a bioaugmentation pilot test at Kelly Air Force Base (AFB) in San Antonio Texas. In this pilot test, *cis*-1,2-dichloroethene (cDCE) was the primary volatile organic compound. A mixed microbial enrichment culture, KB-1™, shown in laboratory experiments to reduce chlorinated ethenes to non-toxic ethene, was added to the pilot test area. Following bioaugmentation with KB-1™, perchloroethene (PCE), trichloroethene (TCE) and cDCE concentrations declined, while vinyl chloride (VC) concentrations increased and subsequently decreased as ethene became the dominant transformation product. Shifts in carbon isotopic values up to 2.7‰, 6.4‰, 10.9‰ and 10.6‰ were observed for PCE, TCE, cDCE and VC, respectively, after bioaugmentation, consistent with the

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effects of biodegradation. While a rising trend of VC concentrations and the first appearance of ethene were indicative of biodegradation by 72 days post-bioaugmentation, the most compelling evidence of biodegradation was the substantial carbon isotope enrichment (2.0‰ to 5.0‰) in $ä^{13}C_{cDCE}$. Fractionation factors obtained in previous laboratory studies were used with isotope field measurements to estimate first-order cDCE degradation rate constants of 0.12 h^{-1} and 0.17 h^{-1} at 115 days post-bioaugmentation. These isotope-derived rate constants were clearly lower than, but within a factor of 2–4 of the previously published rate constant calculated in a parallel study at Kelly AFB using chlorinated ethene concentrations. Stable carbon isotopes can provide not only a sensitive means for early identification of the effects of biodegradation, but an additional means to quantify the rates of biodegradation in the field.

Keywords: Bioaugmentation; Carbon isotope; Isotopic fractionation; Rate constants; Perchloroethene and field study

1. Introduction

The chlorinated solvent perchloroethene (PCE) is one of the most frequently detected groundwater contaminants at hazardous waste sites in North America (National Research Council, 1994). PCE is a potential carcinogen and is classified as a priority pollutant by the United States Environmental Protection Agency (EPA) (USEPA, 2001). Under anaerobic conditions, the primary mechanism for the degradation of PCE and other chlorinated ethenes in the environment is reductive dechlorination (Vogel et al., 1987). Reductive dechlorination involves the sequential replacement of chlorine atoms with hydrogen atoms resulting in the transformation of PCE to trichloroethene (TCE), TCE to *cis*-1,2-dichloroethene (cDCE), cDCE to vinyl chloride (VC) and VC to non-toxic ethene.

Several enrichment cultures capable of mediating reductive dechlorination of chlorinated ethenes have been identified. However, while complete reductive dechlorination of PCE to non-toxic end-products is the ideal outcome, microorganisms that reductively dechlorinate the less chlorinated ethenes are not always present or actively dechlorinating at all contaminated sites (Harkness et al., 1999; Hendrickson et al., 2002; Maymo-Gatell et al., 1997). Incomplete reductive dechlorination has been observed in laboratory (Harkness et al., 1999) and field studies (Ellis et al., 2000), resulting in accumulation of transformation products cDCE, or VC. If the requisite microorganisms are present, then complete dechlorination can be achieved with the addition of electron donors (biostimulation) (Song et al., 2002), or after the addition of a reductively dechlorinating microbial enrichment culture (bioaugmentation) when requisite microorganisms are absent (Major et al., 2002; Ellis et al., 2000; Harkness et al., 1999). Assessing the effectiveness of biodegradation requires monitoring of the primary contaminant and its transformation products, direct microbiological evidence, as well as other geochemical support. In this study, stable carbon isotope analysis was used to verify and quantify the extent of biodegradation at a field site contaminated with chlorinated ethenes during a bioaugmentation pilot study.