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# An assessment of the effectiveness and impact of electrokinetic remediation for pyrene-contaminated soil

Sujuan Xu<sup>1,2</sup>, Shuhai Guo<sup>1,\*</sup>, Bo Wu<sup>1</sup>, Fengmei Li<sup>1</sup>, Tingting Li<sup>1</sup>

1. Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, China

2. Graduate School of Chinese Academy of Sciences, Beijing 100049, China

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## ABSTRACT

The effectiveness of electrokinetic remediation for pyrene-contaminated soil was investigated by an anode–cathode separated system using a salt bridge. The applied constant voltage was 24 V and the electrode gap was 24 cm. Two types of soil (sandy soil and loam soil) were selected because of their different conductive capabilities. The initial concentrations of pyrene in these soil samples were 261.3 mg/kg sandy soil and 259.8 mg/kg loam soil. After treatment of the sandy soil and loam soil for seven days, 56.8% and 20.1% of the pyrene had been removed respectively. Under the same power supply voltage, the removal of the pollutant from the sandy soil was greater than that from the loam soil, due to the higher current and lower pH. Further analysis revealed that the effectiveness of electrokinetic remediation was affected by the energy expenditure, and was associated with changes in soil properties.

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## Introduction

Electrokinetic remediation is an effective technology for the remediation of organic contaminated soil (Alcántara et al., 2008, 2012; Pazos et al., 2010; Reddy et al., 2011). Electrochemical oxidation, an important component process of electrokinetic remediation, has been suggested as an effective pathway to remove organic pollutants from soil (Rahner et al., 2002; Andreottola and Ferrarese, 2008; Istrate et al., 2011). The application of an electric field creates favorable conditions for redox reactions to occur in the soil between the electrodes (Jin and Fallgren, 2010). Thus, electrochemical reactions not only happen on the electrode surfaces, but also within the entire soil matrix (Torres et al., 2003; Alshawabkeh et al., 2004; Sanromán et al., 2005; Jin and Fallgren, 2010). It is surmised that reactive radicals are generated, such as hydroxyl radicals (OH $\cdot$ ) and

oxygen free radicals (O $\cdot$ ), which are strong oxidizing agents and can oxidize organic compounds (Rahner et al., 2002; Sanromán et al., 2005; Pazos et al., 2010).

The effectiveness of electrokinetic remediation depends on many factors (Page and Page, 2002; Virkutyte et al., 2002). According to the Nernst equation, there is a negative correlation between pH and the redox potential, and a high redox potential is good for oxidation reactions; thus, a low pH is conducive to electrochemical oxidation reactions. Indeed, Sanromán et al. (2005) reported that acidic conditions can enhance the electrochemical oxidation reaction. The strength of the electric current affects the electrochemical reaction rate and the overall performance of electrokinetic remediation (Baek et al., 2012; Mouli et al., 2004), and the electrochemical oxidation rate increases with current density (Bouya et al., 2012). In addition, the electric current itself is affected by

\* Corresponding author.

E-mail addresses: [xusujuan919@yeah.net](mailto:xusujuan919@yeah.net) (S. Xu), [shuhaiguo@iae.ac.cn](mailto:shuhaiguo@iae.ac.cn) (S. Guo).

the conductive capability, moisture content, and voltage (Al-Hamdan and Reddy, 2008; Park et al., 2005). In previous studies of electrokinetic remediation, the anode and cathode have generally been located in the same electrokinetic chamber. As a result of electroosmosis and electromigration, organic pollutants and H<sup>+</sup> ions migrate within that electrokinetic cell (Acar et al., 1995; Lima et al., 2011; Cang et al., 2013), inducing changes in the redox environment. Therefore, this conventional apparatus setup neither identifies the factors influencing the electrochemical oxidation process, nor assesses the electrochemical oxidation ability of the anode and cathode.

In this study, an anode–cathode separated electrokinetic remediation system was employed. An agar–KCl saturated salt bridge was applied to connect the anode and cathode regions to form a complete electrokinetic remediation system. Due to the separation of the anode and cathode, the electroosmosis process and the migration of H<sup>+</sup> ions between the anode and cathode chambers were impeded. Therefore, our expectation was that the results would be able to reflect the independent effects of the anode and cathode on electrochemical oxidation. Sandy soil and loam soil were selected to determine the effects of different conductive capabilities and redox conditions on the removal of the chosen organic pollutant (pyrene) from the soil. The efficiency of the treatment was evaluated based on the amount of pyrene removed and the impact of the technology on soil properties (pH, conductivity, moisture content). At the same time, the energy expenditure was also estimated.

## 1. Materials and methods

### 1.1. Soil

In order to investigate the effect of soil properties on electrochemical oxidation, sandy soil and loam soil were used, samples of which were taken from Shenyang City, Liaoning Province, China. The soil was air-dried at room temperature after removal of debris and plant roots, and then passed through a 20-mesh sieve. Table 1 presents the characteristics of the soils used in this study. The concentrations of iron and manganese in the sandy soil were both higher than those in the loam soil, indicating that redox

Table 1 – Main characteristics of the tested soils.		
Parameter	Soil 1	Soil 2
Texture	Sandy	Loam
Particle size analysis (%)		
>20 μm	98.7	40.2
20–2 μm	1.1	48.7
<2 μm	0.2	11.1
pH	6.18	6.44
EC (μS/cm)	23.3	72.5
CEC (cmol/kg)	17.88	21.65
Organic matter (%)	0.20	1.34
Iron (mg/kg)	36,460.4	21,512.5
Manganese (mg/kg)	844.8	601.9

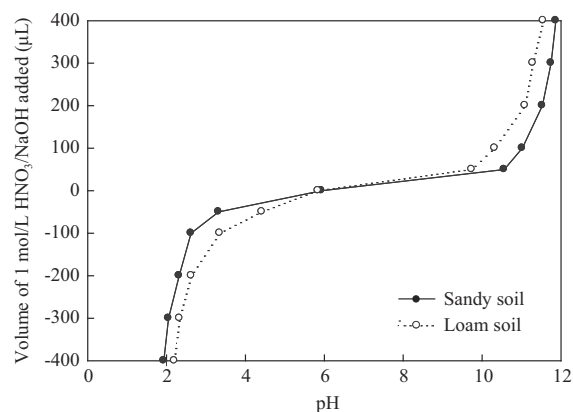


Fig. 1 – Acid/base buffering capacities of the soils used in this study.

reactions in the sandy soil may occur at a relatively higher rate than those in the loam soil (Jin and Fallgren, 2010). Fig. 1 displays the buffer capacities of the two soils at different pH values. The volume of 1 mol/L HNO<sub>3</sub> added to the soil was taken to be negative to be consistent with the definition of buffer capacity. It can be seen that the loam soil had a higher acid/base buffer capacity than the sandy soil at different pH values. Therefore, the pH of the sandy soil was expected to change more easily than the loam soil due to the electrolysis reaction.

Pyrene, a four-ring polycyclic aromatic hydrocarbon (PAH), was used as the target compound. It is a rigid, carcinogenic, unreactive and non-electrooxidizable compound (Barathi and Kumar, 2013), and has been used as a target compound for many researches (Sun and Yan, 2007; Barathi and Kumar, 2013; Cang et al., 2013). The soils were artificially contaminated with a pyrene–acetone solution, and the soil–acetone–pyrene mixture was then placed in a ventilation hood for one week until the acetone had completely evaporated and the contaminated soil was dry. During the drying period, occasional stirring was necessary to increase the rate of drying and further ensure uniform pyrene distribution. The soil was spiked with pyrene at a target concentration of 300 mg/kg (mass of pyrene/mass of dry soil).

### 1.2. Experimental setup and procedure

Fig. 2 shows the electrokinetic remediation setup used throughout this study and the sampling sites. The setup consisted of two rectangular Perspex boxes (15 cm in length, 10 cm in width, 4 cm in height), two pairs of columnar graphite electrodes (1 cm in diameter, 10 cm in length), two agar–KCl-saturated salt bridges (1 cm in diameter, 30 cm in length), an ammeter, and a stabilized DC power supply (24 V). The electrode gap was 24 cm. The reaction cell was closed with a Perspex cover to prevent evaporation of water.

As summarized in Table 2, four experiments were designed to investigate the pyrene removal rate under different treatment conditions. Control 1 and Control 2 were control experiments with no electric field applied; while Test 1 and Test 2 were treated with a constant electric potential (24 V). Approximately 700 g of pyrene-spiked soil with the

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