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Direct-Current Based Remedial Technologies for Contaminated Soils and Groundwaters

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ABSTRACT

Electron transfer is the major natural process governing the behavior of contaminants in soils and groundwaters. Biological degradation of contaminants, i.e., microbial transformation of hazardous compounds, is a well known irreversible electron transfer process. Although it is not well defined as a separate process, abiotic electron-transfer is also an important process for mobilizing/demobilizing inorganic contaminants in soils and groundwaters. Therefore, numerous remedial technologies have been developed on the basis of electron transfer concept. Among them, "electrokinetic technology" is relatively well known process which could enhance the mobility of selected ionic or polarized species in the negatively charged clay mineral media imposed by direct current (DC) supply. In this presentation, authors want to present an overview of the electrokinetic-based technologies and introduce other DC-based innovative remedial technologies developed for contaminated soil and groundwater remediation.

Key word: DC-based technology, electrokinetic, remediation, soil and groundwater

Introduction

The DC-based remedial technologies have been investigated for soil and groundwater decontamination, wastewater treatment, and metal and cement surface cleanup in the past. Among them, so-called "electrokinetic process" is a well known technology for heavy metals and radionuclides contaminated soils. The first observations of electroosmosis and electrophoresis processes are generally credited to Reuss (1809). Later, Casagrande (1949) pioneered the use of electroosmosis for the dewatering and stabilization of soft (swelling) soils. In 1990s, several pilot scale demonstration of electrokinetic processes as a contaminated soil remediation technology had been conducted in European countries, Russia, and the United States (Acar, et al. 1990; Lindgren, et al, 1992). Recently, experimental results of laboratory investigation have been reported in the journals published in Korea (Kim, et al. 2001). Furthermore, the DC has been applied as an electron source for varying remediation technologies to maintain or induce a desirable chemical environments for transforming hazardous chemical species to non-hazardous species or promoting immobilization of the hazardous contaminants. To demonstrate above concept, laboratory and pilot scale studies have been reported. In this review, concept of electro-enhanced bioremediation, TCE degradation reactor (funnel and gate), permeable reactive barrier, contaminated groundwater treatment system, and surface decontamination will be introduced to show the utility of the DC-based remedial technology. The objectives of this presentation are to review the current status of DC-based remedial technology development and to evaluate as an remedial alternative for contaminated media including soil and groundwater.

DC-Based Remedial Technologies

DC-based hazardous waste treatment technologies has been developed by many different group of researchers. In the United States, Department of Energy started a sizeable research program on electrokinetic technologies in 1992 (Kelsh, 1992). A brief description of the technologies investigated directly or indirectly by the senior author is presented in this section.

Electrokinetic Remediation: Soil minerals in contact with soil solution would acquire a net excess charge on the surface, which is balanced by an equal and opposite charge in soil solution forming the well known electrical double layer. The presence of the electrical double layer in soil-water system causes an interesting solute transport process known as the electrokinetic phenomena (electrophoresis, streaming potential, electroosmosis, and sedimentation potential). Accompanying all of these phenomena is the migration of charged ionic species in the electrical fields, which is called electromigration. Most of research and development for electrokinetic remediation have focussed on the application of electroosmosis and electromigration phenomena in saturated and nearly saturated fine textured soils. Many researchers demonstrated the effectiveness of the processes for removing heavy metals and radionuclides from soils. Author will present pilot scale test results for removing uranium from contaminated soils at Former Gaseous Diffusion Plant (Lee, unpublished data).

Electro-Based Hazardous Metal Immobilization: This is an approach developed on the basis of well known phenomena of electromigration and electroosmosis concept in heavy textured soils. This approach is, however, a containment (immobilization) approach of hazardous contaminants rather than removal of the target contaminants from soil. For example, radioactive strontium-90 could be precipitated as phosphate or carbonate compounds if one would supply those anionic species to the contaminated zone uniformly. The electrokinetic process is an excellent tool for injecting organophosphate or changing chemical environment to a desired direction for the precipitation of radionuclide. If the desired chemical environment could be maintained for a few hundred years, the radioactivity would be reduced to an insignificant level. This is a cost effective approach if in-situ containment is a viable option for the contaminated site.

Electro-Enhanced Bioremediation: Subsurface bioremediation could be enhanced by optimum supply of nutrients and microbe to the contaminated area. However, the conventional injection methods of the nutrients and microbe could result in unfavorable distribution of the injected solution because of preferred flow path in the presence of localized macropores. Electroosmosis and electrophoresis could move desired materials from one electroport to the other port through micropores in the soil resulting more desirable uniform distribution of the nutrients for indigenous and foreign microbes in the POL contaminated zone. The new chemical environment generated by the electro system should enhance in-situ biodegradation rate of the contaminants. A moderate heat generated during this process could be an additional benefit for accelerating the in-situ bioremediation.

DC-Based TCE Treatment Reactor: A zero-valent iron (ZVI, Fe^0) treatment reactor system has been known to be an effective system for reductive dechlorination of chlorinated hydrocarbons such as TCE and PCE. As an advancement of the ZVI reactor system, a DC-based reductive dechlorination was developed and demonstrated for TCE (Roh et al. 2000a). Advantage of the newly developed system is able to control the process by supplying external source of electrons to the system. Experimental results showed about ten-fold increase of reaction rate through the DC apply and reduce the surface deposit of oxidation product. This particular system could be installed as a part of treatment train for funnel and gate groundwater treatment system.

DC-Enhanced Permeable Reactive Barrier (PRB): ZVI based PRB system has been commercialized a few years ago to treat TCE contaminated groundwaters. During long-term monitoring studies, investigators raised questions on longevity of ZVI. Major problem was precipitation of iron oxide, carbonate, and sulfide on the surface of ZVI, that could reduced reactivity and permeability of the barrier. An alternative approach to amend such shortcoming of the ZVI-based PRB system is a supplemental DC supply to the system to control oxidation rate or induce surface erosion of the ZVI media (Roh et al. 2000b). However, installation of such system requires on-site pilot scale investigation because the system design is greatly influenced by site-specific environmental conditions including groundwater chemistry and hydrological parameters.

DC-Based Surface Decontamination: *In-situ* technology for material surface decontamination has been investigated for nuclear facility decommission projects in the United States and European countries. Health and safety issues of decommissioning workers are the major factors for the selection process among alternative technologies. A decontamination process using DC and chelating solvent was developed for radioactive uranium and cesium contaminated concrete surface. Electro-polishing and erosion processes were also investigated for cleaning ferrous metal pipe and containers used by nuclear industries. Developer of those technologies claimed that the electo-based technologies could reduce radiation exposure for the workers as well as volume of radioactive wastes generated during decontamination.

Summary

Conceptual models for the technologies introduced and their experimental results acquired from pilot-scale demonstrations will be discussed during the presentation. Summary of the DC-based technologies discussed in this presentation are presented in the Table 1.

Table 1. Summary of DC-enhanced remedial technologies discussed in this presentation.

All of the soil and groundwater remedial technologies have own limitations when they are implemented to a specific contaminated site. Site specific conditions govern the selection of alternative technology rather than advancement or cost effectiveness of the technology. Likewise, the DC-based technologies have also critical limitations. For example, electrokinetic methods could not be implemented to the contaminated site where DC field could be disturbed by the presence of metallic substances in and around area. The contaminated soil should have a low hydraulic conductivity. Otherwise, the electrokinetic method has no advantages over the conventional pumping and treat or in-situ soil washing method. Significant advantages of the DC-based method are low capital cost and reduction of waste volume for disposal. Other

Technology	Principal Mechanism	Target contaminant	Comment
Electrokinetic remediation	Electromigration electroosmosis	Heavy metal, radionuclides (long-half life)	Acid or chelator injection
Electro-based immobilization	Electromigration electroosmosis	Radionuclides (short-half life)	Supply of organo-phosphate, carbonate, hydroxide
Electro-enhanced bioremediation	Electroosmosis electromigration electrophoresis	POL	Supply of nutrients (N,P,K) and microbes
DC-based TCE treatment reactor	Control redox by external electron supply	TCE	Zero-valent iron as reactive surface
DC-based permeable reactive barrier	Control redox by external electron supply	TCE	Zero-valent iron as reactive surface
DC-based surface decontamination	Electroosmosis electropolishing	Radionuclides	Concrete and metallic pipe/container

technologies discussed in this presentation are an innovative approach and conceptual model that is not fully developed for users. More developmental activities in this fascinating research area should be carried out through government and/or private funds in the future.

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