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Review and Prospect of Combination of Various Technologies and Electrokinetic Remediation

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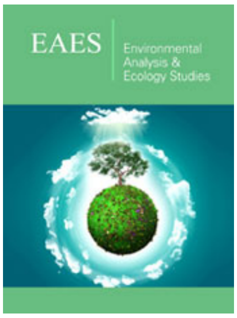

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Abstract

Soil electrokinetic remediation (EKR) is an attractive technology [1,2], due to the optimistic experimental results of extensive laboratory even pilot-scale [3]. This method is designed to remove contaminants from low permeability soils under the effect of applied current. However, this method possesses several drawbacks, for example, the EKR will cause soil acidification, but the EKR process requires an acidic condition during the application, which will promote the release of the heavy metal. Unfortunately, the condition of soil acidification is unacceptable. Furthermore, electrode configuration possesses inefficient electrical area, the EKR process is a very time-consuming application and high energy consumption etc. Obviously, the single EKR technology cannot achieve the best results, but combining electrokinetic with other remediation methods, promises to obtain more efficient removal of pollutant, less time and lower energy consumption. The authors objectively review the various technologies that can be combined with EKR based on these published studies in the last decade and aim to provide massive references to relative researchers.

Principles

Acar, Gale, et al. [4] described the principles of electrokinetic remediation, direct electric current was applied to electrodes immersed in water, results in oxidation at the anode and reduction at the cathode. This is the original EKR, also termed unenhanced electrokinetic remediation. Electric fields are applied to soil to migrate the charged ions via electrodes placed into the ground, negative ions move to anode, and positive ions (such as heavy metal ion) are attracted to cathode. It has been confirmed that the initiates movement of contaminants by electromigration, electro osmosis, electrolysis and diffusion [5], and non-ionic species are transported along with the electroosmotic flow [6]. The key electron transfer reactions that occur at electrodes during the EKR process is the electrolysis of water:

$$H_2O \rightarrow 2H^+ + 1/2\ O_2\ (g) + 2e^- \quad \text{Equation 1}$$

$$2H_2O + 2e^- \rightarrow 2OH^- + H_2\ (g) \quad \text{Equation 2}$$

Application of Combined Technology

According to the experiments and pilot-scale studies conducted in the last 10 years, metals such as cadmium [7], chromium [8-19], copper [20-28], lead [29-35], manganese [36,37], mercury [38,39], nickel [40], uranium [41], and zinc [42], as well as dye [43,44], hydrocarbon[45-54], organochlorines [55-59], polychlorinated biphenyls [60,61], phenols [62,63], chlorophenols [64], are suitable for electrokinetic remediation and recovery. The author divides those technologies combined with EKR into physical technology, biotechnology and chemical technology, provides the application of these combination-technologies in soil remediation and evaluates these technologies. The most commonly used of these techniques are physical techniques, such as activated bamboo charcoal [65,66], electrode matrix-rotational operation mode [67], flushing [30,68-71], hexagonal two dimensional [72-74], ion exchange membranes [75], permeable reaction barrier (e.g. activated charcoal [28,76], Fe(0) [77,78]), pulsed variable electric field [26,79-81], sequential extraction analysis [82], ultrasonically [83], upward [84], washing [85] and several methods about electrode configuration [11,86, 87]. As for chemical technology, some enhancement methods such as acid enhanced [88], ammonia enhanced [21,66], iodide-enhanced [89] and enhanced solution (e.g. complexing agent [86], chelate agents [90-93], cosolvent [94], surfactants [51,52,95-97]) are also more commonly used, in addition, there are some other interesting methods such as chemical oxidation [98-101] and zero-valent iron [102]. There are few examples of biotechnology applications, but it is a very promising research direction, including bioleaching [103], bio stimulation [104,105], microbial pretreatment [106], phytoremediation [107], sulfur-oxidizing bacteria [108]. In addition, in order to solve the energy problem, microbial fuel cell [109] and solar cell [19,27,110-114] are also used in combination with EKR technology for soil remediation.

Opportunities and Prospect

EKR is very powerful for inducing controlled changes in soil, however, no single EKR technology that can achieve the best results but mixing electrokinetic with other technology promises to be the most effective method so far. Over the past decade, two potential applications caught our attention. The first is the hexagonal two-dimensional electrode, which can effectively minimize the inefficient electrical area. The second is the pulsed variable electric field, which can effectively minimize energy consumption. In addition, an interesting idea targets mobile contamination plumes by development of permeable reaction barrier (PRB). Throughout the past several decades, the development of EKR was rapidly, therefore, it is also important to review the studies and findings so as to estimate the prospect for future researches. Extensive literatures are reviewed and some of the thoughts on future development directions of EKR combination-technology are proposed in this invited paper. This paper aim to provide massive references to relative researchers, and hope to become a useful document recording.

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