

***In-situ* Bioelectrokinetic Remediation of Contaminated Soils Using Non-uniform Electrokinetics**

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ABSTRACT

In situ bioremediation is an attractive technology for the cleanup of contaminated sites with organic pollutants. It neither alters the intrinsic soil properties nor does it produces second pollution in the process of remediation. However, it requires extended time to complete the remediation in most cases, especially in field conditions. The slow rate of *in situ* bioremediation results primarily from limited opportunities of interactions among contaminants, bacteria, and bacterial nutrients under *in situ* conditions. When organic chemicals, especially hydrophobic compounds, are released into subsurface environments, they are typically absorbed on soil particle surface, partitioned into soil organic matter, sequestered within tortuous micro-pores, or form into non-aqueous-phase liquids. On the other side, the degrading bacterial cells tend to adhere to soil surface particles and are hindered by soil matrix. Consequently, the mass transfer and the opportunity of contact between the organics and the bacteria are very limited. Many studies had supported this by demonstrating that the well-mixed *ex situ* systems are often orders of magnitude faster than the undisturbed systems. Unfortunately the energy consumption and costs associated with the well mixed *ex situ* operation are considerable.

The present studies aim to accelerate *in situ* bioremediation by mixing the organic contaminants, bacteria, and bacterial nutrients under *in situ* conditions to increase contact opportunities between the organics and the degrading bacteria in soils. This may be achieved by using non-uniform electrokinetics

and periodically reversing the polarity of the applied direct current electric field (DC field). Non-uniform DC field imposed upon soil matrix can induce a variety of transport processes, including electromigration, electroosmosis, electrophoresis and dielectrophoresis. These transport mechanisms may cause the movement of contaminants, bacteria, nutrients, and pore fluids through soil matrix, and thus have the potential for accelerating the mass transfer and interaction between bacteria and contaminants during in situ bioremediation. At the same time, periodic polarity-reversal of DC field can change the direction of movement, and hence may produce more opportunities to interact.

A non-uniform electrokinetic system with periodic polarity-reversal was developed for this purpose and tested in laboratory by using kaolin soil and sandy loam spiked with phenol, 2,4-dichlorophenol (2,4-DCP), and phenanthrene, respectively. Three operation modes (including unidirectional, bidirectional, and rotational operation), and two electrode configurations (including 1-D and 2-D configuration) were tested at same experimental conditions. The results demonstrated that non-uniform electrokinetics can accelerate the movement and in situ biodegradation of phenol, 2,4-DCP, and phenanthrene in the tested soils depending upon the electric field applied, operation mode, electrode configuration, and soil properties. The following findings have been achieved:

(1) Electromigration and electroosmotic flow were the main driving forces for the movement of phenol and 2,4-DCP, and their roles in the mobilization varied with soil pH. The movement of 2,4-DCP in the sandy loam towards the anode (about 1.0 cm/d-V) was 1.0–1.5 cm/d-V slower than that in the kaolin soil, but about 0.5 cm/d-V greater than that of phenol in the sandy loam. When the sandy loam was adjusted to pH 9.3, the movement of phenol and 2,4-DCP towards the anode was about twice and five times faster than that at pH 7.7, respectively. However, the phenanthrene in the soil is mobilized mainly by dielectrophoresis due to its polarization in a non-uniform electric field, and the movement rate (about 0.3 cm/d-V) was much slower than that of phenol and 2,4-DCP under same conditions.

(2) Bidirectional operation enhanced the biodegradation of phenol and 2,4-DCP more effectively than unidirectional operation, and rotational mode generated more uniform biodegradation. At the same time, a smaller polarity-reversing interval induced a higher and more uniform removal of phenol and 2,4-DCP from the soil. However, the biodegradation of phenanthrene was independent upon the operation mode and polarity-reversing interval of non-uniform electrokinetics.

(3) The movement and biodegradation of phenol and 2,4-DCP in soils could be easily controlled by regulating the operational mode of electric field. However, the movement of phenanthrene in the soil

was not related with the operation mode and electrode configuration.

(4) Reversing the polarity of electric field applied could maintain the soil pH and moisture, but it increased the consumption of electricity. It is believed that non-uniform electrokinetics has the potential for practical application to in situ remediation of organics-contaminated sites.