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Evaluation of Electrokinetic Removal of Heavy Metals from Tailing Soils

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Abstract

Electrokinetic remediation was studied for the removal of toxic heavy metals from tailing soils. This study emphasized the dependency of removal efficiency upon heavy metal speciation, as demonstrated by different extraction methods (sequential extraction, total digestion, and 0.1 N HCl extraction). The tailing soils examined showed different physicochemical characteristics, in view of initial pH, particle size distribution, and major mineral constituents, and contained high concentrations of target metal contaminants in various forms. The electrokinetic removal efficiency of heavy metals was significantly influenced by their partitioning prior to treatment, and by the pHs of the tailing soils. The mobile and weakly bound fractions of heavy metals, such as exchangeable fraction, were easily removed by electrokinetic treatment (more than 90% in removal efficiency), whereas immobile and strongly bound fractions, such as organically bound and residual fractions, were not effectively removed (less than 20% in removal efficiency).

Keywords: electrokinetics, heavy metals, removal efficiency, speciation, sequential extraction, soil pollution, tailing soils

1. Introduction

Thousands of metal mining operations have been closed in Korea, and mounds of contaminated tailings remain near the mining sites. Many of these contain heavy metals at high concentrations, and recently they have been considered to be a serious potential contaminating source. According to changes in their physico-chemical conditions and the prevailing chemical conditions, these metal contaminants migrate and threaten human health by contaminating soil, streams, groundwater, and food crops. However, technologies for decontaminating these sites have not been well developed. In addition, it has been recently reported that soil contamination is increasing in sensitive areas, such as paddy fields, residential districts, and reservoirs of drinking water near mining areas. Heavy metals in tailings occur in various forms, such as exchangeable, adsorbed, precipitated, organically complexed, and residual phases. The forms determine their environmental mobilities and bioavailabilities, and finally their potential to contaminate the environment [1]. If heavy metals exist as loosely bound fractions, such as exchangeable or adsorbed forms on clay surface, or associated with organic matter and oxides with weak bonding strength, they tend to be easily moved and dispersed. However, metals complexed with organic ligands or in crystal lattices are not easily separated or mobilized. To determine the nature of any given system in terms of the chemical species present and their relative mobilities, sequential extraction techniques have been suggested [2-6]. Sequential extraction method consists of several steps that allow one to determine the form of the contaminating metals, and therefore the results help in the assessment of the risk of continued contamination in the long-term. Electrokinetic soil processing is also called electrokinetic remediation, electro-reclamation, and electrochemical decontamination. The electrokinetic technique needs a low-level direct current of the order of mA/cm^2 between electrodes to remove contaminants. The application of a low-level direct current results in physicochemical changes in the applied media, leading to species transport by coupled mechanisms, such as electromigration, electroosmosis, and the electrolysis of water. Electromigration and electroosmosis are the most important mechanisms operating during the electrokinetic removal of contaminants from soils. The electrokinetic technique is one of the most promising remediation processes, and offers high efficiency and time-effectiveness in the decontamination of low-permeability soils contaminated with heavy metals, radionuclides, or organic compounds.

The objectives of this study were to determine the concentrations of heavy metals and their partitioning in tailing soils prior to treatment using different modes of extraction, to investigate the most important factors controlling the electrokinetic removal of heavy metals, and to monitor the relationship between the effectiveness of the electrokinetic technique and the speciation of metal contaminants.

2. Experimental results and discussion

Tailing soils used in this study were taken from tailing dumps in three different mining areas in Korea, i.e., the Goobong (GB), Duckum (DU), and Duckpyeong (DP) areas, which were abandoned several years ago. In order to determine the speciation and concentration of each fraction of target metal contaminants (Cd, Cu, Pb, and Zn) in tailing soils before the electrokinetic remediation treatment, a sequential extraction method was used. It was originally suggested by Tessier et al. (1979) [6] and later revised by the Environmental Geochemistry Research Group at Imperial College, UK [7]. The chemicals used in each step of the sequential extraction and initial concentrations of metal contaminants are described in detail by Kim et al. (2002) [8]. Fig. 1 shows the metal speciation analyzed by the sequential extraction method. In case of the GB tailing soil, most of metal contaminants exist in the organic and sulfide fractions, except for Pb which exists dominantly in the residual form. The pH value of the DU tailing soil was very low (about 2), and heavy metals were partitioned in exchangeable forms at high concentrations. In case of the DP tailing soil, most of heavy metals exist in the residual fractions, except for Pb that is distributed in various fractions.

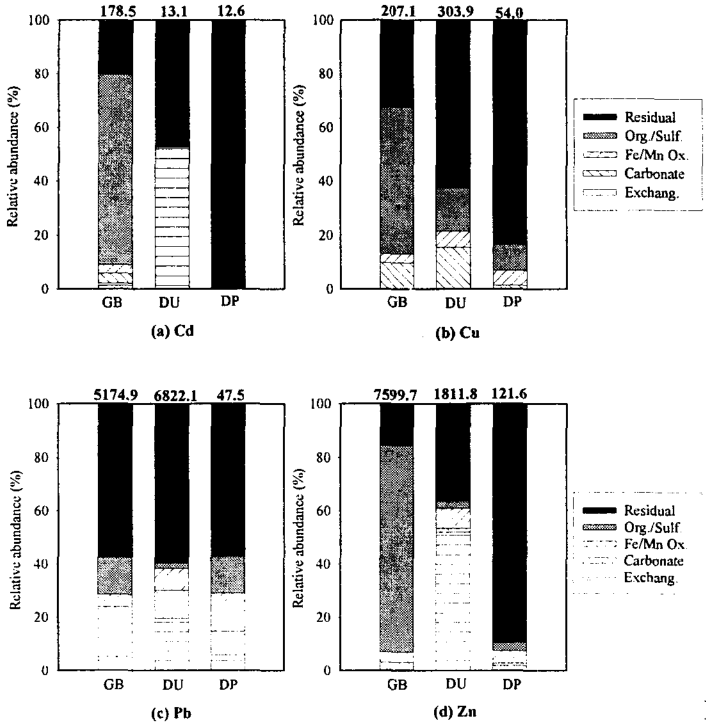

Fig. 1. Initial concentrations of different fractions analyzed by sequential extraction method [top of each column: sum of concentrations of each fraction (mg/kg)].

Fig. 2 shows the distribution of residual metal concentration in the GB soil cell after electrokinetic processing. Even though the results for the other tailing soils (DU and DP) are not presented here, the similar removal trend was observed. In the electric field, the acid front is produced by the electrolysis of water in the anode compartment and migrates toward the cathode by electromigration and electroosmosis, resulting in dissolution or desorption of contaminants in soil particles. Dissolution and desorption of species in the soil cell occurred concurrently with the acid front migration, and the contaminant species appeared to be gradually transported toward the cathode under the influence of the electric field. Based on the comparison of removal efficiencies with the results of sequential extraction analysis, it is suggested that the more weakly bound fractions of metal contaminants were more easily removed by the electrokinetic technique. In other words, it is evident that the electrokinetic technique is effective for the removal of evironmentally important, highly mobile and bioavailable metal fractions in contaminated soils. This observation is also verified by comparing the removal efficiencies with the results of 0.1 N HCl extraction and total digestion for the GB soils. Although the total removal efficiencies for the total metal concentration analysis were low (15.0 % for Cd and 13.3 % for Pb), those for 0.1 N HCl extracted metal concentration were relatively high (67.6 % for Cd and 49.8 % for Pb). This finding confirms that the metal contaminants existing in weakly bound fractions, such as the exchangeable and carbonate fractions, can be effectively removed using the electrokinetic technique.

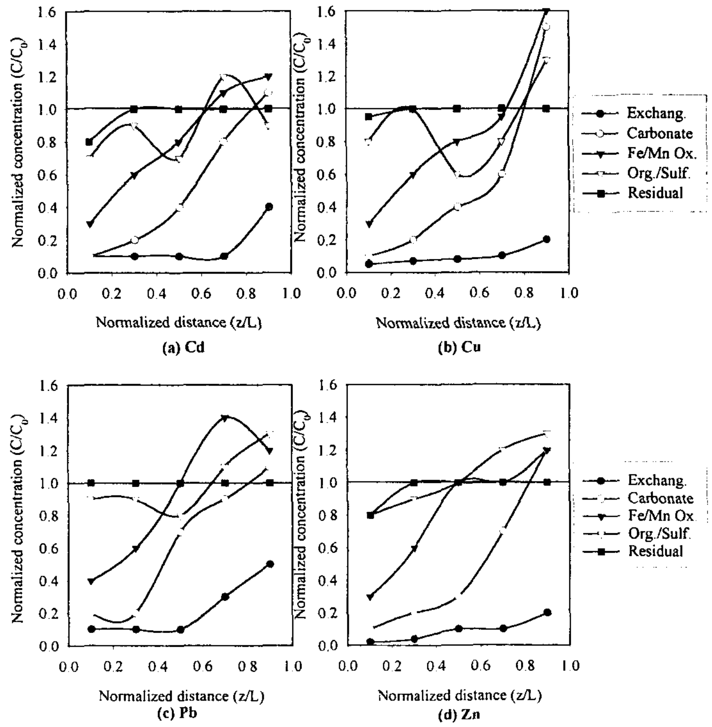

Fig. 2. Distribution of the metal concentration in soil cell after the electrokinetic treatment of GB sample, depending on their speciation.

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