Use of Electrokinetics in the Remediation of Low Permeability Soils

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Resumo

Um método promissor para a remediação de aqüíferos de baixa permeabilidade é o transporte eletrocinético de doadores por oxidação química *in situ*. Os resultados laboratoriais mostraram a abordagem a ser capaz de migrar produtos químicos através de argilas de baixa permeabilidade às taxas de ordens de magnitude superior a advecção hidráulica ou de difusão. Protelação ou dispersão rápida das frentes de tratamento de fluidos, no entanto, foi observado na maioria dos experimentos. Protelação é atribuído à influência do pH baixo, devido à migração de íons de hidrogênio gerado através da eletrólise no ânodo. Modelagem numérica mostrou que a injeção de doadores resultou na diminução do gradiente de tensão ao lado do cátodo abaixo de um gradiente linear, resultando em maior gradiente de tensão com a distância do ponto de injeção, e, portanto, menor concentração possível de doadores nas argilas. Mesmo com baixas concentrações realizadas, a análise mostrou que a remediação eletrocinética é viável devido à sua capacidade de oferecer um fluxo de massa significativamente maior em solos de baixa permeabilidade do que sob um gradiente hidráulico.

Abstract

A promising method for remediation of low-permeability aquifers is the electrokinetic transport of amendments for in-situ chemical oxidation. Laboratory results have shown the approach to be capable of migrating chemicals through low permeability clays at rates orders of magnitude greater than hydraulic advection or diffusion. Stalling or rapid dispersion of the treatment fluid fronts, however, was observed in most experiments. Stalling is attributed to the influence of low pH due to the migration of H+ generated through electrolysis at the anode. Numerical modelling showed that amendment injection resulted in the voltage gradient adjacent to the cathode decreasing below a linear gradient resulting in a higher voltage gradient with distance from the injection point, and therefore lower achievable concentrations of the amendment in the medium. Even with low

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achievable concentrations, analysis showed that electrokinetic remediation is feasible due to its ability to deliver a significantly higher mass flux in low permeability media than under a hydraulic gradient.

Key Words: Electrokinetics, In-Situ Chemical Oxidation, Remediation, Back Diffusion

1 – INTRODUCTION

The effective remediation of low-permeability porous media (clays, silts) contaminated with dissolved and sorbed organic contaminants is an unresolved challenge for practitioners. In this type of setting historical remediation methods, such as pump-and-treat technology, are often ineffective and the treatment effectiveness is often limited by very slow rates of molecular diffusion. The long-term “back-diffusion” of contaminants from contaminated low-permeability media to the surrounding aquifer is probably the most significant remaining challenge in environmental restoration of highly contaminated sites.

Electrokinetic remediation (EK) has significant potential for remediating low-permeability sediments. EK relies on the emplacement of electrodes into the contaminated subsurface and application of a low electric potential or current, which induces several solute transport mechanisms. Recent studies have investigated combining electrokinetic transport with remediation technologies such as in situ chemical oxidation (ISCO), in which suitable amendments are injected into the subsurface and driven to the contaminated zone under an electric gradient.

To date, demonstrating the feasibility of the coupled EK technologies has mostly been limited to the laboratory-scale. These studies also identified possible limitations to the method, with several studies finding that EK transport resulted in lower than expected amendment concentrations in the porous media. The present work is aimed at understanding the observed stalling of amendment transport during EK. Laboratory and numerical modelling are combined to demonstrate the mechanisms behind the stalling, as well as to look at engineering solutions to overcoming this potential limitation.

2 – LABORATORY RESULTS

A series of experiments were undertaken to assess the electromigration of $MnO4^-$ through a porous low permeability kaolinitic clay. The apparatus consisted of a cylindrical 10 cm long saturated core with reservoirs on either end. The experiments minimised the accumulation of H^+ and OH^- at the cathode and anode (due to electrolysis) by continuously purging the electrode reservoir with a pH neutral fluid. During experiments where purging was not performed (Figure 1A), it was found that the $MnO4^-$ electromigration would stall at some distance along the clay core which corresponded very closely to the length of H^+ electromigration in the core. The average migration rate of permanganate through the clay (for an applied voltage gradient of 1 V/cm) was 1.5 cm/day. The distribution of permanganate in a typical core and the breakthrough curve for a representative experiment are shown in Figures 1B and 1C respectively.

Analysis of the permanganate concentrations within the core at the end of the tests found that the distribution of permanganate was not that of a typical 1-D advective breakthrough experiment, in that the high concentrations near the source did not advance through the core with time (note lack of colour in left hand side of Figure 1B, despite rising permanganate concentrations in the target reservoir).

3 – MODELLING STUDY

The numerical model was used to investigate the underlying mechanisms for the lack of propagation of the high concentration front through the core, and the contribution that individual factors such as the inlet concentration, background electrical conductivity and electrode spacing may have. Under an artificial constant linear voltage gradient, the concentration of the oxidant approaches a steady state concentration that is the same as the injected concentration. The behaviour of the oxidant is in this case similar to that for purely advective transport. However, once the voltage gradient is no longer constrained, and is allowed to change in response to electrogeochemical changes in the system, the voltage profile drops below the linear profile. The decrease in the voltage profile is caused by an increased electrical conductivity (decreased resistivity) due to an increased concentration of the oxidant.

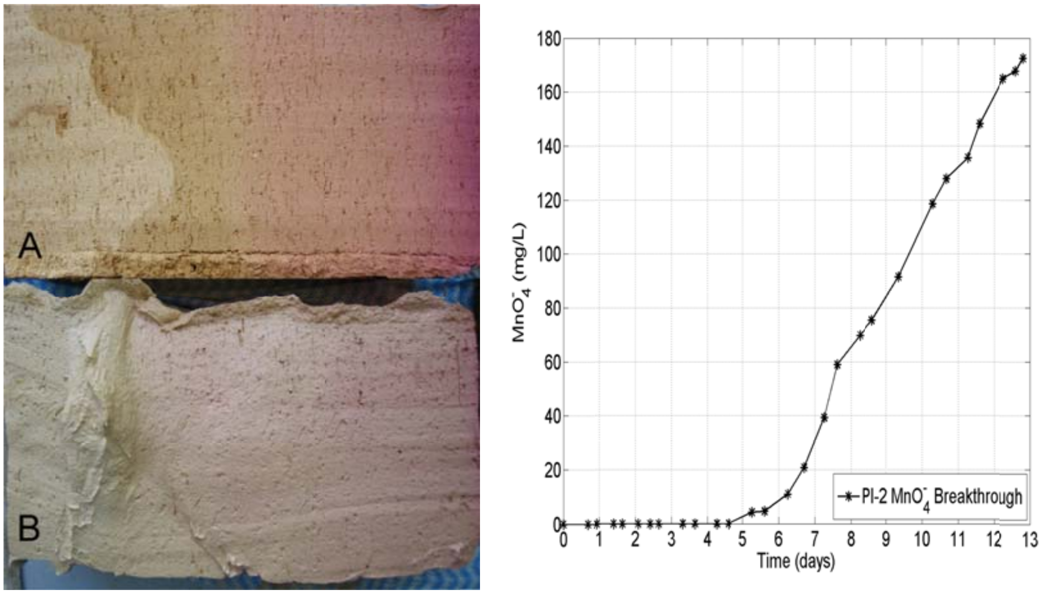

Figure 1 – A) Permanganate Migration Without Purging, B) Permanganate Migration With Purging, C) Permanganate Breakthrough from the Core

This study demonstrates that the assumption of a linear gradient in electrokinetic modelling may not be sufficient if there is a relatively large increase in the electrical conductivity due to the injected amendment. The results suggest that there is a need to both monitor the voltage gradient in future field trial applications and adjust the amendment concentration or application method.

4 - CONCLUSIONS

The use of electrokinetics to migrate treatment compounds such as oxidants has been proposed as a method of remediating sites where back diffusion from clays and other media poses a risk to downgradient receptors. Laboratory studies have shown that the approach is viable if stalling of the treatment fluid front can be avoided, and enough mass can be migrarted to contaminated areas. Modelling studies determined that stalling and high dispersion of the fluid fronts are the result of low pH interference, and a steeper voltage gradient as the distance from the injection point increases. Engineering solutions to these complications should be relatively straightforward.