Chemical Engineering and Processing 100 (2016) 37–48

Contents lists available at ScienceDirect

Chemical Engineering and Processing: Process Intensification

journal homepage: www.elsevier.com/locate/cep

Electro-remediation of lead contaminated kaolinite: An electro-kinetic treatment

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ARTICLE INFO

Article history:
Received 6 August 2015
Received in revised form 19 November 2015
Accepted 6 December 2015
Available online 8 December 2015

Keywords:
Soil
Electroremediation
Lead
Kaolinite
Modelling

ABSTRACT

Electroextraction is an innovating separation process which removes in situ heavy metal contained in soil, under the application of an electric field. The paper reports the remediation of kaolinite contaminated with lead by electro-kinetic treatment using a three compartment cell. As a consequence of intensive water dissociation, the high concentration of hydroxyl ions led to precipitation of lead from the soil and formed non-conducting species such as $Pb(OH)_2$. The two chelating agents Citric acid and EDTA are used as anode reservoir to produce protons which exchanged lead cation. Meanwhile, they were also used as cathode reservoir to neutralize hydroxyl anions generated at the electrode, to avoid the formation of the solid species. After seven days, EDTA allowed complete lead removal twice than citric acid, with low energy consumption. The ion migration and the concentration gradient were described by Nernst–Planck equations. In contrast to long period experiments, the ion migration inside the soil progressed from cathode toward anode for short periods. This finding was well supported by pH values.

1. Introduction

Soil contamination is caused by the presence of chemicals or other alteration. It is typically caused by industrial activity, agricultural chemicals, or improper disposal of waste. There are many remediation technologies available for treating contaminated soils such as thermal desorption, excavation, solidification and electro-kinetic [1–7]. Indeed, the electro-kinetic remediation is one of the most promising methods and has been shown to be quite effective in removing both organic [8] and inorganic contaminants [2,6,1,9].

This process is a primary emerging in-situ technology for extracting metals and inorganic contaminants from soils [10–14]. Indeed, electro-kinetic extraction is an emerging technology that can be used to remove in situ contaminants from soil or industrial sludge by application of an electric field [15].

This method utilizes the response of charged molecules and particles to an applied voltage gradient to move the pollutants. Previous studies regarding electro-kinetic remediation have shown that the principal mechanisms causing the contaminant migration are electro-osmosis and electro-migration [16–23].

Electro-osmosis is the movement of the pore fluid which contains dissolved ionic and non-ionic species, relative to the stationary soil mass, towards the cathode due to the application of a low direct current or voltage gradient to the electrodes [21,24,25].

Electro-osmosis is more effective for the removal of cationic contaminants than anionic ones. The electro-osmotic flow moves through the soil and desorbs contaminants into pore-liquid. However, electro-migration is the movement of the dissolved ionic species present in the pore fluid, including H^+ and OH^- ions produced by water electrolysis, towards the opposite electrode [26]. For inorganic contaminants such as heavy metals, the electro-migration is considered to be the dominant transport mechanism at high concentrations of ionic species [26], while electro-osmosis is more pronounced at lower concentrations [27].

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http://dx.doi.org/10.1016/j.cep.2015.12.002

Numerous electrochemical reactions and soil contaminant interactions, such as electrolysis, sorption/desorption of contaminants onto and from a clay particle surface, acidification of soil by the transport of the hydrogen ion, precipitation of inorganic species, occur simultaneously [26,28,29].

For mobilization of lead, Bonilla et al. [30], showed that pH values below 6 would be sufficient to dissolve and remove it from the soil. Also Polcaro [8] reported that precipitation reactions were minimum for pH below 4.

The purpose of this paper is to mobilize lead under acidic condition and to investigate the effects of application of two different chemicals, as anodic solutions (citric acid or EDTA). In effect, the transport and removal of lead can be achieved by electro-kinetic process through two different ways:

1) Changing the acidity of the anodic reservoir was adopted by using 0.1 M of citric acid in both the cathode and anode reservoirs [30–36].

The increase in pH at the cathode reservoir due to the electrolysis of water precipitates the metallic cationic contaminant at the cathode leading to a reduction in removal of contaminants from the soil. Weak acids, such as citric acid, may be introduced at the anode to depolarise the hydroxyl ions generated by the cathode reaction.

The acid front H^+ advanced across the soil specimen towards the cathode by electro-osmosis or migration and exchanges with adsorbed cation Pb^{+2} in the electric double layer of contaminated soil particles.

2) Forming complexes by using 0.1 M of citric acid as catholyte and 0.1 M of EDTA as anolyte solutions [9,37].

Chelating agents such as citric acid (test 1) or EDTA (test 2) can readily form soluble complexes with lead ions, reducing the quantity of metals retained by the soils particles, thereby increasing heavy metals mobility and easily removing metals bound by soils.

The use of two chelating agents provided information on the transport of lead in ionic or complex forms and allowed to identify the main transport of lead during the electro-kinetic treatment.

2. Experimental

2.1. Reagents

Citric acid, H_4EDTA, lead nitrate, and others chemical compounds used in this work were all reagent grade.

2.2. Soil sample

The material used was P300 kaolin, marketed by Dousselin (the Rhone, France). It was an industrial clay containing about 95% of pure kaolinite [38–40]. It was chosen for its low buffering soil and simple physico-chemical properties. Soil samples were prepared by mixing 80 ml of a solution of lead nitrate (0.1 M) to 1 kg of kaolinite, to obtain a specimen at water content of 40% (limit of liquidity of kaolinite). Even though lead nitrate $Pb(NO_3)_2$ was soluble in water, and under acid pH (below pH 5.5), lead speciation was almost totally Pb^{+2} in aqueous solutions [41,42]. In this study, artificially contaminated soil was prepared by mixing the soil with $Pb(NO3)_2$ solution to create Pb contaminated soil with desired contamination level.

2.3. Experimental set up

The cell was made of Plexiglas to avoid electricity danger. The soil sample was placed in an acrylic cylindrical cell of 12 cm in length and 3.4 cm in diameter. Alongside the longitudinal axis of the cylindrical cell, two holes at 10 cm apart were drilled in which two platinum electrodes were put for voltage measurements (Fig. 1). The cell was linked to anodic and cathode reservoirs, by two graphite electrodes fixed, at the ends of the soil cell. Filter pieces of propylene were used to prevent soil particles from penetrating into the electrolyte solution. The plate type electrodes of graphite (2.8 cm × 12 cm × 0.43 cm) were partly immersed in the anodic and the cathode reservoir fluid and connected to a direct-current power supply (0–300 V, 0–1 A). An ammeter was placed in series to measure applied current. The ends of anode and cathode of the cell were connected to graduated reservoirs of volume

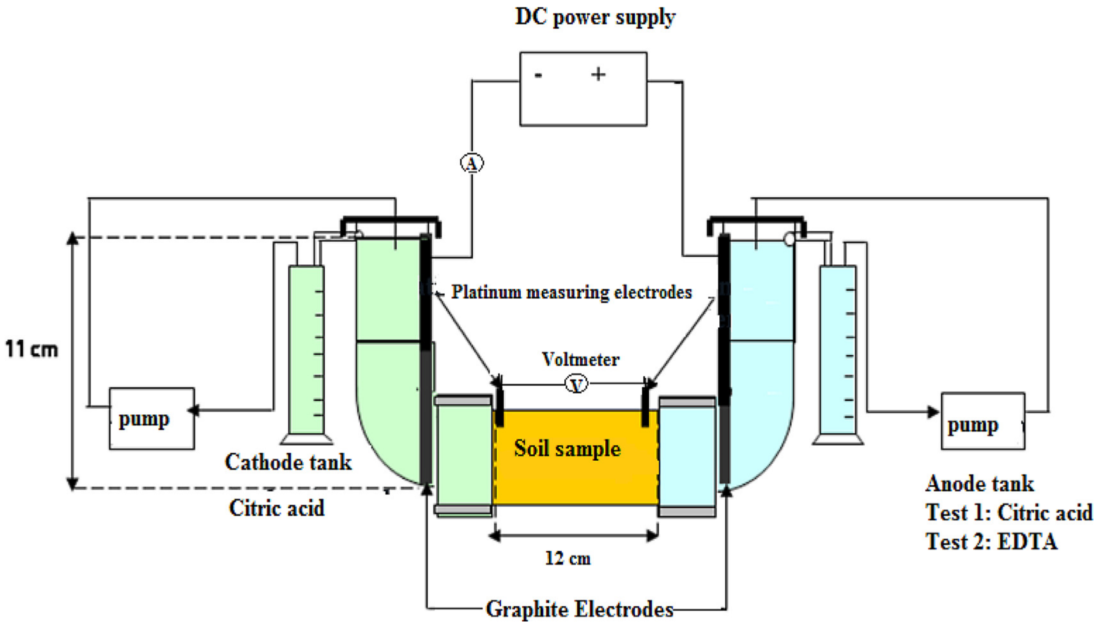

Fig 1. Schematic diagram of electrokinetic experimental apparatus used in this work.