



Review

Electrokinetic-enhanced bioremediation of organic contaminants: A review of processes and environmental applications



R.T. Gill ^{a,*}, M.J. Harbottle ^b, J.W.N. Smith ^{c,a}, S.F. Thornton ^a

^a Groundwater Protection and Restoration Group, University of Sheffield, Department of Civil & Structural Engineering, Kroto Research Institute, Broad Lane, Sheffield S3 7HQ, UK

^b Institute of Environment and Sustainability, Cardiff University, School of Engineering, Queen's Buildings, The Parade, Cardiff CF24 3AA, UK

^c Shell Global Solutions, Lange Kleiweg 40, 2288 GK Rijswijk, The Netherlands

HIGHLIGHTS

- We investigate the influence of geological matrices on EK-enhanced mixing.
- Mechanisms of EK-BIO at the field-scale including several novel applications.
- Review of the physicochemical processes that effect EK-BIO in the environment.
- Summary of design options available to enhance EK-BIO treatment at the field-scale.
- Spreadsheet model that applies EK-BIO treatment to a contaminant plume scenario.

ARTICLE INFO

Article history:

Received 27 November 2013
Received in revised form 18 February 2014
Accepted 3 March 2014

Handling Editor: X. Cao

Keywords:

Electrokinetic
Bioremediation
Groundwater
Organic contaminants
Biodegradation

ABSTRACT

There is current interest in finding sustainable remediation technologies for the removal of contaminants from soil and groundwater. This review focuses on the combination of electrokinetics, the use of an electric potential to move organic and inorganic compounds, or charged particles/organisms in the subsurface independent of hydraulic conductivity; and bioremediation, the destruction of organic contaminants or attenuation of inorganic compounds by the activity of microorganisms *in situ* or *ex situ*. The objective of the review is to examine the state of knowledge on electrokinetic bioremediation and critically evaluate factors which affect the up-scaling of laboratory and bench-scale research to field-scale application. It discusses the mechanisms of electrokinetic bioremediation in the subsurface environment at different micro and macroscales, the influence of environmental processes on electrokinetic phenomena and the design options available for application to the field scale. The review also presents results from a modelling exercise to illustrate the effectiveness of electrokinetics on the supply electron acceptors to a plume scale scenario where these are limiting. Current research needs include analysis of electrokinetic bioremediation in more representative environmental settings, such as those in physically heterogeneous systems in order to gain a greater understanding of the controlling mechanisms on both electrokinetics and bioremediation in those scenarios.

© 2014 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/3.0/>).

Contents

1. Introduction	32
2. EK-BIO processes in the subsurface environment	32
2.1. Micro-scale	32
2.1.1. Substance transport by EK	32
2.1.2. Contaminant desorption by EK	33
2.1.3. Influence of EK on microbial community viability	33
2.2. Macro-scale	34
2.2.1. EK-Bioattenuation	34

* Corresponding author. Tel.: +44 1142225786; fax: +44 1142225701.

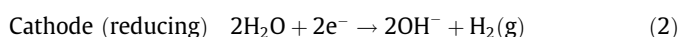
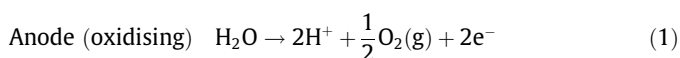
E-mail address: richard.gill@sheffield.ac.uk (R.T. Gill).

2.2.2.	EK-Biostimulation	35
2.2.3.	EK-Bioaugmentation	35
2.2.4.	EK-Phytoremediation	36
3.	Practical aspects of applying EK-BIO	36
3.1.	Influence of subsurface environmental processes on EK-BIO	36
3.1.1.	EK and electrolyte properties	36
3.1.2.	EK interactions with geological strata	36
3.1.3.	EK and hydrodynamics	36
3.1.4.	EK and physical heterogeneity	37
3.1.5.	EK and mixed contaminants	37
3.2.	Design of field-scale EK-BIO	37
3.2.1.	Electrochemical optimisation of amendment addition	37
3.2.2.	Electrode optimisation	37
3.2.3.	Electrode configuration	38
3.3.	Additional techniques to develop the application of EK-BIO	38
3.3.1.	Permeable reactive barriers	38
3.3.2.	<i>In situ</i> chemical oxidation and reduction	38
4.	Simulating the performance of EK-BIO at field-scale	39
5.	Conclusions	39
	Acknowledgements	40
Appendix A.	Supplementary material	40
	References	40

1. Introduction

Land contaminated by anthropogenic activities is of global concern and where exposure to harmful substances occurs there is potential for unacceptable risks to human and environmental health. Bioremediation is a well-established technology used to treat biodegradable contaminants, according to concepts based in general on *ex situ* treatment of excavated material (mainly used in pollutant source removal), and *in situ* treatment of sites with restricted access (where less disturbance is desirable and extended remediation timescales are acceptable) (CIRIA, 2002). Bioremediation requires environmental conditions which are favourable for the particular biochemical process and interaction between microorganisms, contaminants, nutrients and electron acceptors/donors (Sturman et al., 1995). *In situ* biodegradation can be limited by contaminant bioavailability: the immediate contact between microorganisms and substances required for contaminant biodegradation, and bioaccessibility: the fraction of these components accessible to microorganisms in the environment (Semple et al., 2004). Consequently, biodegradation processes may occur in the subsurface environment, but not at a rate to mitigate risks at a particular site.

These limitations can be overcome by coupling bioremediation with electrokinetics (EK), a remediation technology where direct current is applied within subsurface porous media to induce specific transport phenomena (Fig. 1), namely: (1) electroosmosis – the bulk movement of fluid through pores; (2) electromigration – the movement of ions in solution; and (3) electrophoresis – the movement of charged, dissolved or suspended particles in pore fluid. It is also characterised by the electrolysis of water at the electrodes (Virikutyte et al., 2002):



The reaction products, hydrogen (H^+) and hydroxyl (OH^-) ions migrate towards their oppositely charged electrode, generating acid and base fronts (Acar et al., 1993). Electromigration and electroosmosis are independent of hydraulic conductivity and EK can be used to generate mass flux in zones impervious to advective

transport (Jones, C.J.F.P et al., 2011). The principles of electrokinetics have been reviewed by Acar and Alshawabkeh (1993), Virikutyte et al. (2002), Yeung and Gu (2011).

Factors which limit the performance of *in situ* bioremediation are often highly site-specific (Boopathy, 2000) and commonly include: (1) mass transfer of electron acceptors and nutrients to microorganisms responsible for biodegradation (Simoni et al., 2001), (2) limited bioaccessibility of contaminants (e.g. partitioning to aquifer material) for biodegradation (Lohner et al., 2009), and (3) adaptation of the indigenous microorganisms for biodegradation of a particular contaminant (Mrozik and Piotrowska-Seget, 2010). The aim of coupling EK to bioremediation is to overcome these limitations, increasing the effectiveness of remediation measures. This review covers a number of related topics: (1) EK-bioremediation (EK-BIO) processes at the micro and macroscale (e.g. Wick et al. (2007), Lohner et al. (2009), Wick (2009)), but with greater focus on the interactions between EK-BIO processes and the subsurface environment; (2) mechanisms supporting field application, considering the practical aspects of using EK-BIO in specific cases such as the direct influence of environmental factors on EK (e.g. Page and Page (2002)) with a critical focus on bioremediation; and (3) up-scaling EK-BIO at the field-scale. An analysis of coupled electrokinetic/bioremediation processes and the potential for application of EK-BIO as a sustainable remediation technique is also presented.

2. EK-BIO processes in the subsurface environment

The processes and mechanisms that constitute EK-BIO operate at the micro and the macroscale (Sturman et al., 1995). Micro-scale (<10 mm) processes occur at pore-level and include interactions between contaminants, microorganisms and their surrounding subsurface environment. At the macro-scale (>10 mm) these processes are manipulated for application to plume-scale management and remediation.

2.1. Micro-scale

2.1.1. Substance transport by EK

EK enhances bioremediation by making bioaccessible contaminants, nutrients, electron acceptors (EAs) and electron donors

Download English Version:

<https://daneshyari.com/en/article/6309083>

Download Persian Version:

<https://daneshyari.com/article/6309083>

[Daneshyari.com](https://daneshyari.com)