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Field Applications on Electrokinetic Reactive Pile Technology for Removal of Cu from In-situ and Excavated Soils

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Abstract: This paper presents a preliminary field application of an electrokinetic reactive pile technology for removal of copper (Cu) from in-situ and excavated sorted soils. The electrokinetic reactive pile is composed of an electrokinetic remediation and permeable reactive pile system. Field electrokinetic reactive pile tests were carried out for the treatment of copper contaminated soil in-situ and sorted soil from buried waste material of this landfill. From the preliminary field investigations, the applicability of the electrokinetic reactive pile technology was evaluated. It was found that electrokinetic reactive pile system would be effective for removal of copper from in-situ and sorted soils.

Keywords: Copper, electrokinetic reactive file, field application

INTRODUCTION

Heavy metals including lead, chromium, arsenic, zinc, cadmium, copper, and mercury can cause significant damage to the environment and human health as a result of their mobility and solubility. Many techniques exist for the remedial treatment of contaminated sites including isolation, immobilization, toxicity reduction, physical separation and extraction. Figure 1 presents a schematic diagram of the electrokinetic

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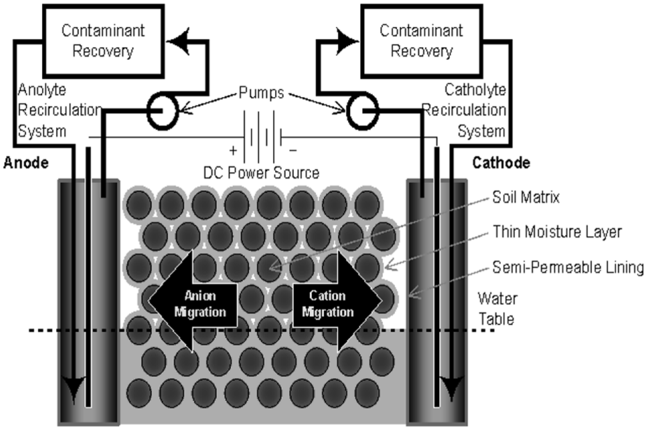

Figure 1. Electrokinetic remediation system.

remediation system. The electrokinetic remediation involves passing a low electrical current between electrode pairs imbedded in the contaminated ground for the removal of subsurface contaminants via electrophoresis, electro-osmosis and electromigration. The method is applicable to low permeability soils, where hydrodynamic techniques would not be suitable (1–7).

Permeable reactive barriers are a passive remediation technology to remediate contaminated groundwater (Fig. 2). A typical in situ configuration consists of a permeable reactive barrier system placed across the flow path of a contaminated plume. As the plume flows through the permeable reactive barrier, the contaminants are destroyed to non-toxic end products by reactions between the contaminants in plume and the reactive materials in permeable reactive barrier (8–10).

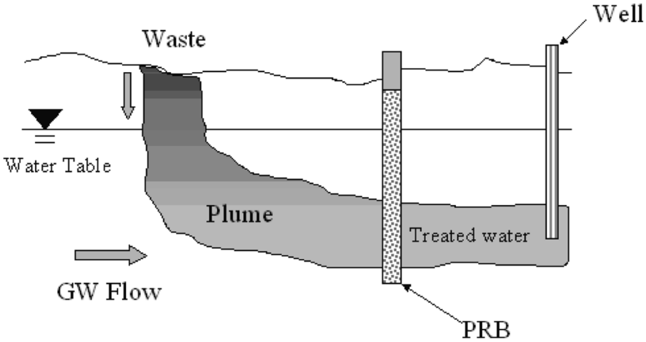

Figure 2. Permeable reactive barrier system.

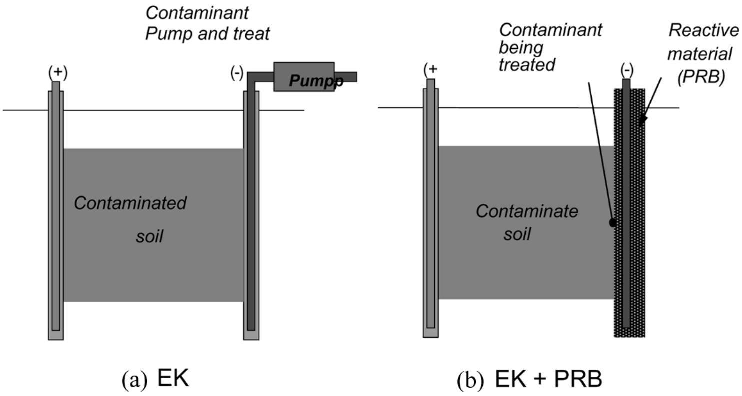

Figure 3. Schematics of proposed electrokinetic reactive pile system.

Figure 3 illustrates the schematics of the proposed electrokinetic reactive pile system. Figure 3(a) shows a schematic diagram of the electrokinetic remediation system, which requires a pumping and treatment system at the cathode in order to extract and treat the contaminant flux migrating in the soil from the anode side. The contaminants at the cathodes are extracted and treated above ground in an electrokinetic remediation system. However, as illustrated in Fig. 3(b) showing the electrokinetic reactive pile, if the cathode electrode was installed with reactive materials, the migrating contaminant in the soil towards the cathode could be destroyed by the reactive material. The contaminants at the cathode side are treated in-situ in an electrokinetic reactive pile system (11–14).

The purpose of this research programme was to investigate a possible application of an electrokinetic reactive pile system, which is electrokinetic remediation coupled with a permeable reactive barrier system to remediate Cu contaminated soil. In this research, the permeable reactive pile system was applied instead of the permeable reactive barrier in order to test the performance of the perforated hollow cathode piles as reactive piles.

FIELD TESTS

An old-fashioned, unregulated, open dumping waste landfill site located in Incheon City (Republic of Korea) was selected as field test site. The waste buried in this site has already been treated for developing this site to new residential town. Excavation and sorting method which involves excavating and sorting the buried soil into sorted soil and waste, was adopted for the treatment of the buried waste. The sorted soil will be used as banking material on site after clean up treatment. The waste is transported and treated at an incineration plant or sanitary waste landfill. Some of the in-situ soil and sorted soil however might be contaminated with heavy metals. As copper (Cu) concentration is dominant among the heavy metals contained in these soils, Cu was selected as the target heavy metal for remediation by the electrokinetic reactive pile. Thus, in-situ electrokinetic reactive pile (electrokinetic remediation coupled with permeable reactive barrier) tests were carried out in the environs of this waste landfill site in order to investigate the removal capability of Cu from these soils as well (14).

Figure 4 shows the schematics of the in-situ electrokinetic reactive pile system for remediation of in-situ contaminated soils. The soil profile consists of 1.0 m cover soil, 2.5 m waste and clay below the waste. The treatment zone in this system was determined by the level of waste buried underground (i.e., 2 to 3.5 m below the ground surface). The groundwater level was situated 2.0 m below the ground surface. The electrode piles were installed to the depth of 4.0 m below the ground surface.

Figure 5 shows the schematics of in-situ electrokinetic reactive pile system for removal of Cu from the sorted soil. The sorted soil was derived from the excavated. As the soil was dried through sorting process, water

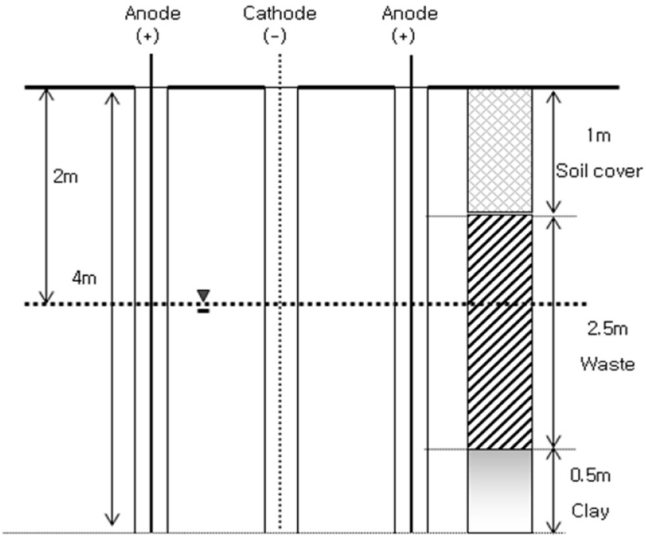

Figure 4. Schematics of in-situ electrokinetic reactive pile system for remediation of in-situ contaminated soils.

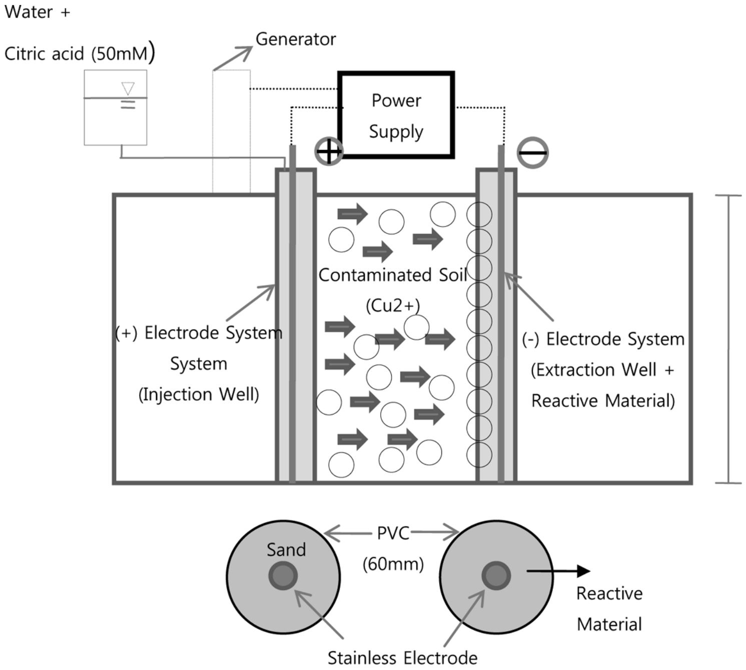

Figure 5. Schematics of in-situ electrokinetic reactive pile system for remediation of sorted contaminated soil.

was supplied into anode hollow piles to saturate the soil. The electrode piles were installed vertically to a depth of 2.5 m below ground surface. Stainless anode and cathode rods for rust reduction were installed in anode and cathode hollow pile. The perforated cathode pile was filled with reactive materials. Copper migrated from the anode side towards cathode and was captured or adsorbed.

The in-situ electrokinetic reactive pile system basically consists of an array of electrodes, anode electrode hollow piles, a DC power supply, vacuum pump, water reservoir, cathode electrode hollow piles, and process tubing to inject water to the anode electrode hollow piles and to extract contaminants from the cathode electrode piles. The electrode array consists of a series of anodes and cathodes housed in hollow piles. Figures 6 and 7 illustrate the array of anode and cathodes that were installed in in-situ and sorted soil, respectively. For the in-situ soil, the cathode piles were located in the center, and the anode piles were located to the right and left at a distance of approximately 2.0 m to the central cathode pile sting as shown in Fig. 6. For the sorted soil, the cathode piles were located in the center, and the anode piles were located in radial

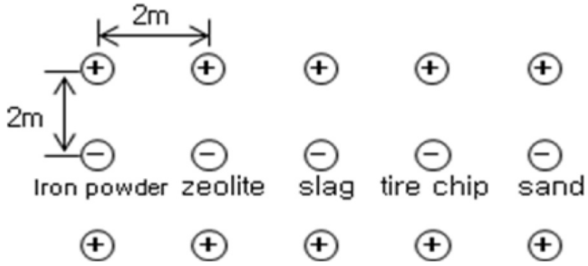

Figure 6. Schematic diagram of electrode layout for remediation of in-situ soil.

shape at a distance of approximately 1.0 from the central cathode piles as shown in Fig. 7.

The applied electrical potential difference between the electrodes was approximately 1 V/cm. As seen in Figs. 6 and 7, two different conditions such as reactive condition or non-reactive condition were considered; In Case 1, a basic electrokinetic extraction system (both anode and cathode piles filled with sand which is non-reactive material) and in Case 2, an electrokinetic reactive extraction system (anode piles filled with sand, and cathode piles filled with reactive materials such as slag, zeolite, iron powder, and tire chips and non-reactive material such as sand) as seen in Fig. 6.

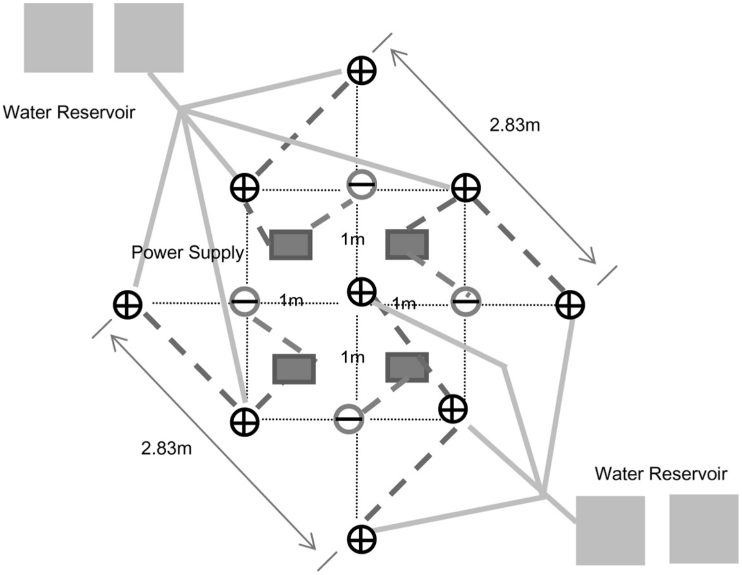

Figure 7. Schematic diagram of electrode layout for remediation of sorted soil.

Table 1. The properties of reactive materials

Properties	Iron powder	Zeolite	Slag	Tire chip	Sand
Specific gravity	3.5	2.6	3.6	0.6	2.5
Effective diameter (mm)	0.05	0.5	4.0	5.0	1.0
Specific surface (cm^2/g)	400	210	150	280	30
Cation exchange capacity (me/100 g)	40	150	70	120	5
pH	7.5	8.5	10.5	7.5	6.5
Permeability (cm/sec)	8.3×10^{-4}	1.2×10^{-4}	2.4×10^{-1}	3.3×10^{-2}	1.8×10^{-3}

The properties of reactive materials were illustrated in Table 1. The pH value of iron powder, zeolite, slag, tire chip, and sand were 7.5, 8.5, 10.5, 7.5, and 6.5, respectively. The specific surface of iron powder, zeolite, slag, tire chip, and sand were 400, 210, 150, 280, and 30, respectively. The cation exchange capacity of iron powder, zeolite, slag, tire chip, and sand were 40, 150, 70, 120, and 5, respectively.

Figure 8 presents the field electrokinetic reactive pile system setup. Figure 8(a) shows field installation of the electrokinetic reactive pile system for removal of Cu from in-situ soil and Fig. 8(b) shows field installation of electrokinetic reactive pile system for removal of Cu from sorted soil. Slotted perforated PVC pipes were used as the anode and cathode electrode piles. After the installation of the PVC piles into bore holes, the inner part of piles was filled with either sand or reactive materials (slag,

(a) (b)

Figure 8. Details of electrokinetic reactive pile experimental setup. (a) Field installation of electrokinetic reactive pile system for remediation of in-situ soil; (b) Field installation of electrokinetic reactive pile system for remediation of sorted soil.

zeolite, iron power, and tire chip). Thereafter, stainless steel electrode rods and drainage tubes were installed into the electrode piles. The stainless steel electrode was chosen for rust reduction of electrode. The electrodes were connected to a DC power supply, and the inlet tube at the anode compartment and outlet tube at the cathode compartment were connected to a water reservoir and vacuum pump, respectively. A constant electric field, rather than a constant electrical current, was applied to the electrode because significant power loss may occur due to the increase of soil resistance by the depletion of ions resulting in the premature termination of experiment. Citric acid (50 mM) was supplied as a desorption agent at the anode compartment to improve the desorption efficiency of Cu from soil (15,16). The field electrokinetic reactive processing was conducted for 30 days in both cases of in-situ soil and sorted soil.

RESULTS AND DISCUSSION

Table 2 shows the Cu concentration of five in-situ soils, sampled at the middle section between anode and cathode piles for iron powder, zeolite, slag powder, tire chips, and sand before and after the electrokinetic reactive processing. The in-situ soils were contaminated with copper at levels ranging from 170.1 to 176.4 mg/kg. The Cu concentration of in-situ soil was reduced after the electrokinetic reactive processing compared to the initial concentration. The average initial Cu concentration of in-situ soil was 172.9 mg/kg. The average final Cu concentration of in-situ soil was 24.9 mg/kg, thus the average removal Cu concentration of in-situ soil was 148.0 mg/kg. The average residual rate of Cu is 14.2% and the average removal rate of Cu is 85.7%. It appears that the copper migrated from the anode towards the cathode by the effects of electroosmotic advection and electro ion migration.

Table 2. Cu concentration of in-situ soil before and after electrokinetic reactive processing

Reactive material	Initial con. (mg/kg)	Final con. (mg/kg)	Removal con. (mg/kg)	Residual rate (%)	Removal rate (%)
1 (iron powder)	170.1	23.1	147.0	13.5	86.5
2 (zeolite)	172.3	26.3	146.0	15.1	84.4
3 (slag powder)	174.3	27.4	146.9	15.5	84.5
4 (tire chip)	171.6	21.3	150.3	12.3	87.7
5 (sand)	176.4	26.3	150.1	14.7	85.3
6 Average	172.9	24.9	148.0	14.2	85.7

Table 3. Cu concentration in in-situ soil and reactive material after electrokinetic reactive processing

Reactive material	Removal con. (mg/kg)	Residual con. (mg/kg)	Extracted con. (mg/kg)	Reactive rate (%)	Non-reactive rate (%)
1 (iron powder)	147.0	100.9	46.1	68.7	31.3
2 (zeolite)	146.0	136.7	9.3	93.7	6.3
3 (slag powder)	146.9	109.6	37.3	74.8	25.2
4 (tire chip)	150.3	132.0	18.3	88.0	12.0
5 (sand)	150.1	6.7	143.4	4.7	95.3

Table 3 presents the removal Cu concentration from in-situ soil and residual concentration in the reactive material after electrokinetic reactive processing. The removal Cu concentrations from in-situ soils were 147.0, 146.0, 146.9, 150.3, and 150.1 mg/kg. The residual Cu concentrations at reactive materials were 100.9, 136.7, 109.6, 132.0, and 6.7 mg/kg, and the extracted concentration from cathode reactive pile by pumping were 46.1, 9.3, 37.3, 18.3, and 143.4 mg/kg in the case of iron powder, zeolite, slag powder, tire chip, and sand, respectively. The removal of Cu from in-situ soil was occurring in the reactive material and extracted water. Figure 9 shows the variation of reactive rate of reactive materials with time elapse in electrokinetic reactive processing for in-situ soil. The adsorbed reactive rates of Cu onto the reactive material were 20.4, 34.7, 23.4, 28.6, 1.7% at 10 days, 38.7, 63.4, 44.8, 53.4, 3.3% at 20 days, and 68.7, 93.7, 74.8, 88.0,

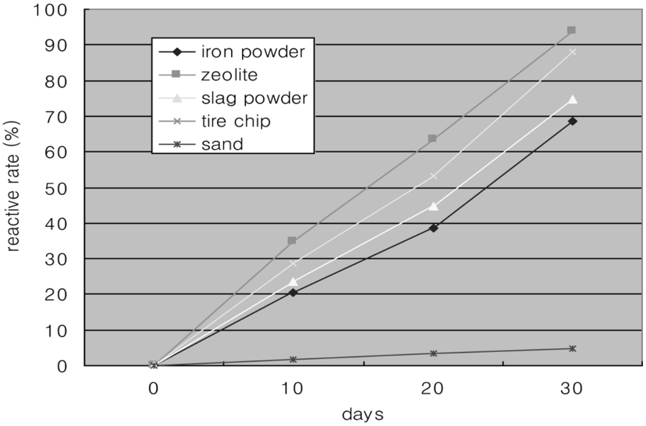

Figure 9. The variation of reactive rate of reactive materials with time elapse in electrokinetic reactive processing for in-situ soil.

4.7% at 30 days in the cases of iron powder, zeolite, slag powder, tire chip, and sand, respectively. This means that the reactive efficiency to adsorb Cu was highest in the case of zeolite and lowest in the case of sand. The cation exchange capacity of iron powder, zeolite, slag, tire chip, and sand were 40, 150, 70, 120, and 5, respectively as shown in Table 1. The zeolite has the highest Cu reactive rate due to its highest cation exchange capacity. In the electrokinetic reactive pile system, the majority of heavy metals adsorbed onto the reactive materials. Thus, if a reactive material with a high sufficiency for Cu removal is selected, the Cu can be captured at the reactive cathode compartment below the ground without pumping and treatment above ground.

Table 4 shows the Cu concentration of 4 sorted soils sampled at the middle section between anode and cathode piles before and after electrokinetic reactive processing in the case of iron powder, zeolite, slag powder, and tire chips, respectively. The sorted soils were contaminated with copper and the contamination levels were found to be 171.3–173.4 mg/kg. The measured copper levels were similar to the in-situ soil. After electrokinetic reactive processing, the Cu concentration of sorted soil was reduced significantly. The average initial Cu concentration of sorted soil was 172.7 mg/kg, while the average final Cu concentration of sorted soil was 24.8 mg/kg, the average removal Cu concentration of sorted soil was 147.9 mg/kg. Thus, an average residual rate of Cu is 14.4% and the average removal rate of Cu is 85.6% was confirmed. The removal of copper is attributed to electroosmosis and electromigration processes.

Table 5 shows the Cu concentration in sorted soil and reactive material after electrokinetic reactive processing. The removal Cu concentrations from sorted soils were 147.6, 146.3, 146.7, and 152.1 mg/kg, the residual Cu concentrations at reactive materials in cathode reactive piles were 100.3, 136.6, 110.1, and 132.8 mg/kg, and the extracted concentration from the cathode reactive pile by pumping were 47.3,

Table 4. Cu concentration of sorted soil before and after electrokinetic reactive processing

Reactive material	Initial con. (mg/kg)	Final con. (mg/kg)	Removal con. (mg/kg)	Residual rate (%)	Removal rate (%)
1 (iron powder)	171.3	23.7	147.6	13.8	86.2
2 (zeolite)	173.1	26.8	146.3	15.5	84.5
3 (slag powder)	173.4	26.7	146.7	15.4	84.6
4 (tire chip)	173.1	21.9	152.1	12.7	87.3
5 Average	172.7	24.8	147.9	14.4	85.6

Table 5. Cu concentration in sorted soil and reactive material after electrokinetic reactive processing

Reactive material	Removal con. (mg/kg)	Residual con. (mg/kg)	Extracted con. (mg/kg)	Reactive rate (%)	Non-reactive rate (%)
1 (iron powder)	147.6	100.3	47.3	68.0	32.0
2 (zeolite)	146.3	136.6	9.7	93.4	6.6
3 (slag powder)	146.7	110.0	36.7	75.0	25.0
4 (tire chip)	152.1	132.8	19.3	87.3	12.7

9.7, 36.7, and 19.3 mg/kg in the cases of iron powder, zeolite, slag powder, and tire chip, respectively.

The removal of Cu from the sorted soil was due to reactions with the reactive materials and the extraction of water by pumping. Some of the removed Cu from the sorted soil was adsorbed into reactive materials, and some of the Cu removed from the sorted soil was extracted from the cathode reactive pile by pumping system. The remediation efficiency of in-situ soil and excavated sorted soil was similar because the properties of the in-situ soil and excavated sorted soil were similar and the same reactive materials were used in in-situ soil and excavated sorted soil remediation tests. Figure 10 shows the variation of reactive rate of reactive

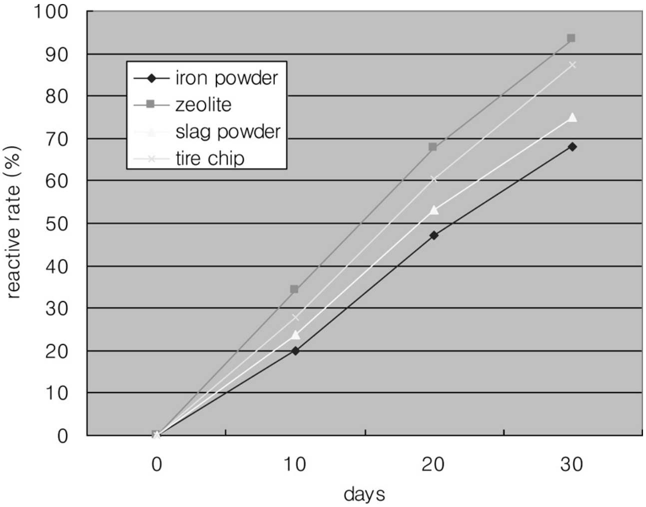

Figure 10. The variation of reactive rate of reactive materials with time elapse in electrokinetic reactive processing for sorted soil.

materials with time elapse in electrokinetic reactive processing for sorted soil. The adsorbed reactive rates of Cu onto the reactive material were 20.0, 34.1, 23.6, 27.8% at 10 days, 47, 67.8, 53.3, 60.4% at 20 days, and 68.0, 93.4, 75.0, 87.3% at 30 days in the cases of iron powder, zeolite, slag powder, and tire chip, respectively. This is attributed to the reactive efficiency of the material that was the highest in the case of zeolite and the lowest in the case of iron powder among the ones used in this study. The majority of the Cu adsorbed onto the reactive materials in the electrokinetic reactive pile system. Thus, the selection of the proper high efficiency reactive material, which captured the contaminant in the cathode reactive pile, is of utmost importance. By this process, Cu moved towards the cathode pile can be treated by reactive material at the cathode compartment below the ground without pumping and treatment above the ground. After finishing the electrokinetic reactive processing, the reactive material that adsorbed Cu at the cathode compartment can be transported and treated as waste in landfill.

CONCLUSIONS

The objective of this paper is to investigate the potential use of ekectrokinetic reactive pile as an inexpensive remediation technology in order to remove Cu from in-situ and excavated soil. Copper migrated from the anode side towards the cathode compartment being captured and adsorbed onto reactive material in the cathode reactive pile. The sorption reactive rates of Cu onto reactive material were 68–68.7, 93.4–93.7, 74.8–75, 87.3–88.0, and 4.7% in the studied cases of iron powder, zeolite, slag powder, tire chip, and sand, respectively. In the electrokinetic reactive pile system, the majority of migrating Cu adsorbed onto the reactive materials. From the preliminary field investigations it was found, that the electrokinetic reactive pile would be effective to remove Cu without the extraction of contaminants from the subsurface.

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