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## Electrossmotic flow and electroosmosis in soil

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### Abstract

There is motion of a fluid with respect to a rigid wall when an electric potential gradient is applied across it. This process is called electroosmosis. The aspect by which rate of electro-osmotic flow is managed is the coefficient of electro-osmotic permeability of the soil which is zeta potential dependent. Many researches have measured the variation of the coefficient of electro-osmotic permeability of soils. The value varies from  $4.91 \times 10^{-6}$  to  $1.57 \times 10^{-5} \text{ cm}^2 \text{ S}^{-1} \text{ V}^{-1}$ . The Helmholtz-Smoluchowski model is largely used to explain electroosmosis process. In this paper first of all the cause of flow is discussed and then electroosmosis in soil is studied and alongwith that applications of electroosmotic flow are also briefly framed.

**Keywords:** Electroosmosis, Potential gradient, electroosmotic flow, Zeta Potential

### 1. Introduction

Electroosmosis is the process of transportation of water through an endless soil particle system, where the motion is firstly produced in the moisture film in the diffuse double layer (where the cations command). Reuss (1809) discovered that water flow could be induced through a capillary by an external electrical gradient. With the application of the straight electrical gradient to a clay-water system, the mobile diffused layer moves and the solution with it is carried while the surface or particle is fixed. The main mechanism in the electroosmosis is the movement of charged particles; anions (-ve charge) move towards +vely charged electrodes (anode) and cations (+ve charge) move towards -vely charged electrode (cathode) (fig. 1)

Mausmann (1990) has proposed higher soil particle surface results in greater moisture film transfers. Viscosity and electrical potential applied can also affect this process [22]. There are many other theories which explain theory of electroosmosis including Helmholtz-Smoleachowski theory, Buckingham TC theory, Ion hydration theory, Spiegler friction model, Schmid theory [6].

The flow which is the result of the fluid surrounding the soil particles is persuaded by ionic fluxes is Electro-Osmotic flow [12]. Also, the direction of flow of the water molecules in bulk phase and flow from fluid surrounding the soil particles is same. Flow in the fluid surrounding the soil particles is first region and flow in bulk phase is second region and when interaction takes place between the two, it enables the motion of water in bulk phase which implies that a drag action is the major reason of the electro-osmotic flow. Therefore, movement of these two water layers is main cause of the overall noticed electro-osmotic flow. Electroosmosis occurs from cathode to anode since positive charged surface has opposing action.

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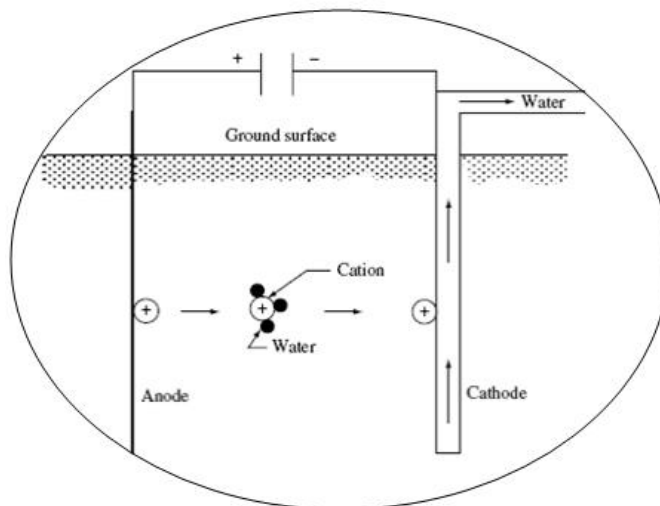


Fig 1: Principles of Electroosmosis (Modified from [21])

**Cause of Electroosmotic flow**

Electroosmotic flow takes place when Coulomb force is induced by an electric field on net moving charge in a solution. There is generally a formation of interface (constant), a layer of mobile ions (electrical double layer) formed in the area near the interface due to the chemical equilibrium between any rigid surface and an electrolyte

solution. Net charge in the electrical double layer is induced to move from Coulomb force generated, when an electric field is applied to the fluid. Hence, we get electroosmotic flow. For the determination of electro-osmotic flow, charge distribution in fluid adjacent to flow, soil surface and  $\zeta$  play significant role according to Hemholtz-Smoluchowski theory.

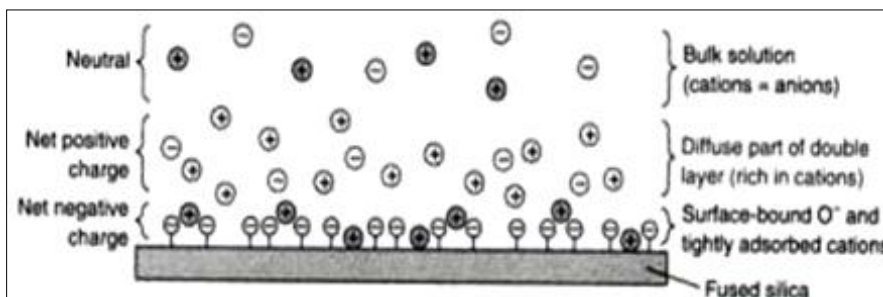


Fig 2: Formation of double layer for electroosmotic flow

**Helmholtz-Smoluchowski Theory**

To describe electroosmotic process, this theory is widely used. The assumption of the theory is:

(i) The charge distribution in the fluid adjacent to soil surface and the zeta potential play major roles in evaluating electro-osmotic flow. The electric potential developed at liquid-solid interface as a result of the motion of colloidal particles is  $\zeta$  i.e. the potential at junction between the mobile parts and fixed part of the electrical double layer. Surface potential of particle is more than  $\zeta$  and lists the value at the slip plane which is placed at a small unknown distance from the colloidal surface [14, 15].

(ii) The size of the pore radii is comparatively big in contrast to the thickness of the diffuse double layer and mobile ions which are collected near the soil-water interface. The value of this potential is also effected by thickness of the double layer, ion exchange capacity and size of ion radius [9, 10]. Also, sign and magnitude of  $\zeta$  varies with interaction of both solid and liquid phases.

The coefficient of electro-osmotic permeability of the soil,  $K_e$ , which is a measure of the fluid flux per unit area of soil per unit electric gradient regulates the rate of electroosmotic flow. The coefficient of electro-osmotic permeability is given by:-

$$q = \frac{\epsilon \zeta}{V_t} n \frac{E}{L} A$$

where, L = length

$\Sigma$  = soil electrical permittivity

q = flow rate.

$\zeta$  = zeta potential

A = Gross cross sectional area normal to flow of water

$V_t$  = Viscosity of the pure fluid

n = soil porosity

The value of  $K_e$  based on the Helmholtz Smoluchowski theory depends mainly on  $\zeta$  and n. One of the significant electrokinetic properties of soil colloids is  $\zeta$ .

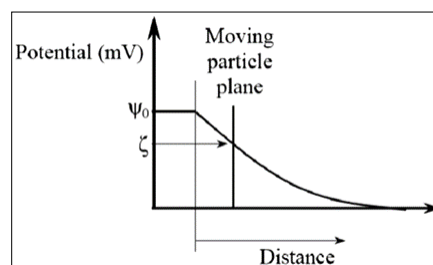


Fig 3: Distribution of potential indicating the slipping plane (Zeta) potential (Modified from [13])

After many researches on  $\zeta$  potential of clay minerals in various solutions [19, 28], it has been found that valence of ions, concentration of electrolyte, pH and type of electrolyte are significant factors which can affect  $\zeta$  values.

During electrokinetic process, as long as there is zero change in pH of the pore liquid and the concentration of ions, it is assumed that  $K_e$  remains constant. The measurement of  $\zeta$  is simple and direct and can be measured by Zeta meter. Firstly, the sample is put in a chamber which is known as electrophoresis cell. After that electric field is applied, consequently particles move with velocity that is directly proportional to Zeta potential. To know whether their change is positive or negative, the direction of the movement of particles is considered.

It is generally preferable to calculate  $\zeta$  in millivolts instead of in electrostatic units. The formula which shows relation is:

$$\zeta = 11300V_t \frac{EM}{D_i}$$

Which is obtained from most simple expression for  $\zeta$ ,

$$\zeta = 4\pi V_t \frac{EM}{D_i}$$

Where, EM = Electrophoretic mobility at actual temperature

$D_i$  = dielectric constant

$\zeta$  = Zeta potential

$V_t$  = Velocity of suspending liquid

As  $\zeta$  increases the thickness of the double layer increase. The value of  $\zeta$  is negative for clay. Due to negative  $\zeta$ , electroosmosis occurs from anode to cathode whereas positive surface charge causes electroosmosis to occur from cathode to anode. There is zero variation of  $\zeta$  in organic soils while in clay, variation of  $\zeta$  has been observed. Both  $\zeta$  and acidity are inversely proportional.

As long as soils with big pores are soaked with water assumption (b) is valid. Helmholtz Smoluchowski equation is less applicable for unsaturated soils or small capillaries.

Casangrade [17] has proposed the most widely used electro-osmotic flow equation for soil system (Eq. 1)

$$q = i_e AK_e \text{ (Eq. 1)}$$

Where,

$K_e$  = Coefficient of electro-osmotic permeability

$q$  = flow rate

$i_e$  = Applied electrical gradient

$A$  = Gross cross sectional area normal to water flow

**Table 1:** is showing source general values of  $K_e$  for various soils (adjusted from [4, 13, 21])

Soil type	$K_e, \text{Cm}^2/\text{V.S}$
Peat	$4.91 \times 10^{-6}$ to $1.57 \times 10^{-5}$
Clay slit	$5.0 \times 10^{-5}$
Kaolin	$5.7 \times 10^{-5}$
London clay	$5.8 \times 10^{-5}$
Boston Blue clay	$5.1 \times 10^{-5}$
Na- montmorillonite	$2.0 \times 10^{-5}$ to $12 \times 10^{-5}$

Electrolysis reactions at electrodes are caused by the application of straight (direct) current through electrodes [9, 10, 24]. Base and Acid are generated by the reduction at the cathode and oxidation of water at the anode respectively. The reactions are:



The acid produced at the anode proceeds through the soil towards cathode due to electroosmosis and ionic migration. Similarly, because of ionic migration and diffusion the base formed at the cathode firstly moves towards the anode. However, the opposite flow due to the electroosmosis makes migration of the base front and back diffusion slower. The movement of the acid front is faster than movement of the base front due to following reasons:

a) Nature of electroosmotic flow is counteracting.

b)  $\text{H}^+$  has more ionic mobility than  $\text{OH}^-$  [26-32]

The electrokinetic process can be increased or decreased, since in geotechnical reactions, soil pores remarkably affect electrokinetic phenomena. The reactions such as dissolution, complexation and precipitation are called geochemical reaction and are highly dependent on pH conditions [5, 18, 32].

### Applications

Electro-osmotic flow is generally used in soil analysis and processing and chemical analysis mainly of oxides which are highly charged surfaces and in microfluidic devices. Capillary electrophoresis is an example in which electric field is applied to narrow capillary which is made up of silica to separate chemicals according to their electrophoretic mobility. The electroosmotic flow affects the elution time of analytes in electrophoretic separations.

Microfluidic devices utilizing electroosmotic flow will have applications in medical research, it is planned. The ability to separate fluids on the atomic level will be a most important component for drug dischargers, once the flow is controlled and implemented. Currently, it is troublesome to mix fluids at micro scale. It is believed that when small fluids are mixed, electrically controlling fluids will be one of the methods.

#### 1. Vascular plant biology

Electro-osmosis is also used as an alternative or supplemental explanation for the movement of polar liquids in vascular plant biology, via the phloem that varies from the cohesion-tension theory supplied in the mass flow hypothesis.

#### 2. Physics

Electro-osmosis causes protons moving through a membrane called proton exchange membrane (PEM) to drag water molecules from one side (anode) to the other (cathode) in fuel cells.

#### Disadvantages

Such a process adversely affects biological cells and biomolecules such as proteins due to the changes in pH value due to formation of hydrogen peroxide since maintaining an electric field in an electrolyte requires faradaic reactions to occur both at cathode and anode. This is typically electrolysis of water which generates hydrogen ions (acid), hydrogen peroxide and hydroxide (base) as well as hydrogen and oxygen gas bubbles. Hence, conjugated Polymers are used as electrode materials which can dramatically reduce electrolysis by undergoing faradaic reactions by themselves.

#### Conclusion

Electro-osmosis of soil is the process in which when soil is placed between two electrodes in a fluid. An electromotive force develops and hence the fluid will move from one side to the other under the application of electric field. Reuss was first to discover that a water flow could be induced through a

capillary by an external electric field. A net electric driving force moves the water layer from anode to cathode due to the presence of large amount of positive charges on the surface of soil.

The Zeta potential based on Helmholtz-Smoluchowski plays an important role in electro-osmotic phenomenon. Now days, conjugated polymers are used as electrode materials because they reduce the pH level by undergoing reactions by themselves since the biological cells and biomolecules are affected by the pH changes due to electrolysis of water.

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