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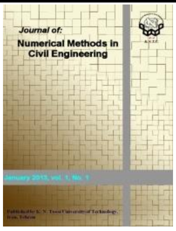

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Experimental modeling of Electric kinetic barrier (EKB) in Porous Medium, Explain its numerical solution methods and analysis of the relations in the Hydraulic-Electric coupled flow

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Abstract:

Despite the information obtained about the types of flow passing through soils and their potential effects on geotechnical problems, so far the subject of discovering the basic factors in preventing seepage by Hydraulic-Electric coupled flows and providing a model (numerical and laboratory) which can relate the electric current to hydraulic flow remains unknown. The phenomenon of coupled flows is a type of flow that is created due to the driving force or gradient of another type In fact, this research project is aimed at developing the theoretical knowledge of hydraulic-electric coupled flows and its results can be used to zero the flow in a porous medium such as seepage in engineering . Also, the simulation of the electrokinetic barrier process was carried out using the finite difference method and the methods of solving the numerical model of this process were investigated.Finally, the progressive difference approximation scheme was proposed for coding in MATLAB program due to its greater accuracy. In the laboratory part of the studies, an innovative physical model was provided. In order to achieve this purpose, several experiments were conducted on kaolinite soil with a dry specific gravity 1.3 gr/cm^3 , 1.315 gr/cm^3 , and 1.33 gr/cm^3, compared with each other. The results showed that in denser samples (γ_d=1.33 gr/cm^3) the electrical gradients applied to the cell could stop the hydraulic flow at higher hydraulic heads, while in less dense samples (γ_d=1.315 gr/cm^3 and γ_d=1.3 gr/cm^3) applied electrical gradients caused hydraulic heads to stop at lower values. It was found that the ability of the electrical gradient to create an electroosmotic flow to overcome the hydraulic flow and create an electrokinetic barrier is influenced by the input voltage, and also the dry specific gravity of the samples in the cell, and this ability increases under the influence their increase.

1. Introduction

Seepage is a quantity that can be used to gauge subsurface water flow, drainage during building construction, clay soil consolidation, the stability of an earth dam, etc. In soil engineering and geotechnics, leaking is constantly considered an issue. For example, in engineering barriers made with clay soils or in clay cores of earthen dams, exposure to seepage flows in these layers is a major issue.

In addition to the water transfer in the soil, additional flows (chemical, electrical, and heat) traveling through it and interacting with it have raised serious issues in a number of circumstances [27]. Any of these flows follow the gradient of their potential [28]. Direct flow systems include hydraulic transfer (Darcy law), electrical transfer (Ohm's law), heat transfer (Fourier law), and chemical transfer (Fick law).

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One flow may result from another potential gradient in the soil; for instance, in addition to the hydraulic gradient, flow may also result from chemical, electrical, and heat slopes. Accordingly, Chemistry-osmosis, Electro-osmosis, and Thermo-osmosis are the names given to these three processes. Electrical osmosis (the movement of water by the electrical field) Some of the most significant coupled flows in soil and water systems include osmotic chemistry (water flow as a result of an imposed chemical gradient on a layer of clay) and advection (ionic movement due to the flow force in the soil between two places).In general, it is feasible for fluid, chemical, electrical, and thermal to all be active in the system at once, and each of them contributes to the gradient of the others. The electrokinetic phenomenon is a case of simultaneous direct and indirect flow.

1.1 Electrokinetic

Generally speaking, the term "electrokinetic" refers to the movement of particles due to an electrical field. This term in geotechnics refers to a low-intensity direct electrical flow (DC) or potential differential to both positive and negative electrodes buried in the soil. Three key ideas have been drawn from electro-kinetics depending on the sort of particle that moves in the electrical field produced: Water molecules move through electroosmosis, ions move through electro-ion transmission, and solid particles move through electrophoresis when there is an electrical field present [1]. In the general case, in a transfer phenomenon, a combination of fluid, chemical, electrical, and heat flows may exist simultaneously in the system, and each type of flow includes a different type of gradient.

1.2 Electroosmosis

This phenomenon, by definition, means that if a mass of moist or saturated soil is placed in a direct electrical field, water molecules, or other words, the moisture of the soil will move from the positive pole to the negative one in case of the existence of Excess cations in the porous electrolyte and stored in the negative pole. The reason behind this transfer is the polar nature of the water molecule and the existence of cations in the porous electrolyte of the soil.

The amount of electro-osmotic flow depends on k_e, electro-osmotic conductivity, and voltage gradient, which is represented by the following equation (1).

$$q_e=k_e\times i_e\times A \quad (1)$$

(m^3/s) electroosmotic flow q_e, (m^2/s.V)electroosmotic conductivity coefficient k_e, (m^2)cross-section A, (V/m)electrical gradient i_e. It is expressed as follows using the relations of viscous fluids K_e.

Where ε is the permeability of the medium between the anode and cathode plates, ζ is the zeta potential, and μ is the viscosity of the fluid [2].

In 1985, Maurice Wells from Canada and Caldon from America did research to stabilize a dam on soft and sensitive clay-silty soil [3]. The effect of freezing and melting cycles on the properties of Merle soils, treated by electroosmosis has been analyzed by Vakili et al., have cured Merle clay, which is composed of 35% to 65% of calcareous material and has very low transfer capacity, especially after freezing and melting cycles, through electroosmosis. The results indicated that by unlimited pushing resistance of the samples taken from around the anode (under the operation of electroosmosis), the transfer capacity is significantly increased (2.8 times over) [4]. Since stabilizing clay will lead to a decrease in the space in the soil, the consolidation of pair flows can also increase the sturdiness of the clay. The chemical reaction concerning the electroosmosis process will cause the physical and chemical properties of the soil to change. If in the chemical electroosmosis, the injected salt solution is added on the anode side, it will penetrate the soil at a faster rate through electroosmosis and ion transfer into the fine soil and will adjust the soil microstructure and enhance its shear strength [5].

The effects of chemical solutions on the mechanical properties of the soil using electrokinetic [6], enhancement of Montmorillonite electrochemistry through injection of magnesium and Brucite deposition [7], injection of Bentonite suspension at a faster rate into the fine soil through electroosmosis [8], injection of aluminum with electrochemical gradient and enhancement of clay soil resistance [9], injection of potassium in the swollen soil under a highway [10], electrokinetic injection of copper and aluminum ions and its effects of the shear strength [11], injection of phosphate ion and aluminum in kaolinite soil [12], Increased adhesion of carbonate soils with Stabilizing solution of calcium chloride and aluminum sulfate [13 & 14], stabilizing soft soils through injection of phosphoric acid from cathode [15], change in the soil's crustal structure from the initial clotted structure into granular or multilayer structure through injection of $CaCl_2$ and $MgCl_2$ salts, which is a key factor in drainage efficiency and process guidance of Electroosmosis [16] are examples of this research. Electrokinetic is a new method for extracting industrial pollution, especially heavy metals from polluted soils (Electro Remediation). By applying direct electrical flow, electrolyze reaction of water occurs in the electrodes and hydrogen Ions, and the produced hydroxide will move towards the electrode with the opposite electrical charge until they reach one another. During the process of this transfer, they change the pH of the soil as well. Sedimentation and dissolution of the pollution particles during the electrokinetic process can deeply affect the

functionality of the removal process. The dissolution of sediments of the released hydrogen ions in the anode, which will make the soil acidic as it moves to the cathode, will be affected and will lead to the dissolution of hydroxide of metals and carbonates. During electro-kinetic remediation, heavy metals move toward the cathode [17]. In new studies of electro-kinetic phenomena, using biodegradable complexing agents for treating soil contaminated with heavy metals using electro-kinetic remediation can be mentioned. [18] Recently, some studies have focused on the development of electro-kinetic numerical models. This numerical solution was created by the finite difference-finite volume method with a first-order linear differential equation of advection-diffusion-absorption. The amount of leachate and potential infiltration to the ground was estimated by the proposed model [19]. In another research study, the groundwater quality of Rey City and the presence of nitrate pollutants were used as the most appropriate indicators of groundwater pollution with PMWIN software code to model the quality of associated aquifers [20].
So, in this research, the effects of an electrokinetic barrier on the relations of a coupled hydraulic-electrical flow will be examined with Lab Method. Past research has shown that electro-kinetic technology uses physical, chemical, and biological principles to remove contaminants from soils, increase soil shear strength, and so on as an efficient and cost-effective method. Intense scientific research related to preventing the passage of weak seepage flows due to the hydraulic gradient and how to neutralize and zero the flow in the water and soil system using reverse Coupled flow (electro-osmosis) led to the definition of the concept of electro-kinetic barrier in a porous medium.

1.3 The concept of electro-kinetic engineering barrier

For an electrokinetic barrier system, optimal voltage is the voltage at which the ions are carried by the hydraulic flux and prevents the penetration of impermeable soil by the flow of electro-osmotic fluid. However, when the hydraulic flow is equal to the electro-osmotic flow, the fluid flow stops, which is shown in Figure1.

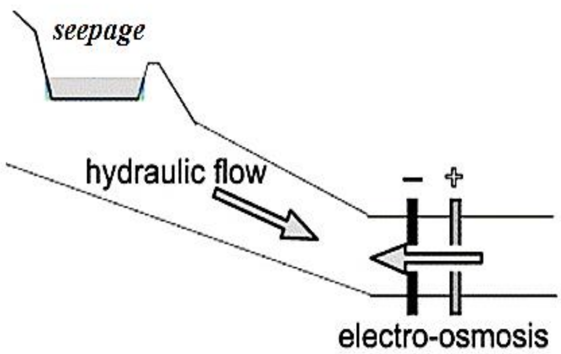

Fig. 1: The concept of the electrokinetic barrier

$$Q_t = Q_h + Q_e = K_h i_h + K_e i_e \geq \text{Barrier} \geq Q_t = 0 \geq Q_h = Q_e \geq k_h i_h = k_e i_e \qquad (2)$$

Electro-osmotic flow = hydraulic flow

The importance of research in this case has paved the way for raising issues and conducting further studies. Understanding these basics, while creating insight, leads to a better perception of the important types of coupled flow. This study aims to perform laboratory and numerical analysis of the electro-kinetic barrier (EKB).

2. Material and methods

2.1 Substances and Methods in Laboratory Study

The first step in this research was to build a model of an electrokinetic barrier idea. Examining the balance between the hydraulic and electrical flows and creating the mentioned flows is considered the aim of the study and fitting the proportions of the physical modeling machine.
In the following step, the kaolinite clay will be provided and the sample inside the improvised electrokinetic device will be prepared, considering clay is the chosen soil for this study. In addition, previous studies on electrokinetics indicate that the efficiency of electroosmosis flow in kaolinite soil is much higher than other soil types. The reason is the lower buffering ability (maintenance) in kaolinite soil [21]. In Table 2, parameters regarding the geotechnical properties of kaolinite soil are shown.

Table 1: Geotechnical characteristics of super Kaolinite

Geotechnical Characteristics of Kaolitite Z	Measured Quantity	Reference(s) of Experimental Methods
Soil Classification	CL (clays of low plasticity)	ASTM D2487
LL	36	ASTM D4318
PL	20	
PI	16	
ω_{Opt}(%)	1۹.۵	ASTML D698 - 78
γ_{dmax}(g/cm3)	1.۵۳	
Gs	2.68	ASTM1 1854, Methods A

The soil used, according to the unified classification system, is clay with a low "CL" paste.
The electrokinetic device used in the personal lab is built based on the model of the Faculty of Engineering of Hamedan's Bu Ali Sina University [21]. The primary cell of the device is cube-shaped with a 180 mm length, 140 mm

width, and 100 mm height, built with plexiglass. The soil sample is horizontally placed in the primary cell of the device. At both ends of the cell, anode and cathode storage are placed. At the end of the primary cell, a perforated cover is placed on it to place the electrode and filter paper which enables liquid transfer between the soil sample and anode and cathode storages. Filter paper, which is placed between the electrode and the sample soil, will prevent soil washing. In the cathode storage, a pipe with a height of 160 cm and a diameter of 1.4 cm is placed to create a Hydraulic head in the soil sample. Also, to create an electrical field and conductivity between the electrodes, the end of the storage is connected to a power supply. Figure 2 illustrates a schematic diagram of the device and the details of the main cell used in this study. In the next stage, by placing the sample in the device, the hydraulic flow is modeled via a slim pipe. Considering the mechanism of creating hydraulic flow, the water in the slim pipe to reach a certain height is required. Also, there is no doubt that this is a calm flow, and the Reynolds number can be easily calculated and determined. So, by establishing a potential electrical difference between the two ends of the sample, a reverse electroosmosis flow is created. In this study, by establishing the hydraulic and electrical flows in the sample, the relations and the balance between these two flows will be examined. Also, the amount of these two flows will be calculated at the moment of balance.

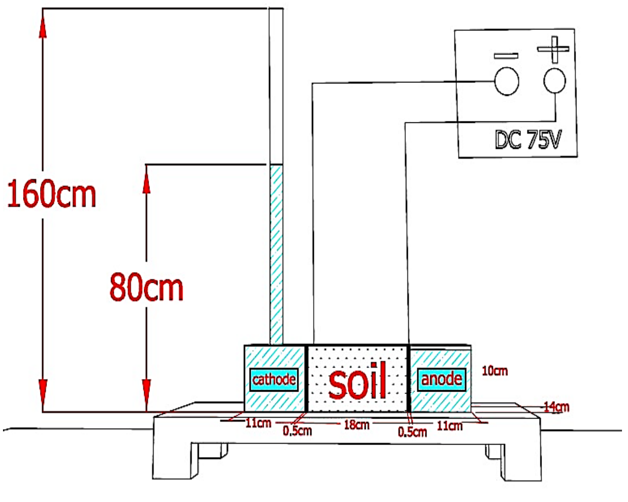

Fig. 2: schematic diagram of the improvised electro-kinetic device

The power supply used in this study has adjustability of 0–75 V and a maximum flow of 20 A. The input for it, is a 220 V AC power supply, and the output is direct (DC). In this study, the constant voltage method for every electrokinetic testis used. the effects of the soil's specific gravity and potential difference in creating an electrokinetic barrier are examined through numerous tests. In this study, any test group performed the specific gravity constant and saturation moisture content. Based on the normal moisture rate in the environment and the required moisture for the electrokinetic test, the construction of homogeneous saturated soil with three different specific gravities of 1.33 gr/cm^3, 1.315 gr/cm^3, and 1.3 gr/cm^3 was chosen alongside three percent saturated moisture. The soil weight was calculated by multiplying the volume and Dry specific gravity. The moisture was calculated by the percentage of saturated soil moisture, and, using a sprayer, distilled water was gradually added to the soil in an electric mixer. Thus, the even distribution of moisture was achieved as much as possible. After adding the moisture, the resulting clay was kept in a plastic bag for 24 hours so the added moisture could spread through the sample and prevent the Evaporation of moisture. After the sample is homogenized, it was placed in the cell. In this method, for every step of the test, about 4.5 kilograms of saturated soil was prepared. This way, the amount of saturated soil needed to fill the layer and reach the intended specific gravity was calculated. Also, the soil sample in the electrokinetic device was compressed as homogenous using a wooden hammer and in 5 layers as possible. Hence, The soil was completely density. After placing the soil clay in the cell and sealing the cell, both anode and cathode storages were filled with water, and the water in the cathode storage was raised to the Hydraulic head which initially specified (80 cm). A summary of the Laboratory specifications is presented in Table 2.

Table 2: Summary of Laboratory specifications

Parameter type	Amount/dimension of the parameter
Cell dimensions (cm)	42*14*10
Hydraulic head initial (cm)	80
Distance between electrodes (cm)	18
specific gravity Saturated soil samples(gr)	4500
Material of electrodes	Graphite
Cell voltage(volt)	0 or 75

One of the physical factors of soil that controls seepage is hydraulic control, known as the permeability coefficient. Therefore, to calculate the soil hydraulic permeability coefficient (Kh) falling head permeability test was considered, and to determine the electro-osmotic conductivity (Ke), after establishing electrical flow to both ends of the cell, the output electroosmosis discharge of the cathode storage was measured during a specified period. By Establishing different electrical gradients in both cells, the amount of electro-osmotic flow output from the cathode reservoir was measured for 24 hours. A summary of electrokinetic barrier (EKB) tests is given in Table 3.

Table 3: Test schedule

Duration (Hour)/explanation	Applied voltages (volt)	Percentage of saturated moisture	Dry specific gravity (cm3/g)	Test No.
Calculation of hydraulic permeability coefficient(k_h)	٠ (Control sample)	36-37-38	1.33-1.315-1.3	1
24hours	6.6-10-15-20-25-30-40-50-60-70	36	1.33	2
3hours	30-40-50-60-70	37	1.315	3
2hours	50-60-70	38	1.3	4
24hours Calculation of conductivity of Electroosmosis (k_e)	18-36-54	36-37-38	1.33-1.315-1.3	5

Laboratory modeling of the electrokinetic barrier to observe the contrast of the electric and hydraulic flow was performed by three specific gravities with various electric gradients during a specific period (48 hours for each test) and permanent voltage for each test with an electric gradient between 4 v/cm and 0.37 v/cm (with 6 to 70 applied volts to both ends of the cell). During the test, constant changes in the water level of the cathode storage (slim pipe) were measured and noted until the end of the test.

2.1.1 Definition of electro-kinetic numerical model

A model is a tool designed to justify and introduce truth with simple expression and interpretation. A mathematical model consists of a set of differential equations that govern a variety of currents. The subject of this discussion is to describe numerical solutions to solve mathematical models that simulate Hydraulic-Electric coupled flows. Thus, there are two types of models, the finite difference model and the finite element model. In each of the mentioned types, a system of node points will be spread at the level of the desired area. Here, the purpose of the modeling method is to determine and predict the unknown quantity related to the desired variable at the node point. (Such as the height of the water level or the corresponding voltage in the sample).

2.1.1.1 Electro-kinetic model theory

According to the definition of the concept of electro-kinetic barrier in the section 2.1.1, when the electro-osmosis flow and hydraulic flow are equal and the outflow is zero, it results as:

$$Q_t=Q_h+Q_e=0 \geq v_t=v_h+v_e=0 \quad (3)$$

$$-\frac{k_h}{\gamma_w}\frac{\partial u}{\partial x} = k_e\frac{\partial V}{\partial x} \quad (4)$$

By simplifying the first-order differential equation, the following is obtained:

$$\frac{\partial u}{\partial x} = -\frac{k_e\gamma_w}{k_h}\frac{\partial V_x}{\partial x}\frac{\partial V}{\partial x} \quad (5)$$

$$V_x = \left(\frac{v_{finANOD}-v_{iniCATH}}{x_{fin}-x_{ini}}\right)(x-x_0) \qquad \frac{\partial V_x}{\partial x} = \text{Slope}$$

diagram of voltage changes

$$\frac{\partial u}{\partial x} + \frac{k_e\gamma_w}{k_h}\frac{\partial V_x}{\partial x} = 0 \quad (6)$$

The analytical solution of the above equation leads to the following answer.

$$u = -\left(\frac{k_e}{k_h}\right)\gamma_w V(x) + C \quad (7)$$

u: The pore water pressure (hydraulic head) created at the end of each experiment which is in the tube of the cathode part of the cell when an electro-kinetic barrier is created along with the soil sample.

It should be noted that, since the amount of pore water pressure at the endpoint of the boundary condition (anode) is always known, the value of C (constant-coefficient) is obtained from Equation (6). The analytical solution of the above equation provides a model for the system so that for each applied voltage to the model, the value of the hydraulic head corresponding to the electro-kinetic barrier at the end of the test is determined along the entire length of the sample and at a certain distance from the cathode as the output of this model. Where X = 0cm is the origin of the sample and in the cathodic part (narrow tube) and, X = 18cm is the end of the sample in the anodic part of the cell.

2.2.1 Numerical solution methods used to Introduce the finite difference method

In this study, the Finite Difference Method was used to solve the differential equation describing the electro-kinetic barrier.

The finite difference method is one of the common methods for the approximate solving of partial differential equations. This solution method can be used in various situations and

provides relatively accurate results. In this paper, a variety of finite difference methods are investigated. To solve partial differential equations, finite difference methods need to be discretized. The finite difference method is a direct way to discretize these equations. In this method, a mesh network is considered for the medium to discretize the equations. This means that instead of analyzing an equation in a continuous place, the medium is converted two or more equations in discrete places. This will make problem analysis much easier. Networking in this method is done in a rectangular and simple way, which means it uses regular networking in problem analysis. This method is still used for many numerical analyzes.
As mentioned, the discretization of the problem in the location dimension will take the form of Figure 3.

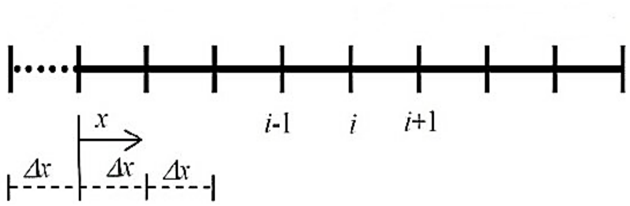

Fig. 3: One-dimensional mesh for finite difference approximation.

This figure is a representation of one-dimensional networking to approximate the finite-difference of the problem. The distances between the two points in this category are Δx. The finite-difference approximation is discretized and calculated by three common methods, which are:
1 .Forward Difference Method
In this method, point i + 1 is used for discretization next to the point i. The mathematical relation of the leading finite difference method for the first-order derivative is as follows:

$$f(x) = \frac{f(x+\Delta x)-f(x)}{\Delta x} \quad (8)$$

The generalization of this relation for the second-order derivative is as follows:

$$f(x) = \frac{f(x+2\Delta x)-2f(x+\Delta x)+f(x)}{(\Delta x)^2} \quad (9)$$

2 .Central Difference Method
This method is used to discrete two points before and after point i. The mathematical relation of the central finite difference method for the first-order derivative is as follows:

$$f'(x) = \frac{f(x+\Delta x)-f(x-\Delta x)}{2\Delta x} \quad (10)$$

The generalization of this relation for the second-order derivative is as follows:

$$f''(x) = \frac{f(x+\Delta x)-2f(x)+f(x-\Delta x)}{(\Delta x)^2} \quad (11)$$

3 .Backward Difference Method
In this method, point i-1 is used for discretization next to point i. The mathematical relation of the retrograde finite difference method for the first-order derivative is as follows:

$$f'(x) = \frac{f(x)-f(x-\Delta x)}{\Delta x} \quad (12)$$

The generalization of this relation for the second-order derivative is as follows:

$$f''(x) = \frac{f(x)-2f(x-\Delta x)+f(x-2\Delta x)}{(\Delta x)^2} \quad (13)$$

In general, three main advantages of this numerical solution method are:
1 .It is possible to achieve results with higher-order accuracy with the help of this method. With the help of this method, more accurate results can be achieved.
2.This method is much easier to implement in numerical solution software than the finite volume and finite element methods.
3. Finally, learning this method as one of the best tools for the numerical solution of differential equations is very important for specialists and engineers [22].

2.2 Suggesting a suitable method to solve the numerical model

A MATLAB program is used as powerful software for numerical analysis and solving problems of matrix theory. To solve the differential equation in MATLAB, the following discretization is performed.

$$\frac{\partial u}{\partial x} = -\frac{k_e \gamma_w}{k_h}\frac{\partial V_x}{\partial x} \quad (14)$$

$$\frac{u_{i+1}-u_i}{\Delta x} = -\frac{k_e \gamma_w}{k_h}\frac{Vx_{i+1}-Vx_i}{\Delta x} \quad (15)$$

It should be noted that the end point of the boundary conditions is known. It is suggested to use the Forward Difference Approximation method to obtain new answers [63].
Thus, the code of Equation 15 in the MATLAB program can be used for numerical solutions of electro-kinetic process simulation.

u(1,i) = u(1,i+1)+ $\frac{k_e \gamma_w}{k_h}$*(V_matrix(1,i+1)-V_matrix(1,i)) ,
u(1,end) =10 (16)

3. Results and Discussion

After running and testing electro-kinetic barriers on clay soil and extracting the data, the behavior of the coupled hydraulic-electrical flows and the method of creating electro-kinetic barriers are analyzed and discussed. In this study, an electrokinetic integrated system with a coupled flow modeling approach was also used to develop and verify the process governing the model, in addition to creating a barrier in clay soil.

In the Laboratory section, the hydraulic control coefficients and electroosmosis were measured and compared first.

To express this concept, the results of experiments leading to the determination of the coefficient of hydraulic control and the coefficient of conductivity Electroosmosis and the contrast between these two coefficients should be examined first, as shown (Figure 4).

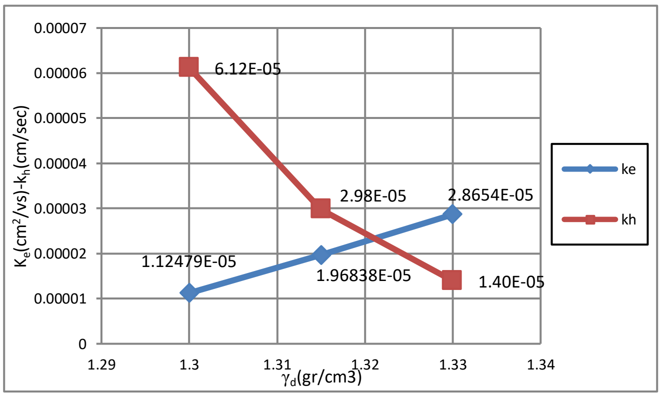

Fig. 4: Correlation of hydraulic permeability coefficient with Electroosmosis conductivity.

The interesting contrast between these two flows indicates that by increasing density of soil, discharge and the electroosmosis flow resulting from this transfer will increase, and the transfer will become harder. In other words, by increasing the specific gravity, the permeability of the soil for hydraulic transfer is reduced, and electroosmosis transfer will increase as opposed to hydraulic control. The obtained results will be used in the analysis of the following results.

In examining the first group, extremely dense and with a Dry specific gravity of γ_d= 1.33 gr/cm^3, the Hydraulic head reached 51 cm after almost 8 hours of decreasing. The Corresponding voltage with this hydraulic head was 6.6 V which caused a halt in the hydraulic flow. The time was around 10 and 11 hours, respectively, after the start of the test with 10 and 15 voltages. Electroosmosis flow overcame hydraulic flow, and the corresponding hydraulic head was 60 cm and 71 cm, accordingly. In the fourth to tenth tests, not only the Applied voltages didn't lead to a decrease in the slim pipe in the cathode storage, but also it led to an increase in the water level of the cathode storage section. By increasing the optimum voltage, the strength of the electrokinetic barrier in stopping the hydraulic flow increases against the reverse flow electroosmosis (Figure 5).

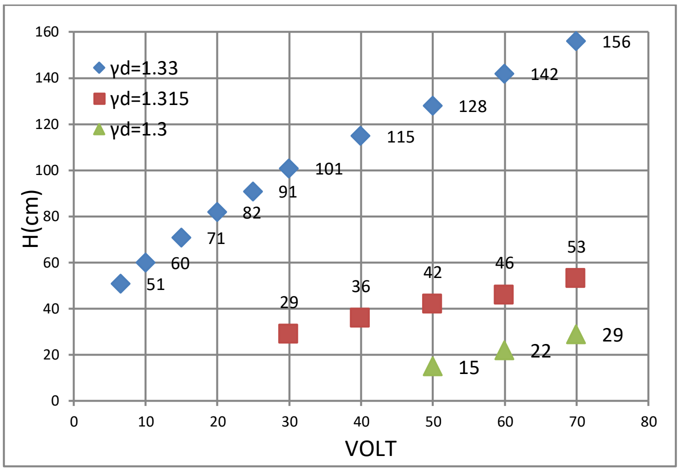

Fig. 5: Corresponding voltage of electro-kinetic barrier in different hydraulic heads at three

different specific gravity

The very low permeability of the soil and the existence of zeta potential are the main factors affecting the progress of the water in the slim cathode pipe. The existence of zeta potential in the dual-layer causes the start of the water molecule movement in the soil wall section, where cations are significantly more prominent than anions due to the closeness of the surface of the clay with the negative flow (Figure 6) .

This reason proves increasing the advancement of Electroosmosis flow in soil and Rising water levels in a narrow cathode tube.

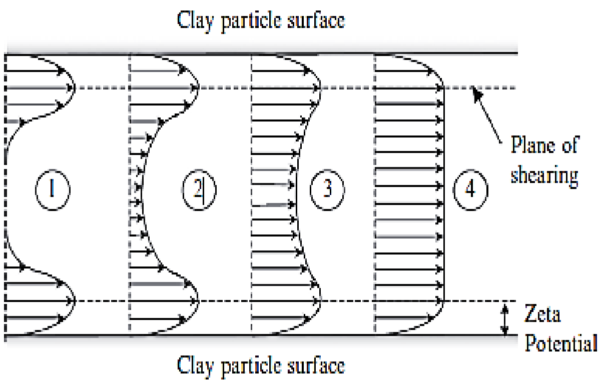

Fig. 6: How Electroosmosis Flow Velocity Develops

In the samples of the second group with Dry specific gravity γ_d= 1.315 gr/cm^3, firstly, the ability of the hydraulic flow to pass through the soil was high, and the balance between the Electroosmosis and hydraulic discharge will be achieved a while after the start of the test (Figure 4)

The loosest and least dense sample was the third group with a Dry specific gravity of γ_d= 1.3 gr/cm^3. It is observed that optimum voltage could only work efficiently and properly in three voltages(50v,60v,70v) and stopped the hydraulic flow.

Figure (7) clearly states that in the first group (γ_d=1.33 gr/cm^3) with an increase in the input voltage, a long time is consumed to create an Electroosmosis flow to reach balance and create an electrokinetic barrier, and the Hydraulic head will stop at a higher point. Therefore, the time for tests to achieve a balance between this hydraulic discharge and Electroosmosis discharge will also increase.

In the second group (γ_d=1.315 gr/cm^3)with a Corresponding voltage of 30 or 40 volts, due to the relatively high speed of the water in the pipe, a longer time is required to create balance and the barrier in the cell compared to other voltages. This time is reduced by increasing the voltage (Figure 7).

The dramatic decrease in the Hydraulic head and establishment of the electrokinetic barrier in the third group (γ_d=1.3 gr/cm^3) of the tests made the tests shorter due to Greater soil permeability and the decreased power of Electroosmosis flow to create an electrokinetic barrier. Therefore, to restrain the hydraulic flow in these samples, more voltage is required (Figure 7).

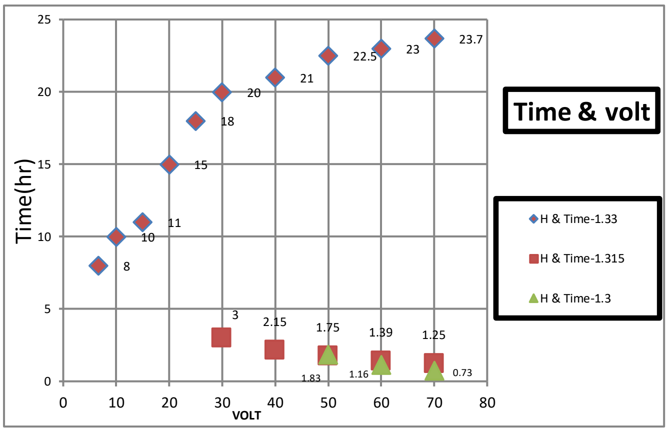

Fig. 7: Corresponding voltage of Electro-kinetic barrier in different hydraulic heads.

3.1 *examining the effects of the specific gravity and soil density*

To compare the specific gravity, various input voltages were taken into account, and the Hydraulic head of the samples was compared with each other. It is obvious that the more specific gravity and soil density increase, the more the power of Electroosmosis flow increases to create an electrokinetic barrier and maintenance of the Hydraulic head at a higher height in a narrow cathode tube. Figure 7 proves the dominance of the soil density controller.

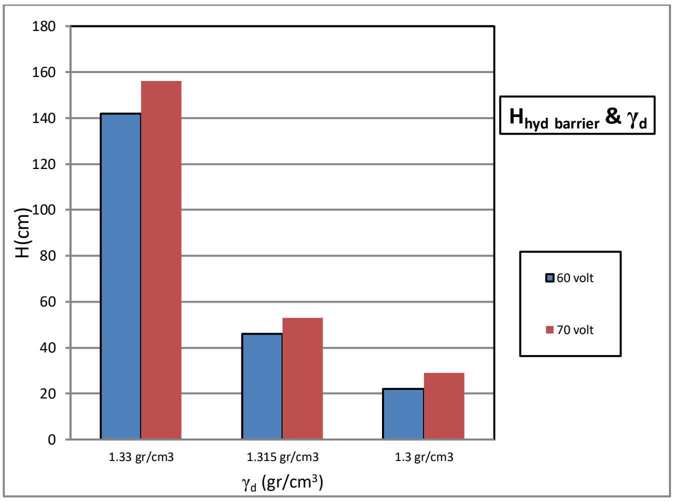

Fig. 8: comparing the effects of the Dry specific gravity of soil in two specific input voltages.

3.2 *Examining the pH of the cathode and anode storage*

The pH changes in the cathode and anode storage pH at the end of the first trial group (γ_d= 1. 33 gr/cm3) are provided. Based on the diagrams, the pH changes were similar, and the change has a decreasing nature in the anodes, and an increasing one in the cathode storage. Also, by increasing the voltage, the speed of chemical reactions increases. the environment becomes Acidic or alkaline faster, and the transfer of Ions and the flow happen at a higher pace. In the previous studies, the same pattern was observed. At the (+) pole of the anode, hydrogen gas is generated, and the density of the hydrogen ions is increased (Figure 9). To evaluate the accuracy of the reactions that took place in the cell, the pH of the anode and cathode reservoirs of the cell was measured because pH is a parameter that affects the zeta potential and thus the strength of the electro-osmosis flow.

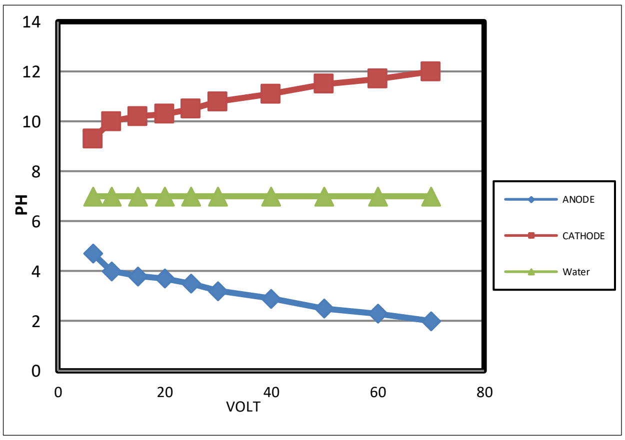

Fig. 9: changes in the pH of the cathode and anode storages in the Dense sample (γ_d= 1.33 gr/cm3)

4. Research limitations

1. There is no standard and specific method for calculating the coefficient of electro-osmotic conductivity.
2. It was very difficult to make samples with very close specific gravities.
3. Using a special clay mineral (kaolinite) to perform experiments as mentioned in section2.
4. Lack of new studies in this field and lack of accurate knowledge of the behavior of hydraulic-electric coupled flows.

Considering the mentioned limitations, this study provides valuable information about the prediction of Coupled flow and the relationship between the hydraulic-electric flow. Also, although it was challenging to make samples, it was observed that this slight difference in specific gravity has led to certain results. It is suggested to use new methods, such as the piston method, to make samples with high accuracy in future studies. Due to the inactivity of kaolinite compared to illite and montmorillonite among clay minerals and the complexity of the electro-kinetic process and having many variables in this process, the use of kaolinite mineral reduces the number of variables of the electro-kinetic method. Suggestion: In future studies, clay sand soil (natural soil) can be used in experiments.

5. Conclusion

Creating an electrokinetic barrier (EKB) in a porous medium through changes in the electric flow and the hydraulic head of the model leads to hydraulic discharge and electroosmosis discharge become equal. Defining the difference between the electrical potential required and the hydraulic flow stop the seepage flow volume. The test duration to create an electrokinetic barrier decreased by density reduction and specific gravity of the soils, because electroosmosis flow had less time to contrast with the hydraulic flow. The more compressed the samples are, the faster the electroosmosis flow will get, and the ability to create the electrokinetic barrier will increase in the samples. In the first sample group with a dry specific gravity γ_d= 1.33 gr/cm^3, the hydraulic control coefficient was very low, and as a result, water infiltration from inside the sample was slow. Therefore, it was a good opportunity for the generated electroosmosis flow to stop the hydraulic discharge or even go up the pipe in the cathode section by increasing the optimum voltage of the electroosmosis flow.

In the second group's samples with a dry specific gravity γ_d= 1.315 gr/cm^3, considering the less density, after a while, the power of electroosmosis flow increased to oppose the hydraulic flow and the electrokinetic barrier was established in the cell. In the third group's samples with Dry specific gravity γ_d= 1.3 gr/cm^3 as the loosest sample, the High hydraulic control coefficient led to the easy passage of water through the samples. Therefore, the electrokinetic barrier was established in low hydraulic heads. Tests for measuring the pH in the cathode and anode storages of the third group were performed. The pH changes were similar to the previous studies, and decreased and increased, accordingly by increasing the voltage in the anode (+) and cathode (-). The results of this study can be utilized in the control of water seepage (leakage) following diversion dams, earthen dams, and small reservoir dams.

The basics of numerical solution of equations and conditions governing the electro-kinetic barrier process were evaluated by the Coupled flow modeling approach using the finite difference method. Also, the leading difference approximation scheme was proposed for coding in the MATLAB program due to the higher accuracy of the electro-kinetic barrier equation. Considering the Hazards arising from the seepage of waste leachate into groundwater aquifers, it can be said that the most important application of this study is Inventing and presenting a method to prevent the above. Also, Considering the hazards caused by waste leachate and nuclear waste (due to the high temperature of landfills caused by waste decomposition) in clay barriers made of clay (Clay Linear), it can be said that the most important application of this research is to develop and present a way to prevent the passage of pollutants due to seepage and infiltration into groundwater aquifers. The unique feature of the electrokinetic barrier process is that while the medium is wet and undisturbed and there is no change in the properties of the clay, the seepage and output flow is zero.

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