

Electrolytic Methods



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Electrolytic Processes

Electrolytic soil decontamination methods:

1. Electro-osmosis

2. Electroacoustic

General mechanisms:

Mobilize ionic species, towards their respective electrodes by applying direct current and acoustical fields

Recovery of contaminants including neutral compounds transported by advection occurs at the electrodes

Dissolved contaminants are pumped to the surface for above ground treatment

Electro-osmosis Physical Mechanisms

Use current flow and electric potential gradients to enhance organic contaminant removal

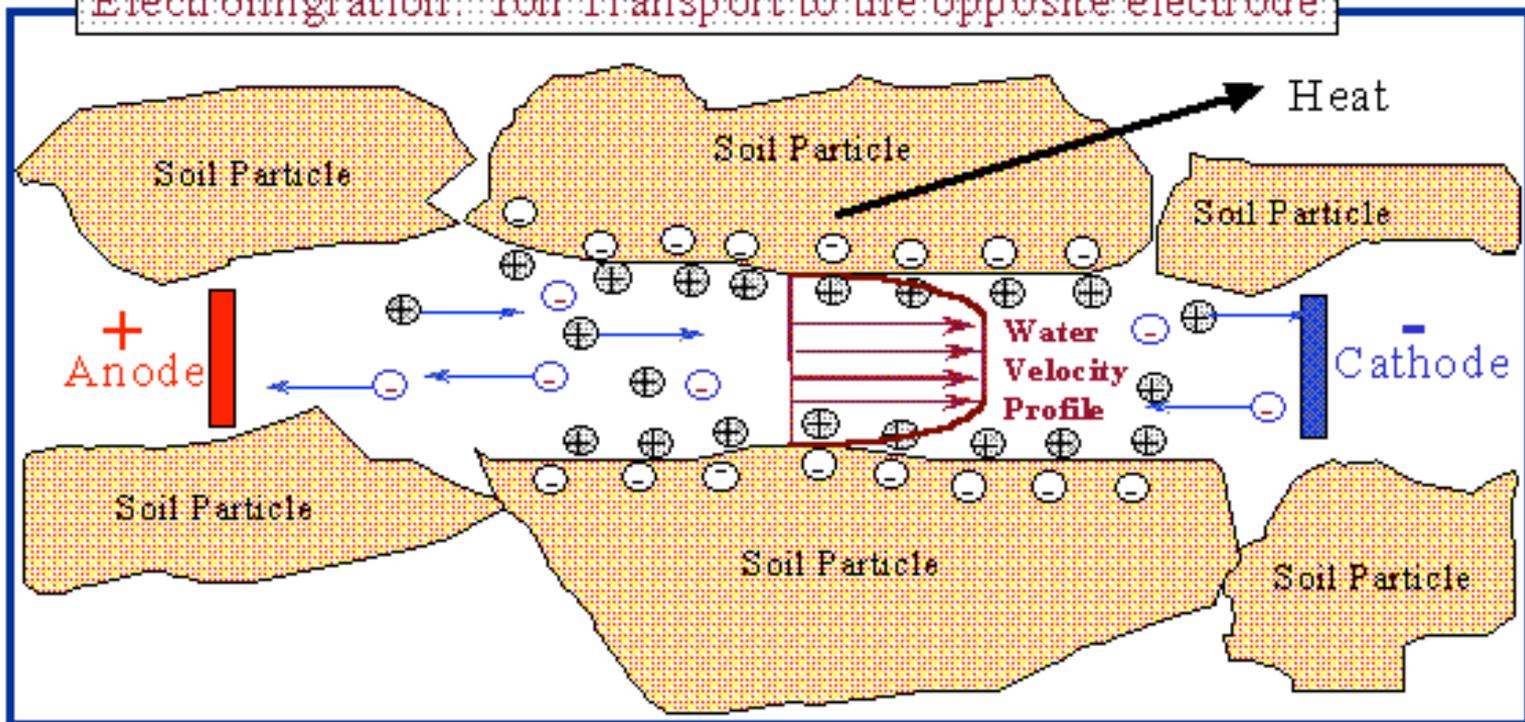
Main Mechanisms:

1. Ionic migration of charged species (cations, anions) resulting from the applied electrical potential
2. Advection of neutrally charged species in the direction of the bulk direction of the bulk diffusive flow of the major ions, usually cations
3. Two forces, motion of liquid and motion of ions, counter direction
4. Electro-osmosis as dominant force. (Similar to Current and Electrons)

Figure 1. Principles of ElectrokINETICS

Electroosmosis: Water Transport from anode to cathode

Electromigration: Ion Transport to the opposite electrode



Electroacoustic Physical Mechanisms

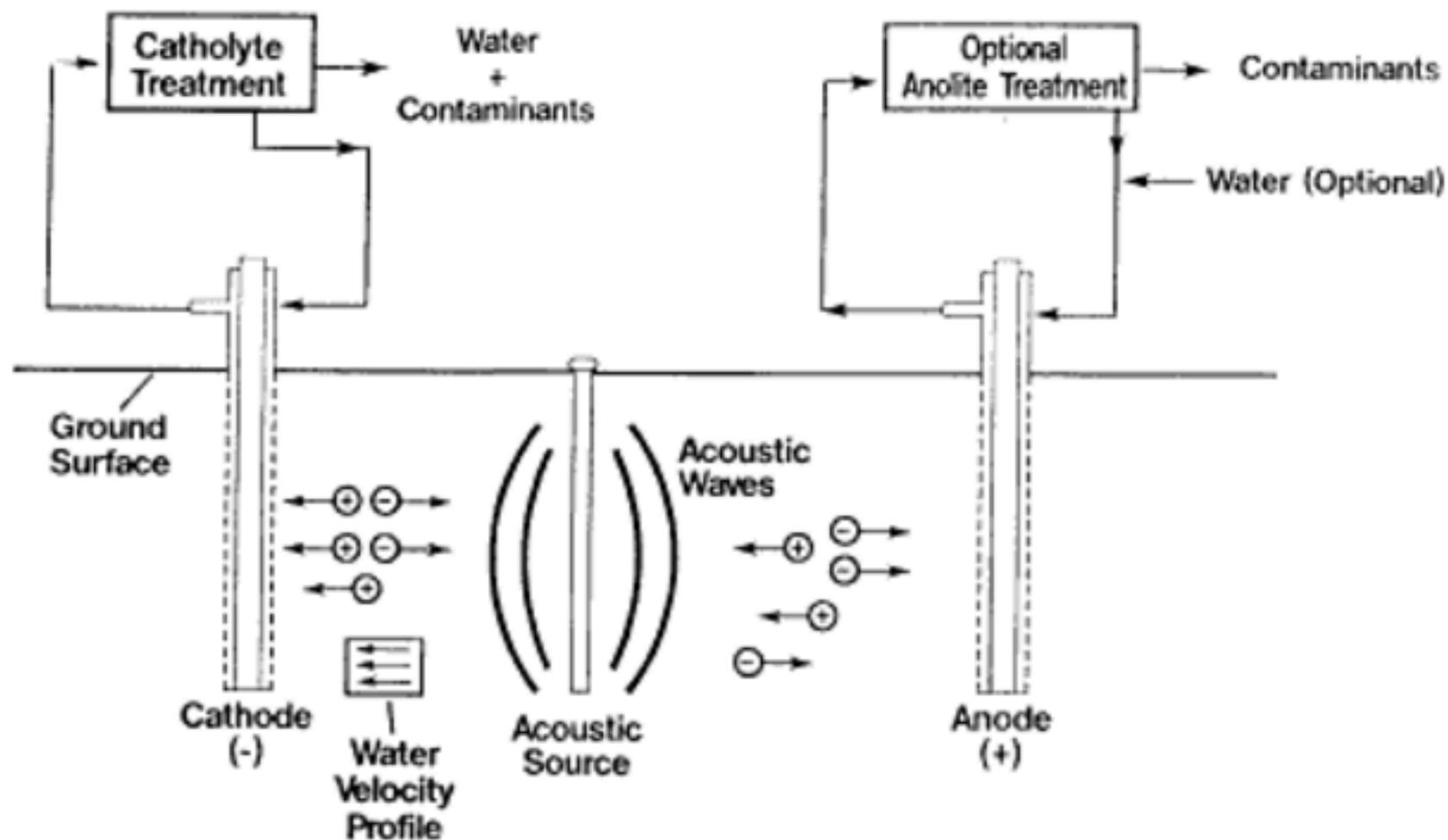
Employs both electrical and acoustical (pressure) gradients

Electrical potential removal mechanism identical to Electro-osmosis

Acoustic fields generate fluctuating pressure waves

Function of time and position

Enhances removal by rearranging particles



Electroacoustic Physical Mechanisms

Primary removal mechanisms:

1. Orthokinetic forces - small particle agglomeration
2. Bernoulli's forces - large particle agglomeration
3. Rectified diffusion - capitation of pore fluids and gas bubbles expel fluid in capillaries
4. Decreased apparent viscosity - from high strain rates and localized heating
5. "Rectified" Stoke's forces - nonlinear spatial variation in fluid viscosity aids in transport to the source

Influencing Factors- Aquifer Conditions

1. Effective in low permeability soils such as clays and silts

Best with low void ratios

2. Aquifers with high electrolytes may drive zeta potential to zero, resulting in a cease of flow

3. Aquifers where zeta potential is negative, flow will be reversed

4. Low salinity desirable

High salinity will increase power consumption per unit volume of water

5. Electricity heats soil which decreases viscosity and increases flow rate

Influencing Factors- Physical Limitations

1. Heterogeneity and anomalies in soil

Large iron deposits or pieces of metal

2. Solubility and sorption

3. The concentrations of target ion and nontarget ions

4. Conductive pore fluid

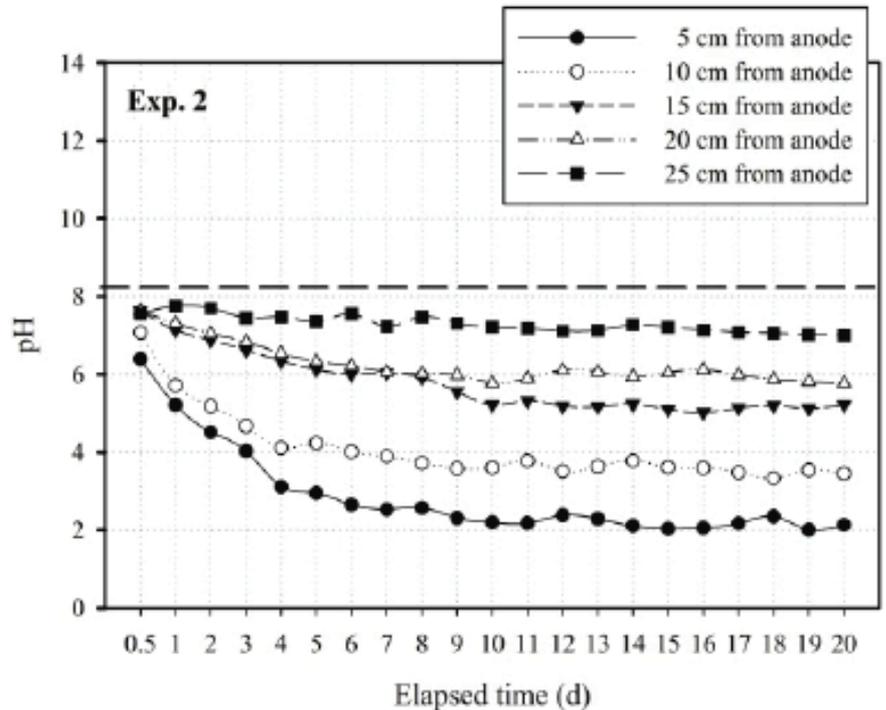
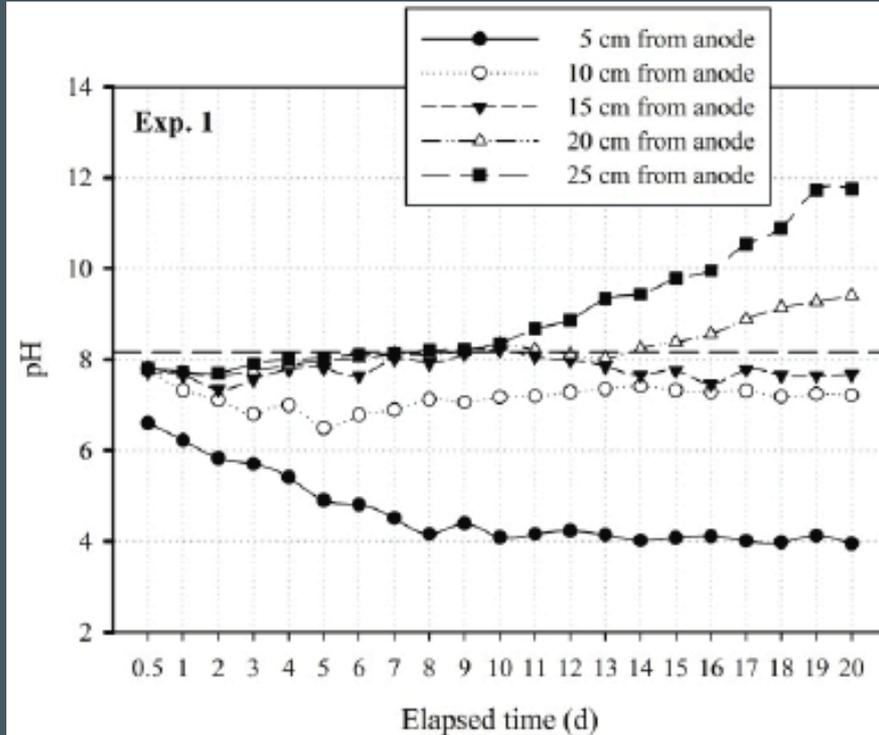
5. pH changes and controls

As acid front is carried to cathode. Hydrogen ions produced at anode and increase of hydroxide ions near the cathode.

Addition of acid can lead to acidification of soil

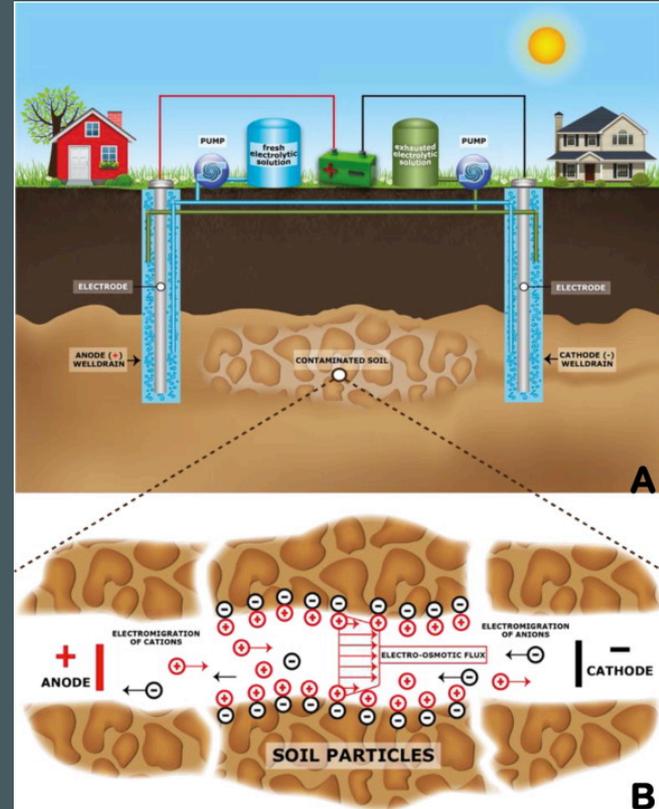
Influencing Factors- pH Gradient

Removing cobalt and lead from soil using catholyte conditioning with nitric acid



Field Implementation of Electro-Osmosis

- Wells are electrically charged into corresponding cathodes and anodes
- Contaminants migrate across electric potential gradient and are recovered at the electrodes
- Heavy metals and other contaminants then are pumped to the surface for treatment



Electro-Osmosis vs. Pump and Treat

- Methods nearly identical, except for current, voltage, and electric gradients as major design variables in Electro-Osmosis
- Due to concentration of plume around wells in Electro-Osmosis, as opposed to locating wells within plume in Pump and Treat, Electro-Osmosis has a lesser impact on surface drilling and reclamation

Examining Electrode Design

Electrodes can be placed in conventional collection and extraction wells

Wells generally encased in steel and electrodes made of graphite

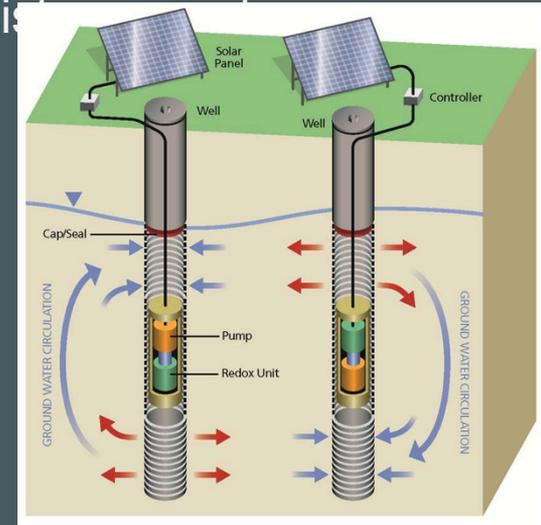
Graphite electrodes - non wetting surfaces, corrosion resistant
hydrogen gas formation

Electrode Spacing depends on potential and purpose:

DC Potential 25-500V

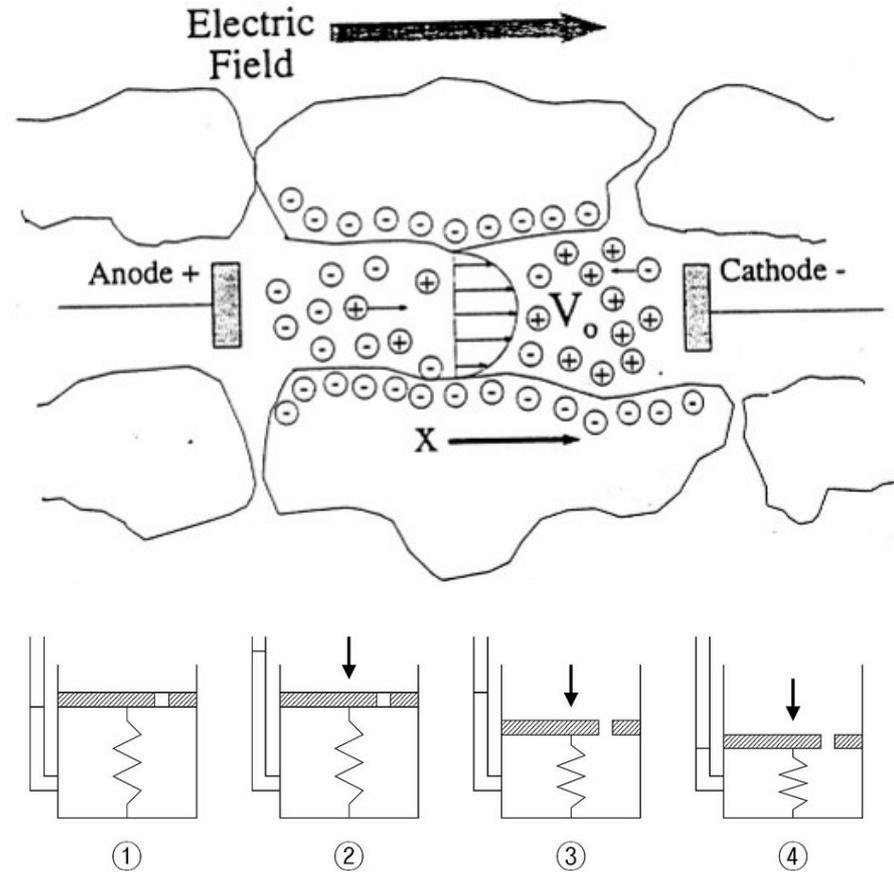
30 ft. (Dewatering)

3-5 ft. (Contaminant Recovery)



Addressing Consolidation at the

- Cations move from anode to cathode during electro-osmosis
- Due to dipolar nature and frictional drag cations pull additional water to cathode
- Leaving anode with little soil water content and resulting instability
- To prevent consolidation at anode lubricants, salts, and water are added



Electro Acoustic Design

- Currently in developmental stages
- Uses acoustic shaker positioned in proximity of wells to enhance contaminant migration by amplifying compression and shear waves
- When applied to electrolytic osmosis new channels may be formed enhancing dewatering
- Most favorable when used in remediation of heavy metals such as zinc or lead

U.S. Patent Mar. 24, 1992 Sheet 1 of 3 5,098,538

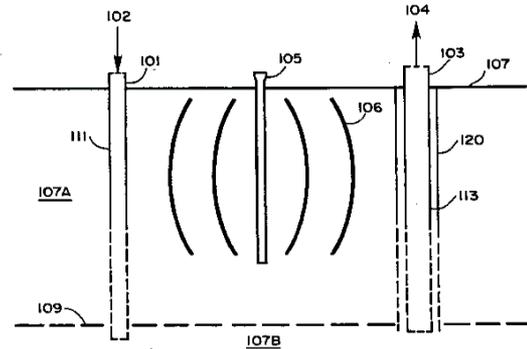


FIG. 1

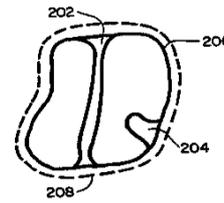


FIG. 2A

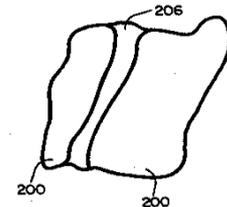


FIG. 2B

Level of Demonstration and Performances

Geotechnical applications of electro-osmosis date back to the 1930's

Clay dewatering

Enhancing rates of clay consolidation

General site and soil improvement

Environmental applications of electro-osmosis

Relatively new

Mostly address the recovery and treatment of heavy metals and radionuclides

Level of Demonstration and Performances

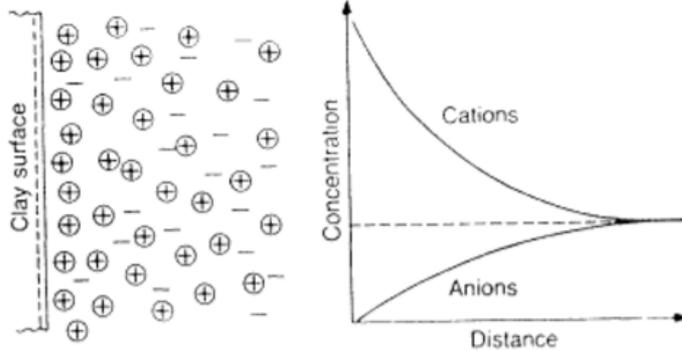


Figure 3.3.1.1 Ion distribution adjacent to clay particle surface [Mitchell, 1991]

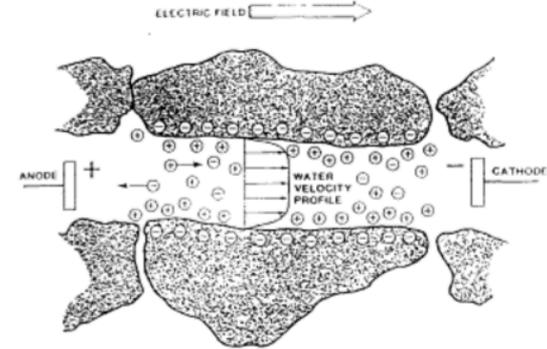


Figure 3.3.1.2 Schematic of electro-osmotic flow resulting from an applied electric field in a charged porous medium [Shapiro et al., 1989b].

Level of Demonstration and Performances

1986 - electro-osmosis was implemented at a chrome-plating facility in Corvallis, Oregon

Subsurface soils included clays and clayey silts

Seven electrodes were installed in monitoring wells at depths of 20-22 ft

An anode was placed in the center of the well in order to obtain a seven spot configuration

Spacings between the center well and perimeter wells was 5 ft

A current of 5-10 amps was applied

Hexavalent chrome and other metals were accurately recovered in the center well

Ground-water concentrations of chrome were reduced from 1,000 mg/l to 35 mg/l

Level of Demonstration and Performances

Most environmental applications of electro-osmosis have been conducted abroad, specifically by Geokinetics, Inc. in your Europe.

Two field tests and one commercial application have been completed

One of the field experiments consisted of sandy, clayey soils located near the ground surface which has soil concentrations of zinc of 7,101 ppm (max) and 2,410 ppm (avg)

After in use for 8 weeks, an energy supply of approximately 160 kW/ton was applied and the zinc concentrations were reduced to 5,300 ppm (max) and 1,620 ppm (avg)

Another field experiment was conducted in sediments located within a drainage ditch which had soil concentrations of copper and lead as high as 5,000 and 10,000 ppm

The commercial application consisted of nearly 350 tons of arsenic contaminated

Level of Demonstration and Performances

Electro-osmosis applications are currently being evaluated as part of the USEPA SITE Program for the removal of tetraethyl lead from clayey soils at a former refinery.

100,000 ppm concentrations of lead have been measured in the soil

Perspectively, normal drinking water standard is 5 ppm

The cleanup goal is roughly 500 ppm

The process was set up similarly to the one in 1986 in Corvallis, Oregon

As of fall 1992, initial results indicated that the electro-osmosis process was unsuccessful and the test program was later temporarily suspended

Level of Demonstration and Performances

Soluble (and polar) organic compounds such as acetic acid and phenol have been successfully removed from clay soils in laboratory samples

Ongoing bench studies are currently examining the viability of electro-osmotically enhanced removal of BTEX, TCE, and other non-polar organic compounds

In one kaolinite soil column study, 25 weight% of TCE (150 ppm) was removed within 5 days

Electrolytic Methods Limitations

Main Limitations:

1. Contaminants must be dissolved by an externally introduced fluid. If a contaminant cannot be dissolved it cannot be removed with electrolytic methods
2. Soil pH becomes very low and acidic during electrolytic treatment
3. Low soil permeability is required for high removal efficiency
4. Gas bubbles from dissociation inhibit the cathodes and increase resistance

Electrolytic Methods Applicability

Main Applications:

1. Implemented when contaminants can be dissolved with groundwater (mainly heavy metals).
2. Mercury, zinc, iron, lead, copper, and magnesium are species easily treatable with Electrolytic methods, but species that can sorb to other material has low efficiency.
3. Polar compounds (phenol), petroleum derivatives, DNAPLs, nitrates, sulfates, and radium are also treatable with electrolytic methods.
4. When excavation and off-site remediation is not an option, Electrolytic methods can be employed on-site (as well as in a laboratory)

Electro-osmosis method cost and availability

- Demonstrated technology
- American Patents:
 - Probst
 - Louisiana State University
- European Patent:
 - Geokinetics International
- No applicability to DNAPL's
- Cost:

Electroacoustic method cost and availability

Lab scale technique

Patent by Batteile Memorial Institute

No applicability to DNAPL's

Cost similar to electro-osmosis plus energy costs