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Research article

Performance of wind-powered soil electroremediation process for the removal of 2,4-D from soil

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ABSTRACT

In this work, it is studied a wind-powered electrokinetic soil flushing process for the removal of pesticides from soil. This approach aims to develop an eco-friendly electrochemical soil treatment technique and to face the in-situ treatment of polluted soils at remote locations. Herbicide 2,4 dichlorophenoxyacetic acid (2,4-D) is selected as a model pollutant for the soil treatment tests. The performance of the wind-powered process throughout a 15 days experiment is compared to the same remediation process powered by a conventional DC power supply. The wind-powered test covered many different wind conditions (from calm to near gale), being performed 20.7% under calm conditions and 17% under moderate or gentle breeze. According to the results obtained, the wind-powered soil treatment is feasible, obtaining a 53.9% removal of 2,4-D after 15 days treatment. Nevertheless, the remediation is more efficient if it is fed by a constant electric input (conventional DC power supply), reaching a 90.2% removal of 2,4-D with a much lower amount of charge supplied (49.2 A h kg^{-1} and 4.33 A h kg^{-1} for wind-powered and conventional) within the same operation time.

1. Introduction

The use of pesticides is one of the main milestones reached within the last century in the search for overcoming food shortage problems associated to the massive growth of the global population. Unfortunately, the use of pesticides may cause an increase in soil and grown water pollution (Kuhlmeier and Sherwood, 1996). The high toxicity, low biodegradability and, in some cases, carcinogenic nature of pesticides make it necessary to limit their presence in the environment and to develop efficient technologies of soil and water remediation (Cao et al., 2015; Castelo-Grande et al., 2005; Dombek et al., 2004; Malpass et al., 2006). Moreover, the massive use of fossil fuels as a primary source of energy is leading to an unsustainable rate of anthropogenic greenhouse gases emissions, being a major cause for climate change. Thus, renewable energy sources play a key role in providing energy sources services in a sustainable, secure and affordable manner.

One of the most interesting technologies to remove pollutants from soil is electrokinetic soil flushing (EKSF) (Alshawabkeh et al., 1999; Rodrigo et al., 2014; Yeung and Gu, 2011). This process is based in the application of an electric field directly to the soil to be treated in order to promote the mobilized ionic species and also to generate an electro-osmotic flow towards the cathode that helps to remove the soluble pollutants (Yeung, 2006).

One of the main opportunities in the intensification of soil and wastewater electrochemical treatment processes is the possibility of coupling these technologies to renewable sources of energy, such as photovoltaic or wind devices (Carta et al., 2003; Souza et al., 2015a, 2015b). Apart from allowing the design of eco-friendly environmental remediation processes, this coupling is especially interesting if the treatment of polluted soils is to be applied in remote locations, where the access to the main electricity grid is difficult or not possible (Bundschuh et al., 2010). Unfortunately, these renewable sources of energy are characterized by an uneven production profile, and little attention have been paid to the effect of this type of electric input in the electrochemical remediation of polluted soils, which is usually studied with an almost constant power input (Ma et al., 2010; Pham et al., 2009).

Some recent works have dealt with the coupling of renewable sources of energy to EKSF devices. These works have been focused on the use of solar photovoltaic panels and the treatment of soils polluted with metals (Hassan et al., 2015; Jeon et al., 2015; Yuan et al., 2009; Zhang et al., 2015) or fluorine (Zhou et al., 2013).

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From the best of the author's knowledge, no previous works of wind-powered electrokinetic soil flushing have been published.

In the present work, a wind-powered soil electroremediation (WPSER) process is presented for the treatment of soil polluted with the herbicide 2,4 dichlorophenoxyacetic acid (2,4-D). In the proposed system, a cell for the electrokinetic soil flushing device is directly connected to a wind turbine, without the use of intermediate batteries. With this system, a short-term soil flushing test (15 days duration) was carried out. Results are compared to the behaviour of the same cell connected to a conventional DC power supply. The main aim of the work is to check the technical feasibility of the direct connection of wind turbine to a soil electroremediation system and to evaluate the influence that the random feed of the energy (characteristic of wind-based generation systems) has on the performance of the process. Although this work is focused on the removal of 2,4-D, it is aimed to be the base for future works regarding the removal of other kind of pollutants (organic and inorganic) by WPSER technique.

2. Material and methods

2.1. Chemicals

Kaolinite, provided by Manuel Riesgo Chemical Products (Madrid, Spain), was used as a model of clay soil. Properties of this synthetic clay soil were provided by the commercial supplier, and are detailed in Table 1. All chemicals, including anhydrous sodium sulphate, sodium phosphate (Fluka, Spain), 2,4-dichlorophenoxyacetic acid (Sigma−Aldrich) were analytical grade and used as received. Acetonitrile HPLC grade (Sigma−Aldrich, Spain) was used for the mobile phase. Double deionized water (Millipore Milli-Q system, resistivity = 18.2 MΩ cm at 25 °C) was used to prepare all solutions.

2.2. Electrokinect cell

Bench-scale setup was made of methacrylate and consists of an orthoedric tank divided into five compartments. It is described in detail elsewhere (Mena et al., 2014). For the wind-powered test, a Bornay 600 wind power turbine provided by Bornay Aerogeneradores (Alicante, Spain) was used to generate electricity. Specifications were provided elsewhere (Souza et al., 2015a). The duration of the experiment was two weeks.

To prepare the soil column, firstly, a pesticide solution containing 500 mg dm^{-3} of 2,4-D was prepared with tap water. This solution was used to pollute the soil, up to a 30% of the moisture. Then, herbicide-polluted soil was compacted manually in the central compartment of the cell. This compaction was done very carefully, in order to avoid the formation of heterogeneities in the soil that may result in preferential paths for the hydraulic fluid transport. Tap water was used as electrolyte in the soil and in the electrodic wells. The loses of water due to the evaporation process and also due to the electro-osmosis were replaced with the same electrolyte, added to the anodic well by means of an on/off regulation loop.

Table 1
Main properties of the soil treated.

Mineralogy		Particle size distribution		Properties	
Al_2O_3	34.50%	Clay	78%	Hydraulic conductivity	10^{-7} cm S^{-1}
CaO	0.10%	Sand	4%	Organic content	0%
Fe_2O_3	0.58%	Silt	18%	Bulk density	2.6 g cm^{-3}
K_2O	0.75%	Grave	0%	pH	4.9
SiO_2	52.35%				
TiO_2	0.27%				
PPC	11.42%				

2.3. Analysis procedures

Daily, the electrical current, the temperature of different portions of the soil, the electro-osmotic volume removed from the cathode collector, pH, pesticide and TOC concentration of the electro-osmotic fluid were monitored. The liquids contained in the electrolyte wells were also daily monitored measuring pH, conductivity and pesticide concentration. At the end of the experiment, a *post mortem* analysis was carried out to evaluate the final state of the treated soil (post-study characterization) and pH, humidity and pesticide concentration were measured. For this analysis, the soil compartment was divided into sixteen equal sections (four from anode to cathode and 4 from top to botton), being Section 1 that closest to the anode. Sampling procedure of each point of the soil consists of taking it out carefully from the set up and manually homogenizing it. Once it was homogeneous, representative samples were taken for carrying out each analysis. Measurement procedures for the moisture, pH, 2,4-D can be found elsewhere (Risco et al., 2016).

3. Results and discussion

Powering soil electroremediation with green energy is a challenge in the search for novel eco-friendly environmental remediation processes. Duration of electroremediation treatment tests is typically very long and due to the large time-constants of the processes involved, coupling of a non-continuous supply should not have a negative impact on results. This work aims at studying the differences between the removal of a model pesticide (2,4-D) using EKSF powered directly with DC power supply or with the output of a wind turbine during a 15 days long treatment. Due to the anode material selected (graphite) the oxidation of 2,4-D on the cathode can be considered negligible. Moreover, it has been tested (data not shown) that the adsorption of 2,4-D in the synthetic soil selected is almost nil. Finally, it has been described in literature that biological degradation of similar refractory organic compounds is not possible due to the type of soil (Mena et al., 2014) and that the volatility of this molecule is also negligible when it is in anionic form (the case under the working pH of the present work). For these reasons, it can be stated that the main mechanism for 2,4-D removal is its electrokinetic flushing from the soil, being the discussion focused on this removal mechanism.

3.1. Wind turbine behaviour

Fig. 1 shows the evolution of wind speed throughout the soil remediation test and the classification of this variable according to the International Beaufort wind force scale. As it can be observed, wind speed behaves as a noisy signal, characteristic of wind-based energy supplies (de la Nuez Pestana et al., 2004; Souza et al., 2015a), with an average value of 1.93 m s^{-1} and a maximum speed of 16.1 m s^{-1} (at the beginning of the eleventh day). Within the first part of the test (first seven days), wind speed was very low (average of 1.07 m s^{-1}), and it increased within the second part of the experiment (from days 8−15), reaching an average value of 2.97 m s^{-1}. Then, 20.7% of the test was carried out at calm condition, meanwhile approximately 17% was performed under moderate or gentle breeze, the most appropriate condition for electricity production in an inland area. According to this data, this test covers from calm to near gale wind speed and it can be considered as a good proof of concept of this technology working under real wind