PHYSICO-CHEMICAL EFFECTS ON THE RECLAMATION OF CONTAMINATED FINE-GRAINED SOILS BY ELECTRO-OSMOSIS

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Dedicated to

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ABSTRACT

Electro-osmotic remediation of soils is an innovative technique to remove contaminants from fine grained soils. This technique is based on the migration of contaminant ions (to cathode and anode) under the influence of a direct current electric field. One dimensional controlled laboratory experiments were conducted to measure physical (porosity, current intensity, volume change and electro-osmotic coefficient of permeability) and chemical (pH, conductivity) changes occurring in soil specimen during the electro-osmosis process. The effect of confining pressure on the removal of Barium adsorbed on fine grained soils was investigated.

Special electro-osmosis cells were designed to accommodate test samples five inch in length and two inch in diameter. A soil containing only particle smaller than 75 microns (passing a U.S. Sieve No. 200) was contaminated with a 0.01N Barium Chloride solution. Consolidated (under confining pressure) samples were loaded into electro-osmosis cells. Test samples were subjected to constant confining pressures of 15 and 50 psi, while a constant voltage gradient of 1 volt/1 inch was impressed between ends using graphite electrodes. Tap water, distilled water and 0.1N Calcium Chloride solution were used as purging solutions at the anode end. Each test was continued until a quasi equilibrium state was attained.

The test results indicate that the electro-osmotic flow and removal efficiency were time dependent. Removal efficiencies of the Barium ranging from 50%-95% were achieved depending on the intensity of the confining pressure and the duration of tests.

In all the tests, accumulation of the Barium was observed at the cathode section. An increase in the pH across the specimen from the anode to cathode, indicates the migration of the acid front from the anode to the cathode. A decrease in conductivity and an increase in porosity from the anode to the cathode were also observed. The changes in the coefficient of permeability (electro-osmotic) and electro-osmotic flow due to confining pressure were compared with the results (without confining pressure) available in the literature. It was found that the confining pressure has a significant effect on the Barium removal during electro-osmosis process. The energy expended in the decontamination process varied from 27 - 62 KW-hr/m^3 of the soil treated.

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Chapter One

INTRODUCTION

The migration of contaminants from hazardous waste facilities, uncontrolled point sources and accidental spill sites results in contamination of large volumes of soils and ground water. The remediation of these sites (soils and ground water) has been the most costly and time consuming part of any site remediation. Currently available waste management alternatives such as physical removal, encapsulation, stabilization, bioremediation and vacuum extraction etc. have advantages and limitations depending on the nature of contaminants and site conditions. The remediation by physical removal of huge mass of contaminated soils becomes very expensive and can cause greater damage to the environment than if the affected soils were left in place. Encapsulation of the contaminated soil mass with impermeable barriers is a temporary measure for arresting the spread of contaminants. Stabilization of the ground by application of chemicals may not be desirable if the site must be restored and rehabilitated. The most successful in-situ remediation technologies such, as vacuum extraction, bioremediation and pump and treat methods are restricted to soils with relatively high hydraulic conductivities and can't be used for low permeability soils.

One technology which has recently received a significant attention involves using the principles of electrokinetics for in-situ remediation of hazardous waste sites. This technique offers a possibility of inducing greater flow through fine grained soils and thus

causing contaminant movement that could not other wise be achieved. Electrokinetics is the complex set of phenomena that occurs on the application of a direct current electric field across the soil-water system. The principal effects of this phenomena are electro-osmosis, electrophoresis, streaming potential and sedimentation. Of these four, electro-osmosis is the potential site remediation technique with a possibility of removing contaminants from fine-grained soils.

The electro-osmosis technique has been used (by Geotechnical Engineers) for several decades for dewatering and consolidation of soils for construction purposes (such as, strengthening steeply cut slopes, pile driving operations, increasing the load capacity of piles) as well as to dewatering of mine tailings and waste sludges and dredge materials (Segall et al).

In recent studies (Renauld and Probstein 1987, Steude et al 1983, Acar 1992, Shapiro et al 1993, and Lageman 1993), electro-osmosis has been described as a possible remedial technique in the remediation of hazardous waste sites. In the laboratory study of electro-osmosis as a potential technique in site remediation, investigators (Pamukku it al 1989, Acar et al 1990, Hamed et al 1991, Van Doren 1987) used commercially available pure clay (Georgia Kaolinite clay) with high water contents. There has been no attempt to consider the effect that confining pressures could have on contaminant removal. Another concern is that kaolinites are low charge clays with minimal cation exchange capacities; thus the effect of the cation exchange capacities of "in-situ" clays appear to have been also ignored in the technical literature.

The unique aspect of the present study is the use of naturally occurring fine-grained soils and the application of confining pressure to simulate the field over burden pressure.

1.1 Research Objectives

The primary purpose of the present research is to help in accomplishing the following objectives:

1. Evaluate the feasibility and extent of electro-osmosis in removal of a barium contaminant adsorbed on fine-grained soils.
2. Documentation of pH, moisture content and conductivity changes occurring in the sample as a result of electro-osmosis.
3. Evaluate the effects of confining pressure on the effectiveness of contaminant removal.
4. Effects that the cation exchange capacity of the "in-situ" soils might have on the feasibility and/or on the rates of Barium removal from the soil.

1.2 Scope of Work

To accomplish the above proposed goals several specimens of soils were prepared and tested in the lab under controlled conditions. Specifically, the following tasks were performed;

1. A stock of fine-grained soil was prepared by washing through U.S Sieve no. 200.

The soil was cleaned for the removal of soluble salts and organic matter. This step was meant to avoid the complexity of physico-chemical conditions that develop as a result of the interaction of the Barium with other species in the soil during the electro-osmosis process.

2 The soil free of soluble salts and organic matter was subjected to classification tests such as Hydrometer analysis and Atterberg limits tests. In addition, tests to identify the mineralogical composition of the soil and cation exchange capacity were performed. These tests were intended to evaluate the effect of cation exchange capacity on the barium removal from the soil.

3. Prepared test specimens were loaded in to specially designed electro-osmosis cells. Tests were performed on the specimens for different test conditions. This was aimed to quantify the extent of Barium removal from the soil subjected to different confining pressures and purging solutions under constant potential difference across the samples.

4. In brief, the specimen preparation and testing and analysis were intended to assess the possible extrapolation of the results of the present study to other soils or to the actual field.

Chapter Two

LITERATURE REVIEW

This chapter includes a summary of electro-kinetics phenomena and basic principles. A brief review of theories for electro-osmosis was made to understand the basic difference in theories proposed by investigators. Potential applications of electrokinetics in waste management are discussed at the end of the chapter. The term "soil" in this study refers to the fine grained soils (particle size less than 75 microns) unless otherwise mentioned.

2.1 Electrokinetic Processes in Soils.

Electrokinetics is the complex set of phenomena that occur with the application of a direct current electric potential across a soil-water system. The principal effects of these phenomena are electro-osmosis, electrophoresis, sedimentation potential and streaming potential as shown in Fig.2.1. Electro-osmosis and electrophoresis are the movement of water and particles (colloids, clay particles, organic particles, droplets etc) (Mitchell J,K. 1993) respectively to the electrodes due to the application of direct current, i.e. electro-osmosis involves the water transport through a continuous pore network and electrophoresis involves a discrete particle transport through water. The streaming potential and migration potentials are the generation of potential difference due to the movement of water under hydraulic gradient and movement of particles under gravitational

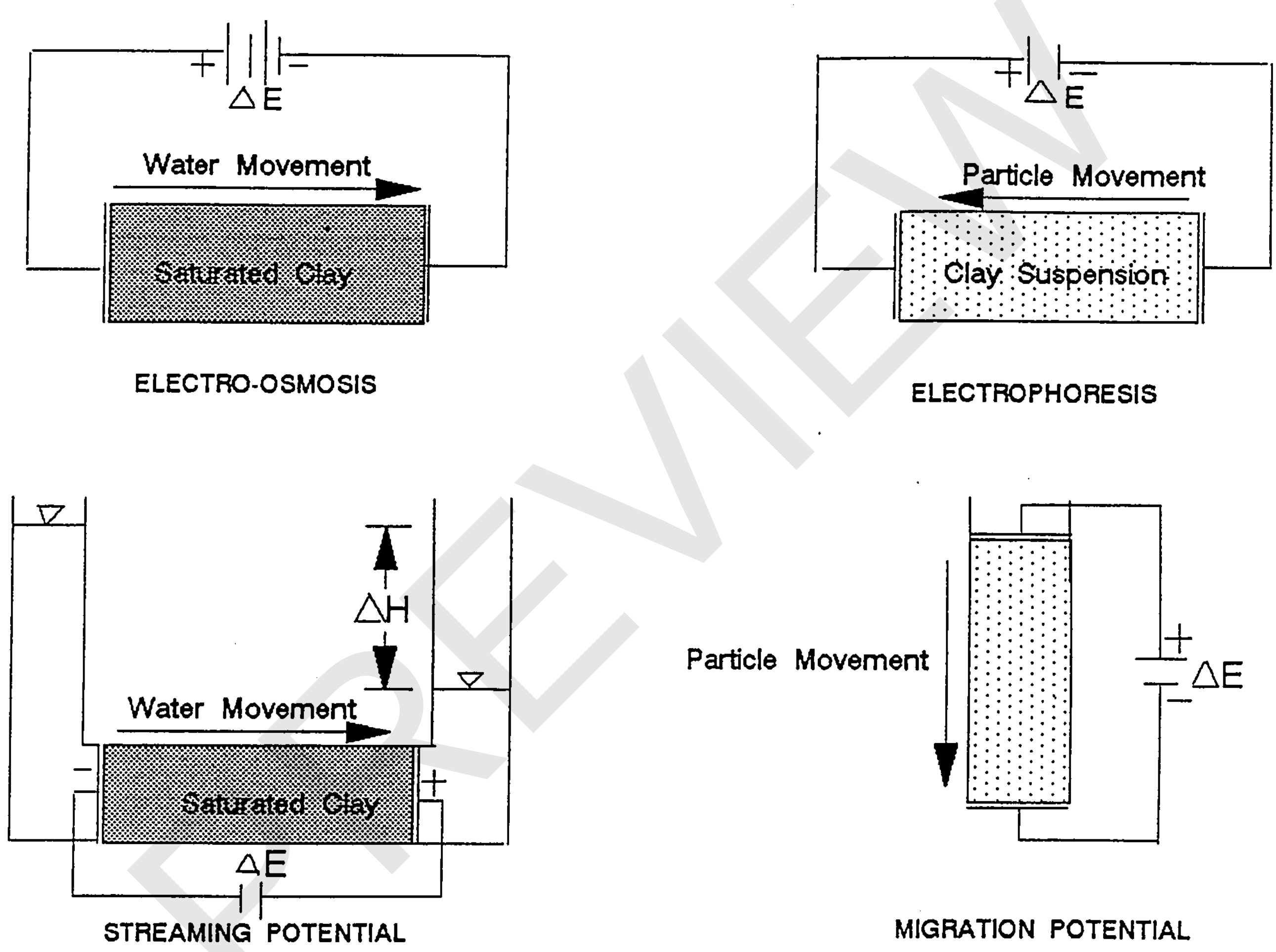

Fig. 2.1 Electrokinetic phenomena in soils (adapted from Mitchell, 1993)

forces respectively. Of these four phenomena, electro-osmosis is potentially more important to site remediation due to the possibility of removing contaminants from fine-grained soils. The theory of electro-osmosis is discussed in the following section.

2.2 Review of Electro-osmosis Theory

Fine-grained soil particles commonly posses a net negative surface charge. When in contact with water each charged soil particle is surrounded by a layer of solution with properties that differ from those of the bulk solution in the soil pores. This layer is known as the electrical double layer and is the region near the pore wall in which the fluid possesses a charge density that balances the surface charge on the pore wall (Probestein.R.F 1989). The application of an external direct electric current causes migration of ions (cations) in double layer toward the cathode in a direction parallel to the electric field as shown in Fig. 2.2. As ions migrate, they exert a viscous drag on their hydration shells resulting in liquid flow through the soil mass. This flow through fine-grained soils due to the application of a direct current potential difference across the electrodes, is called electro-osmosis.

It has been found (Segall and Bruell, 1992) that an empirical relationship similar in form to Darcy's law can be used to relate the electro-osmotic flow rate, Q_e as follows:

$$Q_e = K_e I_e A = K_i I \qquad 2.1$$

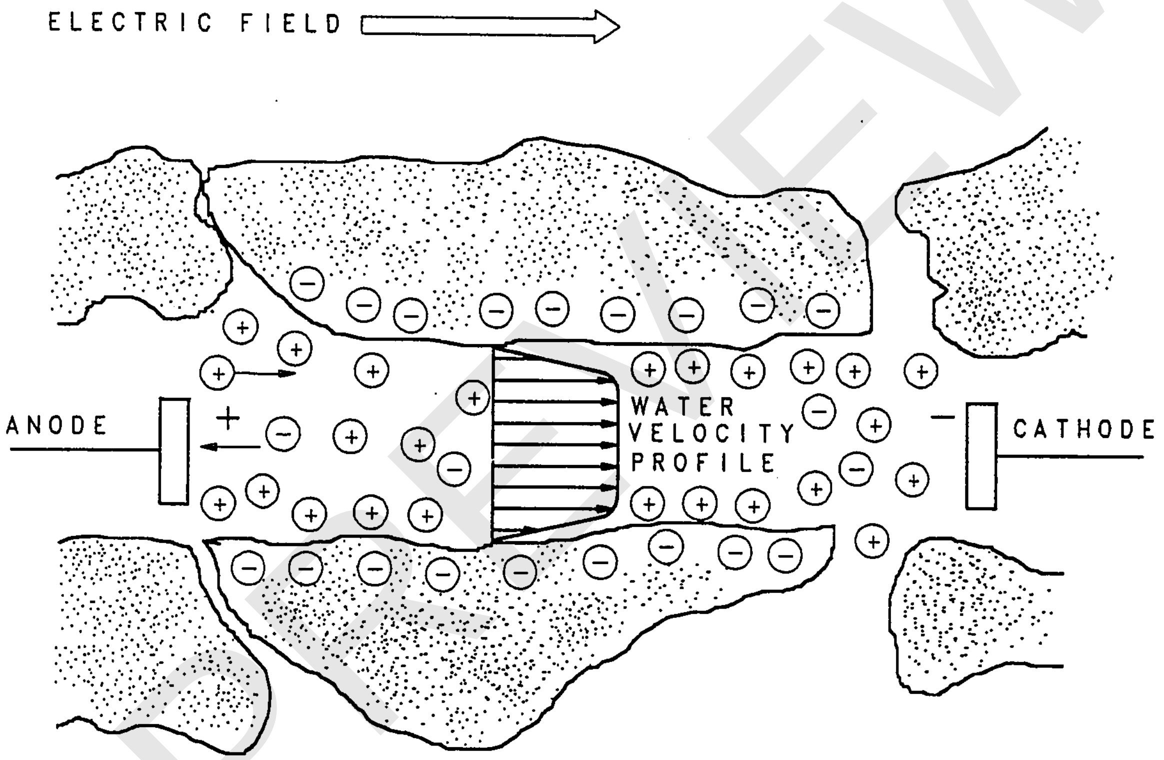

Fig. 2.2 Electro-Osmosis Principle(Probstein, 1989)