SUCCESFULL PILOT TEST OF ELECTROKINETIC-ENHANCED BIOREMEDIATION (EK-BIO) AS AN INNOVATIVE REMEDIAL APPROACH FOR PCE DNAPL SOURCE AREA

Charlotte Riis[1], Martin Bymose[1], Evan Cox[2], James Wang[3], David Gent[4], and Mads Terkelsen[5]

[1]NIRAS A/S, Alleroed, Denmark
[2]Geosyntec Consultants, Columbia, Maryland, USA,
[3]Geosyntec Consultants, Guelph, Ontario, Canada,
[4]US Army Engineering Research and Development Center, Vicksburg, Mississippi, USA
[5]Capital Region, Hilleroed, Denmark
cer@niras.dk

Abstract

At numerous sites in Denmark and other countries, contaminant source areas are located in low permeable deposits. Succesfull implementation of in-situ remediation techniques, such as bioremediation, is dependent on effective delivery of remediation reagents. Electrokinetic transport drivers are relatively independent of hydraulic permeability. As such, electrokinetic technology can efficiently promote delivery of ionic reagents at sites, where permeability is limited and heterogeneous.

At a site in Skuldelev, Denmark, complete PCE DNAPL degradation through bioaugmentation has been demonstrated at laboratory-scale. At this site, a pilot test has been carried out aimed at demonstrating the applicability of electrokinetic-enhanced bioremediation (EK-BIO).

The pilot test has demonstrated that EK-BIO is an effective method for achieving good distribution of donor and dechlorinating microorganisms in low permeable sediments for the purpose of enhancing PCE dechlorination.

Significant reductive dechlorination of PCE to cis-1,2-DCE was achieved within the short pilot test duration. By the end of the pilot test, further dechlorination of cis-1,2-DCE to VC and ethene was observed, suggesting that PCE dechlorination to ethene can be achieved by EK-BIO with KB-1 bioaugmentation. Post-operation data furthermore suggests that PCE DNAPL dissolution/desorption is occurring concurrently with complete reductive dechlorination.

A full-scale implementation design has been prepared and full-scale implementation is planned for early 2013.

Introduction

Effective delivery of remediation reagents is a critical component for successful implementation of in-situ remediation technologies. Traditional injection methods are generally based on hydraulic advection mechanisms and often faced with limitations in areas with low-permeability materials and/or highly heterogeneous geology. Transport of ionic substances such as lactate in an electric field is relatively independent of hydraulic properties and fluid flow. Therefore, effective delivery using electrokinetic technology can be achieved in areas where permeability is limited and heterogeneous.

In 2010 a bench scale treatability test demonstrated the potential to apply electrokinetic-enhanced bioremediation (EK-BIO) for tetrachloroethene (PCE) source remediation at a site in Skuldelev, Denmark [Mao et al., 2012]. The test showed that by applying a direct current electric field, effective transport of both electron donor (lactate) and dechlorinating microorganisms (*Dehalococcoides*) in PCE contaminated, low permeable soil was achieved. The efficient injection and mixing of remediation reagents was achieved by way of two transport mechanisms:

electroosmosis and ion migration. An active microbial population capable of completing PCE dechlorination to ethene was established within the clay matrix under EK conditions.

Materials and Methods

In 2011 a pilot test has been carried out at the Skuldelev site. A PCE DNAPL contamination is located in interbedded glacial deposits of sand and clay till. Highest concentrations (up to 21,000 mg PCE/kg DM) have been observed in clay till between 3 and 7 meters bgs. The EK-BIO pilot test was performed and designed with the objective to demonstrate effective transport of lactate, the viability and migration of augmented *Dehalococcoides*, and PCE dechlorination in the test area achieved within the timeframe of the pilot test.

The pilot test design is an array configuration of the well network covering an area of approximately 3 meters by 2 meters. The design includes 3 pairs of anodes and cathodes, and 3 amendment delivery wells along with 4 monitoring wells, and 4 multilevel well systems to allow for detailed performance monitoring.

Water has been recirculated between cathodes and anodes for pH control in electrode wells as in the treatability test. For supplemental pH control NaOH has been added to the anode wells and lactic acid to the cathode wells.

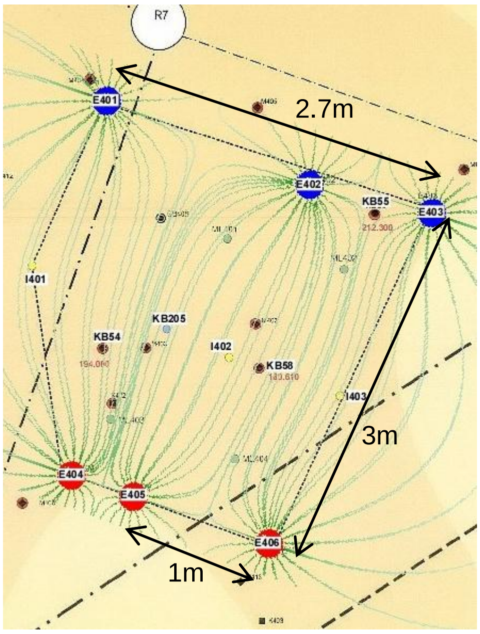

Figure 1   Pilot test layout

The system has been operated for a total of 74 days, from August to November 2011. Monitoring has been performed prior to start up (baseline), during operation and up to 7 months post operation. Monitoring has comprised operational parameters of the electrical system in order to ensure a steady electrical field, leading to steady amendment transport. Furthermore groundwater monitering has been carried out in order to document the progress of amendment distribution and contaminant degradation. To document the distribution of donor and microorganisms in the clay till, soil cores were sampled at three points in time; at baseline, at the end of operation and 7 months after operation of the EK-system. Soil samples from the clay parts of the cores were analyzed for dechlorinating bacteria, chlorinated ethenes, and major cations and anions.

Results

The power supplies were operated with constant current and an even distribution of power to all electrodes was achieved. 6A was applied to the top electrodes and 8A was applied to the lower electrodes.

Monitoring of the geochemical parameters showed that the pH in the groundwater remained neutral throughout the test. The oxidation-reduction potential (ORP) became negative, and thus optimal for reductive dechlorination within the first 30 days of operation. A slight increase in temperature (~5 ^{o}C) was observed during the operation period, but the temperature returned to baseline conditions at the monitoring campaign 3 months after end of operation.

Based on water sampling a lactate transport rate of ~ 2.5 - 5 cm/day was derived, which corresponds well to the lactate transport rate of 3.2 cm/day found in the treatability test.

As expected, the contaminant composition in the groundwater was seen to change during and after the test. At baseline, the major contaminants were PCE and TCE. During EK-operation the major contaminant detected was cisDCE, while a shift in contaminant composition was observed again at 3 and 6 months post-operation. At this time, the major contaminant was still cisDCE, but VC and ethene were seen to increase (up to 3,700 mg/l of ethene) and at the same time PCE started to re-appear at significant concentrations. During the 6 months post-operation a 3 to 5 fold increase in the total molar sum of ethenes was observed. The number of *Dehalococcoides* containing the vinnyl chlorid reductase gene, vcrA, increased by 2 to 3 orders of magnitude during EK-operation and continued to increase by another order of magnitude in some of the monitoring wells post operation.

The results of the groundwater monitoring show ongoing complete reductive dechlorination and concurrent dissolution of PCE DNAPL.

The soil cores confirm that augmented microorganisms and donor have been distributed in the tight clay and not only in the sand stringers; PCE concentrations in the soil are seen to decrease significantly and high numbers of vcrA are found in the clay samples.

Discussion

Based on the results of the pilot test it has been shown that EK can facilitate the transport of amendments (lactate and KB-1) through clay soils. *Dhc* and vcrA levels increased significantly across the pilot test area compared to baseline levels. Evident increase of vcrA detected in clayey materials collected from the interior of the pilot test area suggests that the EK operation was successful in distributing the microorganisms capable of PCE dechlorination to ethene. Significant reductive dechlorination of PCE to cis-1,2-DCE was achieved within the short pilot test duration. By the end of the pilot test, further dechlorination of cis-1,2-DCE to VC and ethene was observed, suggesting that PCE dechlorination to ethene can be achieved by EK-BIO with KB-1 bioaugmentation. Post-operation data furthermore suggests that PCE DNAPL dissolution/desorption is occurring concurrently with complete reductive dechlorination.

The pilot test points to that EK-BIO is an effective method for achieving good distribution of donor and dechlorinating microorganisms in low permeable sedimentes for the purpose of enhancing PCE dechlorination.

The test results have allowed us to derive site-specific measurements and operational conditions that can support the development of full-scale implementation of the technology. A full-scale implementation design has been prepared and full-scale implementation is planned for early 2013.

References

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