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ELECTRO-KINETIC REHABILITATION TECHNOLOGIES FOR SOILS POLLUTED WITH METALS AND ORGANIC COMPOUNDS

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Abstract

Nowdays many industries have an important negative impact on the environment. An important component of the environment is the soil, which requires some specific methods of rehabilitation. Electro-kinetic methods are appropriate for removing heavy metals and organic compounds from the soil

1. GENERAL ASPECTS OF SOIL’S ELECTRO-KINETIC REHABILITATION

Electro-kinetic separation is a method to remove metals and organic compounds from soils with low permeability, based on electrochemical and electro-kinetic processes used for contaminants mobilization and further removal of metals and organic compounds.

Electro-kinetic treatment for soils is based on several transportation mechanisms which include advection, generated by electro osmotic movement and by hydraulic gradients applied to the exterior. Main reactions and the most important reactions which take place during electro-kinetic process are water electrolysis reactions (1).

$$H_2O \longrightarrow 2H^+ + 1/2O_2(g) + 2e^-$$

$$2H_2O + 2e^- \longrightarrow 2HO^- + H_2O(g) \tag{1}$$

Acid front moves for the cathode by electrical migration, diffusion and advection. Hydrogen ions formed determine pH substraction near the anode. At the same time hydroxyl ions concentration increase leads to pH values increase near the cathode.

To dissolve metallic hydroxides and carbonates formed or for other compounds absorbed by soil is necessary to create an acid medium. However this acidification has big disadvantages which are reflected in the low process efficiency.

Acid addition leads to high soil acidification whose consequences cannot be estimated nore the time needed for soil’s rehabilitation.

2. ELECTRO-KINETIC REHABILITATION PURPOSE AND EFFICIENCY

Main purpose of electro-kinetic rehabilitation is to produce the migration of contaminated particles under the soil surface in the presence of an electric field by electro osmosis, electro migration and electrophoresis.

Electro osmosis takes place when a polar liquid passes through a membrane or through a porous structure under the influence of the potential difference between membranes sides. In soil this action is represented by soil humidity or underground water migration from the anode to the cathode. Ions migration to the opposing electrode is known as electro migration. Electrophoresis represents colloid and electrified particles transportation under the influence of an electric field. These kinds of phenomenon take place when the soil is subdued to low voltage.

As an effect of the migration contaminated particles can recide, accumulate near the electrode or they can be retained by ion exchange. Electrodes used can have absorbent properties for the contaminated particles.

Electro migration takes place in the presence of anorganic ions (metal cations, chloride anions, azotate and phosphate) in humid soils. Electro-kinetic rehabilitation technologies based on this phenomenon can be applied on clay soil with low permeability due to the fact that other technologies highly depend on soil's permeability.

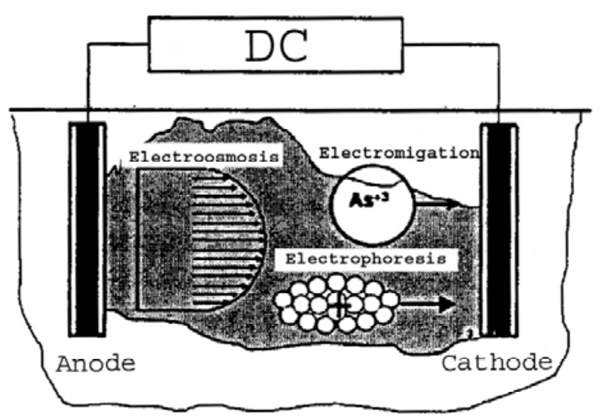

Figure 1. Main ways for ions to change place under the influence of electrical current.

Process efficiency depends on area's specific conditions: soil type, pH, organic compounds content.

In situ method infers to put electrodes in the contaminated area to create an assembly similar to an electrolytic cell. The electrolytes can be put directly in the humid soil or into an electrolyte solution from a confined area. To maintain constant values of process parameters the anode must be put into a cleaning agent or water.

Therefore at the cathode the contaminated water is epurated by electro deposition, precipitation and ions exchange.

It is important to specify that in case of a contamination with organic compounds insoluble in water, liquid pollutants do not ionize but they migrate because of the electro osmosis phenomenon. The process efficiency does not depend on the soil's permeability but on soil's humidity and electro conductibility. Electro-kinetic rehabilitation does not depend on the pore's dimensions and it can be applied on any soil type.

Table 1. Parameters that influence the efficiency of electro-kinetic rehabilitation

Parameters that influence the rehabilitation efficiency	Parameters that influence the electro migration phenomenon	Parameters that influence the electrophoresis transport
Chemical processes from electrodes Soil humidity Soil's type and structure pH value and variation type and concentration of contaminated particles from soil electric density applied	Electric density of the water from pores Soil particles dimension Ionic mobility Contaminant concentration Total ionic concentration	Ions mobility and hydration Ions concentration Inductivity depending on organic and anorganic particles from soil Temperature

It was determined that soils with high clay and sand content have the best results after electro-kinetic rehabilitation method are applied for heavy metal contaminated soils.

Contaminants which can be affected by electro-kinetic processes are:

- heavy metals
- radioactive metals
- anorganic anions (azotate, sulphate)
- cyanides
- petroleum hydrocarbons (diesel fuel, gas, kerosene, lubricant dope)
- explosives
- organic/anorganic contaminants
- halocarbons
- polynomial aromatics

Best results in heavy metals elimination (over 90%) were registered for clay soils with low permeability.

Migrations determined by electro osmosis induce to pH values diminution, which conduct to metallic ions desorbtion and mobilization.

Processes that can take place:

- complexing reactions
- neutralization reactions
- redox reactions
- precipitation/dissolution
- interface reactions

3. HEAVY METAL REMOVAL BY ELECTRO-KINETIC REHABILITATION

Heavy metals ions from soil are connected by electrostatic forces to negative colloidal particles from soil. The strength of the connection depends on soil's electro negativity and on ions dissociation energy (Sah and Chen, 1998). The ions desorbtion is essential for the electro-kinetic rehabilitation process.

The desorbtion mechanism depends on the following parameters:

- charge density from the clay particles surface
- cations type and concentration
- organic matter and carbonates presence
- soil's pH

During the process it was observed a diminution of electric density which supposes to take place as a result of conductivity modification produced by several phenomenons:

- Activation polarization – during the process exposure gases formed (oxygen and hydrogen) cover the electrodes acting as isolators which diminuates the conductivity and the electric density;
- Rezistance polarization – salts layer formation at the surface of the cathode which diminuates the conductivity and the electric density
- Concentration polarization – hydrogen ions formed at the anode are drawn to the cathode and the hydroxyl ions formed at the cathode are drawn to the anode

When the electro osmosis flow is too low the electrodes can be washed with a cleaning agent or water.

To prevent precipitation the electrode can be covered with a material with ionic exchange properties.

Contaminants migration in soil solution is determined by four compounds:

- hydrodynamics flow
- electro-kinetics flow

- dissolved components diffusion in soil solution
- ions migration

Electro-kinetic rehabilitation efficiency on contaminated soils with heavy metals depends on soil humidity, particles dimensions, ions mobility, porosity, electric density and contaminants concentration.

There are several possibilities to increase process efficiency:

- precipitation avoidance
- ionic conductivity increase
- cathode depolarization
- electrical energy consuming diminution by depolarization
- usage of additions which do not precipitate during the process
- usage of additions which do not form dangerous compounds

As depolarization agent can be used hydrochloric acid or acetic acid with low concentrations.

Cadmium and lead removal

In basic conditions cadmium and lead precipitate in soil as hydroxides and carbonates. Soil's pH value determines the hydroxide and carbonate concentrations from soil.

4. METHODS OF ELECTRO-KINETIC REHABILITATION OF POLLUTED SOILS

4.1 Cation selective membrane method

In alkaline agent it is possible that heavy metals ions can be absorbed on soil particles as insoluble precipitates. pH high values from near the cathode is the main obstacle in heavy metals removal.

The disadvantage can be reduced by putting the cathode in a solution with high conductivity. However this method is hard to apply because of the thickness of the solution layer which is supposed to separate the electrolyte from soil and because of its high costs. To reduce the solution/water volume it is used a cation selective membrane which allows cations migration. Most of hydroxyl ions formed stay in the cathodic sector, nearby the memebrane, where they encounter the protons. A sudden pH variation is recorded in this area because of the ions neutralization. Therefore the membrane maintains low pH values in the contaminated soil, not allowing the hydroxyl ions to enter in that area where they could produce heavy metals precipitation.

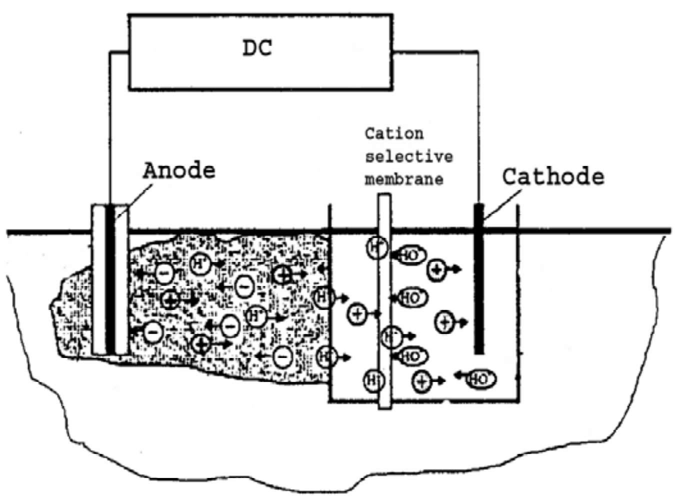

Figure 2. Working principle of cathode selective membrane methode

4.2 Ceramic plates method

For many years it was believed that electro-kinetic rehabilitation was efficient for saturated soils with high content of fine sand and clay.

Applying this method on unsaturated soils has some limits, because the soil's conductivity depends on its humidity. During electro osmotic migration the water volume from the anode decreases and the soil conductivity becomes to low to make electro-kinetic rehabilitation possible.

To control the hydraulic flow from soil there are used ceramic plates put round the anode. The ceramic plates have the role to assure water flow from soil to anodic area. Still the water volume from the anode must not exceed. If the soil is saturated water can migrate to uncontaminated lower layers.

4.3 Lasagna method

This method was used for the first time in USA in the year 1995 and it consists in installing between the electrodes several permeable layers, adding absorbent materials, catalytic agents, oxidation agents and applying electric current. Lasagna method has several advantages comparing to other methods. One of the advantages is that the fluid flow direction can be changed by reversing electrode polarity. This polarity change makes the contaminant to pass through the treatment area for several times. There are two technical configurations: horizontal and vertical. Even though Lasagna method is good for heavy metal removal, but it has other technical limits. One of its disadvantages is blocking formed gases after the electrolysis in soil. Another technological problem is to assure a good contact between the electrodes.

4.4 Electro-klean electrical separation method

This technology can be applied in situ for heavy metal radionuclides and COV from sand soils, loamy soils, clay soils and saturated or non saturated lees by inserting electrodes directly in the contaminated soil. For efficiency increase can be added process intensification fluids (acids). The main disadvantage of this method is soil's capacity to tampon.

4.5 Electrokinetic bio-rehabilitation

This method's main purpose is soil microorganism's activation using nutrients to start growth, reproduction and metabolism, microorganisms able to degrade organic contaminants.

This method guarantees an equal dispersion. But it has big disadvantages: microorganisms can be destroyed by high contaminants concentration and can produce toxic biodegradation intermediates.

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