



Effect of electric field on the performance of soil electro-bioremediation with a periodic polarity reversal strategy



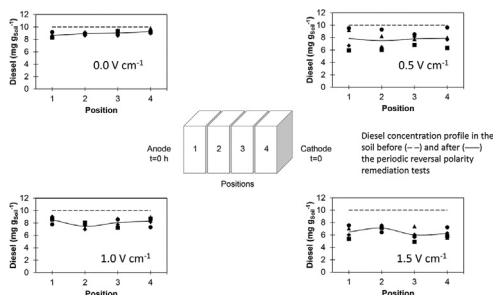
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HIGHLIGHTS

- EBR with polarity reversal is efficient in the removal of diesel from soil.
- Polarity reversal succeeds in keeping suitable pH for microbial life.
- By applying 1.5 V cm^{-1} the bioremediation rate increased by more than 330%.
- Rise in temperature caused by ohmic drops does not affect microbial life.

GRAPHICAL ABSTRACT



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ABSTRACT

In this work, it is studied the effect of the electric fields (within the range $0.0\text{--}1.5 \text{ V cm}^{-1}$) on the performance of electrobioremediation with polarity reversal, using a bench scale plant with diesel-spiked kaolinite with 14-d long tests. Results obtained show that the periodic changes in the polarity of the electric field results in a more efficient treatment as compared with the single electro-bioremediation process, and it does not require the addition of a buffer to keep the pH within a suitable range. The soil heating was not very important and it did not cause a change in the temperature of the soil up to values incompatible with the life of microorganisms. Low values of water transported by the electro-osmosis process were attained with this strategy. After only 14 d of treatment, by using the highest electric field studied in this work (1.5 V cm^{-1}), up to 35.40% of the diesel added at the beginning of the test was removed, value much higher than the 10.5% obtained by the single bioremediation technology in the same period.

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1. Introduction

For the optimal combination of electrokinetics and bioprocesses in the remediation of polluted soils, there is a key point: microorganisms should be kept alive. To attain suitable conditions for life

under the application of an electric field, the most critical parameter is pH (Yeung and Gu, 2011; Gill et al., 2014), which is known to be modified very importantly during the electroremediation of soil (Ruiz et al., 2014). These variations are due to the transport by electromigration of the protons and hydroxyl ions generated on the surface of the electrodes, by the well-known water electrolysis reactions (Eqs. (1) and (2)). (Acar, 1993; Virkutyte et al., 2002)

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The protons, produced on the surface of the anode/s, are transported towards the negatively charged electrode/s (cathode/s), forming the so-called acid front. Likewise, the hydroxyl anions, produced on the surface of the cathode/s, are transported towards the positively charged electrode/s (anode/s) forming the basic front. Due to the higher migration constants of the protons (related not only to the size), their transport under an electric field is faster than the transport of the hydroxyl ions. This higher mobility helps to understand that the acid pH front moves along the soil at higher rate than the basic pH front. (Acar et al., 1995).

There are several relevant consequences of the pH fronts in the soil. Thus the dissolution of precipitates is favored by the acid pH front. This front produces the release of metals from hydroxide and carbonate precipitates and those retained in the soil by ion exchange. This effect is not always important and depends strongly on the characteristic of the soil: in many types of soil the migration of the protons may be hindered, in particular if the soil has a relatively high buffering capacity (Reddy and Cameselle, 2009). On the other hand, as it could be expected, the basic pH front produces the opposite processes and it may cause the precipitation of metals (especially as hydroxide and carbonate salts) and can even prevent the movement of the pollutants particles by blocking pores of the soil. (Reddy and Cameselle, 2009).

Focusing on the effect of the acid and basic fronts on the biological processes, the most important consequence is that the zones of the soil with extreme pH values, are incompatible with the life of the microbial consortia used to degrade pollutants (Jackman et al., 2001; Page and Page, 2002; Lear et al., 2004, 2007; Luo et al., 2006; Wick et al., 2010). pH values below 3 and above 9, as well as sudden changes in the pH of the treatment system matrix, can significantly inhibit microbial growth by interfering with the microbial metabolism, gas solubility in soil water, nutrients availability and bioavailability in soil water, and heavy metals solubilities. (Juwarkar et al., 2010).

In this context, diesel-degrading organisms are not characterized for being a type of biological culture particularly resistant to pH changes. The optimal conditions for the growth of the microorganisms were evaluated in previous works of this research group (Moliterni et al., 2012), and they include mild temperature (around 26 °C) and neutral pH. Taking into account these considerations, it is necessary to look for strategies that help avoiding the lethal influence of the extreme pH fronts on the microbial performance.

Several authors have suggested different strategies to maintain a proper pH value for the combined biological and electrokinetic remediation of soil (Pazos et al., 2010; Yeung and Gu, 2011; Gomes et al., 2012; Gill et al., 2014). Among them, it can be highlighted the dosing of buffering agents to the flushing fluids, and the recirculation of electrolyte solutions between the anode and cathode compartments (Lee and Yang, 2000). The main challenge is to find a life-compatible and environmentally-friendly reagent effective in both the anolyte and the catholyte pH regulation. This strategy is not easy to be applied and it fails in long treatments because it is not easy to get by properly. A different strategy is the periodic change of the polarity of the electric field applied to the soil (periodic polarity reversal). Initially, this is a simple solution for regulating the changes in the pH and it could also be used for improving the distribution of ionic inorganic nutrients (Kim and Han, 2003; Luo et al., 2005, 2006; Fan et al., 2007; Niqui-Arroyo and Ortega-Calvo, 2007; Harbottle et al., 2009; Xu et al., 2010;

Huang et al., 2013) preventing their depletion from the soil by accumulation in the anolyte or in the catholyte. No information is available in the literature about the optimization of the electric field applied and the appropriate time intervals for the change of the polarity of the electric field.

Thus, the main objective of this work is the optimization of the polarity reversal strategy for the synergistic combination of the electrokinetic and the biological treatments. In order to meet this objective, following are detailed the partial objectives that are planned to be assessed:

- Evaluation of the influence of applying a periodic change in the polarity of the electric field for the control of the pH value in an electrokinetic-biological treatment of a diesel polluted clay soil.
- Optimization of the value of electric field applied for the optimal performance of the periodic polarity reversal strategy.
- Comparison between results obtained in the direct application of the electro-bioremediation treatment and results obtained with the polarity reversal strategy.

2. Material and methods

The experimental setup used in the tests was described elsewhere (Ramírez et al., 2015). The soil used was kaolinite clay (provided by Manuel Riesgo Chemical Products, Madrid, Spain). Diesel oil was selected as pollutant. It was purchased from a petrol station in Ciudad Real, Spain. To artificially pollute the soil, the diesel was diluted tenfold in acetone before evenly distributing the solution drop by drop in the corresponding amount of kaolinite. The solvent (acetone) and the higher volatile diesel fractions (approximately 6% of the initial amount of added diesel) were allowed to evaporate at room temperature for at least 2 d. The concentration of diesel present in the soil at the beginning of the experiment was approximately 10 g kg⁻¹. The diesel-degrading microbial consortium used for the experiments was isolated from a diesel-oil contaminated soil, which was collected from a site in the vicinity of an oil refinery near Ciudad Real, Spain. This consortium of microorganisms was maintained and enriched with Bushnell-Hass Broth (BHB) as the mineral medium (the composition of the medium per liter of deionized water was 0.20 g L⁻¹ MgSO₄, 0.02 g L⁻¹ CaCl₂, 1.00 g L⁻¹ KH₂PO₄, 1.00 g L⁻¹ (NH₄)₂HPO₄, 0.05 g L⁻¹ FeCl₃ and 1.00 g L⁻¹ KNO₃) and diesel hydrocarbon as the sole carbon source (1.0% v/v). The electrolyte used both in the anolyte and in the catholyte was a synthetic groundwater (80.75 mg L⁻¹ Na₂SO₄, 70.00 NaHCO₃, 30.36 mg L⁻¹ NaNO₂).

The remediation experiments were carried out applying four electric fields (0.0, 0.5, 1.0 and 1.5 V cm⁻¹). The duration of the treatment processes was two weeks. A daily (every 24 h) polarity reversal of the electric field was applied. The periodicity of the polarity reversal was chosen arbitrarily following some previous tests (not shown) carried out to check the appropriateness of this choice in order to prevent the exhaustion of nutrients by their transport to electrolyte wells. At the end of the experiments, the soil samples were taken in four longitudinal positions, which correspond to four different intermediate points between anode and cathode compartments. In addition, each intermediate longitudinal position also considered four different sampling points, distributed in different axial positions. The results show the average concentration of the four different samples taken at the same longitudinal position, that is, at the same distance of the electrodes, and so it was possible to analyze the axial deviation in the points situated at the same distance of the electrodes. The designation of the sampling points was done following the same procedure previously discussed in the literature (Mena Ramírez

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