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Scale-up of the electrokinetic fence technology for the removal of pesticides. Part II: Does size matter for removal of herbicides?

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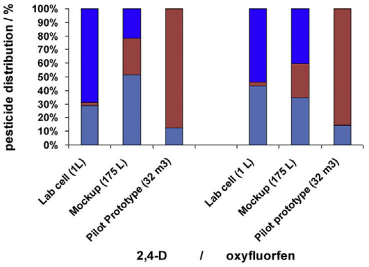
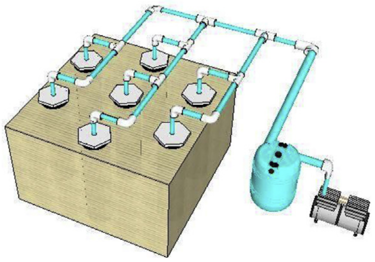
HIGHLIGHTS

- Facility size matters in the mechanisms that explain removal of herbicides from soil.
- Electric heating of soil is the key to explain the remediation in the prototype.
- Electrokinetic transport processes becomes more important as the size of the setup decreases.
- Volatilization is the main mechanisms that explain the removal of 2,4-D and oxyfluorfen.

GRAPHICAL ABSTRACT





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ABSTRACT

This work reports results of the application of electrokinetic fence technology in a 32 m^3 -prototype which contains soil polluted with 2,4-D and oxyfluorfen, focusing on the evaluation of the mechanisms that describe the removal of these two herbicides and comparing results to those obtained in smaller plants: a pilot-scale mockup (175 L) and a lab-scale soil column (1 L). Results show that electric heating of soil (coupled with the increase in the volatility) is the key to explain the removal of pollutants in the largest scale facility while electrokinetic transport processes are the primary mechanisms that explain the removal of herbicides in the lab-scale plant. 2-D and 3-D maps of the temperature and pollutant concentrations are used in the discussion of results trying to give light about the mechanisms and about how the size of the setup can lead to different conclusions, despite the same processes are occurring in the soil.

1. Introduction

The great impact of the environmental problems associated to soil pollution has pushed Society to look for efficient ways to avoid this type of pollution, typically by the application of strict

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prevention actions. When these actions fails (or simply they are not enough to prevent soil pollution), different technological approaches, that help to minimize its impact, need to be applied. This interest of Society is reflected on day-to-day stricter regulations that are arising in many developed countries, where the social conscience about these important problems is greater. In turn, Society is motivating scientist in the search for efficient technologies (with funded research topics in research calls), among which, electrochemically-assisted processes are one of the most promising nowadays, for the treatment of soils polluted with very different types of pollutants.

These electrochemically assisted technologies are the sum of many contributing processes, activated directly or indirectly by the application of an electric field between electrodes placed in the polluted soil. The large number of processes, and the strong interactions of parameters in those processes, makes every application a unique case from which a direct application to other case cannot be expected but from which important lessons can be learned and applied to many other cases (Ribeiro et al., 2005; Alcantara et al., 2010, 2012; Pazos et al., 2010; Ribeiro et al., 2011).

As pointed out in a previous review, pesticides occurrence is becoming an important issue nowadays (Rodrigo et al., 2014). This occurrence is sometimes associated to the application of these chemicals in agricultural activities, leading frequently to diffuse pollution events, very difficult to be solved with current technologies because of the huge extensions affected. Less frequent but more important is the problem associated with accidental discharges during manufacturing or handling of pesticides. In those cases, a very acute and localized problem arose, and here, it is where electrochemically-assisted soil remediation technologies may get a good contribution to the environmental restoration (Gomes et al., 2012; Cao et al., 2013; Vieira dos Santos et al., 2016).

In recent works, we have studied the effect of using different electrodes configuration in the removal of two widely-used herbicides with mockups of 175 L: oxyfluorfen (Risco et al., 2016c, 2016d, 2016e) and 2,4-D (Risco et al., 2015, 2016a, 2016b). Most of these electrodes configurations were studied for different types of pollutants (most of them inorganic) by other groups (Alshawabkeh et al., 1999; Virkutyte et al., 2002; Yeung, 2006; Yuan et al., 2006, 2007; Buchireddy et al., 2009; Reddy et al., 2011; Yeung and Gu, 2011; Cameselle and Reddy, 2013; Li et al., 2016). The significance of our work was based not only in the application of the technology to pesticides (which are also a model of organic pollutant) but most importantly on the comparison of the technologies in terms of the type of pollutant and electrode configuration.

From those works, it was obtained that the electrokinetic fence (EKF) technology showed very good prospects for being used in this application. It was also pointed out that size of the facility seemed to have a relevant role on results. This later conclusion warns and advices us about the necessity of scaling up the processes in other to obtain applicable results in full-scale restoration of polluted sites. A previous work about scale-up (López-Vizcaíno et al., 2016) gave us relevant information about engineering inputs that should be accounted and in Part I of this work this information was complemented by a compared discussion of the results obtained in the prototype with those obtained in lower scale systems for the transport of inorganic species.

Now, in Part 2 of this work, our interest is focused on the removal of the two model pesticides and in the comparison of the obtained results in the prototype with those obtained in lower scales. Thus, results obtained in the prototype are going to be compared with those obtained in the mockups (in which our previous results were obtained) and even with those of a lab-scale soil column with dimension closer to those of most of the works reported in the literature. It is aimed to give light on how size affects to results of the studied of soil remediation, in addition to draw conclusions about the application of EKF to the remediation of a soil pollutes with high concentrations of two pesticides.

2. Materials and methods

In this work the same soil, chemicals, experimental devices and procedures shown in Part I were used. The characteristic part of the results shown in this work deals with the concentration of the two herbicides used. To determine their concentration in solid and liquid samples a HPLC Agilent 1100 with an UV detector, from Agilent Technologies, has been used, following the analytical procedures described in previous works of our group which can be found elsewhere (Risco et al., 2015, 2016a, 2016b, 2016d). Fig. SM-1 shows a picture of the simulated accidental discharge of the soil with pesticides to complement the information supplied in Part I of this work.

3. Results and discussion

Temperature is a factor of the major significance in electrokinetic soil remediation technologies. Electric resistance of the soil causes soil heating and, in turn, the rise in temperature may activate many other processes. Fig. 1 shows the changes in the average temperature, both in wells and soil, during the EKF test performed at the prototype.

At it can be observed, temperature in the soil at the end of the EKF test multiplies by three the initial value while temperature in the wells multiplies it by four. Therefore, and as indicated in the 2-D maps, a clear profile of temperatures is produced in soil. This profile indicates the more active areas in the nearness of the electrodes, not finding any differences between anodes and cathodes, except for small zones of the soil in which the value of temperature is a little bit different of that expected according to a perfect symmetry. As this point, it is worth to state that electrodes wells were connected to gas extraction system and hence volatilization of pesticides arriving these wells is expected to be enhanced by the increase in temperature.

In comparing values to those obtained in previous studies about the EKF technology in smaller scales (Risco et al., 2015, 2016e), it can be drawn that average temperature during the prototype test is 29.4 °C which is more than 10 °C above the average temperature maintained in the mockups (18.2 and 19.3 °C for the oxyfluorfen and the 2,4-D tests, respectively). In those lower-scale cases-of-study, the increase of temperature was much lower, which it can be easily explained because of the lower ohmic loses associated to the closer position between electrodes. Another difference is worth to be pointed out. In the mockup, the portion of soil surrounded by electrodes (so-called electrokinetic zone) showed a temperature which was almost 4° higher than the external zone, although this increase was found to be not high enough to lead to significant changes in the volatilization properties. This is just the opposite behaviour of what it is observed in the prototype, in which the temperature in the zone surrounded by the electrodes is lower. This fact points out that, although the same processes are occurring (in this case, the electric heating, which is more intense in the nearness of electrodes), and the same energy transport mechanisms are affecting to soil, the different sizes of the evaluation facilities lead to a completely different temperatures distribution map. Regarding the lab-scale plant (results not shown), no significant differences in the temperature were observed over the tests. In this case, the very low resulting current intensities (in the range from 10 to 20 mA) helps to explain that any small increase in temperature could be compensated by the evaporative cooling and also by the exchange

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