CERTIFICATION OF APPROVAL

**The effect of Calcium Chloride and Magnesium Hydroxide in Electro-Osmosis Process on Kaolinite Soil**

by

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A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

December 2006

## CERTIFICATION OF ORIGINALITY

This to certify that I am responsible for the work submitted in the project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified resources or persons

NOOR IRMAYATI BINTI ISMAIL

## ABSTRACT

Problems encounter by clay soil such as low permeability, high plasticity, low strength and poor consolidation process has lead to large settlement of construction area when load is applied on clay soil. To enhance the consolidation process and also in order to strengthening the soil, electro-osmosis technique with chemical injection is inspected in this project. Electro-osmosis is the application of direct or alternating current through the soil that will generates dissipation of water despite in low permeability soil such as clay. Injection of chemicals is to enhance clay properties in term of strength. Improvement in clay strength is because of the cementation that take place in clay soil. This cementation process is due to the reaction of dissolve clay ion such as silicates and aluminates with dissolves calcium ion produced by chemicals. Calcium Chloride, $CaCl_2$ and Magnesium Hydroxide, $Mg(OH)_2$ are used in this experiment since both of these chemicals has shown an improvement in soil strength due to cementation process. As regards to the results obtained, $CaCl_2$ is a better chemical solvent used in improving strength of kaolinite soil. Kaolinite soil that recovered from Bidor, Perak is sample that is used for all tests including electro-osmosis test by using box and cylinder. Both of these tests are performed in order to investigate the similarity of electro-osmosis effect by using different apparatus. The shear strength and moisture content test is also conducted for analysis purposes in term of strength of kaolinite soil and amount of water dissipation after electro-osmosis process. Current value is also measured in this project for analysis of the relation between strength of kaolinite soil and current. For this analysis, different voltage is applied and voltages used are 30 Volts and 100 Volts. From the observation, high voltage will effect the increasing in current value. High current value will cause increased in temperature and increasing the dissipation of water.

## ACKNOWLEDGEMENT

I would like to convey my sincere appreciation to the many individuals who contributed to this project. A bunch of thank to my supervisors, Miss Niraku Rosmawati Ahamad and Tuan Syed Baharom Azahar who assist me a lot in preparing reports and conducted laboratory test. Their ideas, guidance and support had given me the courage to complete this project and overcome many problems that I had encountered especially at the beginning of the project development. Thank you for giving me my own wings in completing the project and for being very flexible to me in finishing every task given.

I also would like to express my gratitude to all my colleagues who have managed to help me in this project. A special thanks to my friends, Nur Hafizah Abd Rahman, Gunashenker and Nik Khairul Amir for being very supportive throughout my project endeavor.

Last but not least, I would like to express a special thanks to my beloved parents who inspire me in completing this challenge and make it through no matter how hard it seems to be. Thanks for there priceless support, encouragement, constant love, valuable advices, and understanding given to me.

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| | |
|---|---|
| $CaCl_2$ | - Calcium Chloride |
| $Mg(OH)_2$ | - Magnesium Hydroxyde |
| CSH | - Calcium Silicates Hydrates |
| CAH | - Calcium Aluminates Hydrates |
| $\tau_v$ | - Vane shear strength (kPa) |
| M | - torque applied (N.mm) |
| XRD | - X-ray Diffraction |
| XRF | - X-Ray Fluorescence |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Study

According to K.Y. Lo S. Miciec and J.Q. Shang (1999), the application of direct or alternating currents in soil generates the electro-kinetic process including electro-osmosis, electrophoresis and dielectrophoresis. Electro-osmosis with chemical injection is preferred in this project in order to investigate the effect of electro-osmosis and chemicals reaction on kaolinite soil properties in term of strength. Chemicals that are selected in this project are $CaCl_2$ and $Mg(OH)_2$ because both of these chemicals gave better improvement in kaolinite properties.

The electro-osmosis with chemical injection involves by applying a low direct current to a pair of positive (anode) and negative (cathode) electrodes. The mass transported during this process is based on the electro-kinetic processes that take place in wet porous medium under an electric field. These processes are primarily involved ion migration, electrophoresis transport of colloids and electro-osmosis of water. The rates of efficacy of these processes are often found to depend upon the mineral and chemical composition of the soil.

## 1.2 Problem Statement

Clay soil is a variable and complex material, but because of the availability and low cost clay is frequently used for construction purposes. According to Bell and Tyrer (1989), this soil usually possesses medium or high or even very high plasticity and therefore present soil which would be likely to be more suspect as far as construction is concerned. The large volume change in clay upon wetting causes extensive damage to structures, in particular, light buildings and pavements (Fredlund and Rahardjo, 1993).

Since clay give problems such as settlement to the construction building, many techniques such as grouting and wick drain have been introduced to solve this problem. However, these techniques took a long time to stabilize and accomplish the desire degree of consolidation. The electro-osmosis process is one of technique that can dissipate water from the clay soil and enhanced the time taken for consolidation process that occurred in the soil. Therefore, the introduction of electro-osmosis with chemical injection that has a same function with other techniques is hoped to overcome these problems.

## 1.3 Objectives and Scope of Study

Objectives of this study are listed as below:

i. To investigate kaolinite properties.
ii. To study the effect of different chemical on the kaolinite soil.
iii. To study the effect of current on the shear strength and moisture content of the soil.
iv. To study the effectiveness of electro-osmosis with chemical injection on kaolinite soil.

Scope of this project is to investigate the effect of different chemicals on the kaolinite soil by using electro-osmosis process. Different chemicals will be tested in this project and chemicals that are used in this project are $CaCl_2$ and $Mg(OH)_2$. Various voltages are applied on the soil to see the optimum voltage that will give the best results for the sample. In this project, 30 Volts and 100 Volts were chosen.

Soil used for this project is kaolinite soil originated from Bidor, Perak. The Company that responsible to supply kaolinite soil is the Associated Kaolin Industries (AKI) which is located in the southern tip of the tin-rich Kinta Valley in Penisular Malaysia.

### 1.4 Time Frame

Time allocated for this project is about 14 weeks. Within this time, lab test is prepared with various tests. **Table 1.1** as attached in appendices showed the flow of project activities including various tests that have been performed during the project investigation.

**CHAPTER 2**

**LITERATURE REVIEW**

## 2.1 Kaolinite

Kaolinite is one of clay types which basically belonging to the 1:1 group of phyllosilicates (sheet silicates) and the layer are held together by hydrogen bonding. Main component of clay is Silica Tetrahedron and Alumina Octahedron. Tetrahedron is referring to four surfaces with four oxygen and one silica atom. Octahedron is referring to eight surfaces with six oxygen and one aluminum atom. The structure of kaolinite soil is shown in **Figure 1.1.**

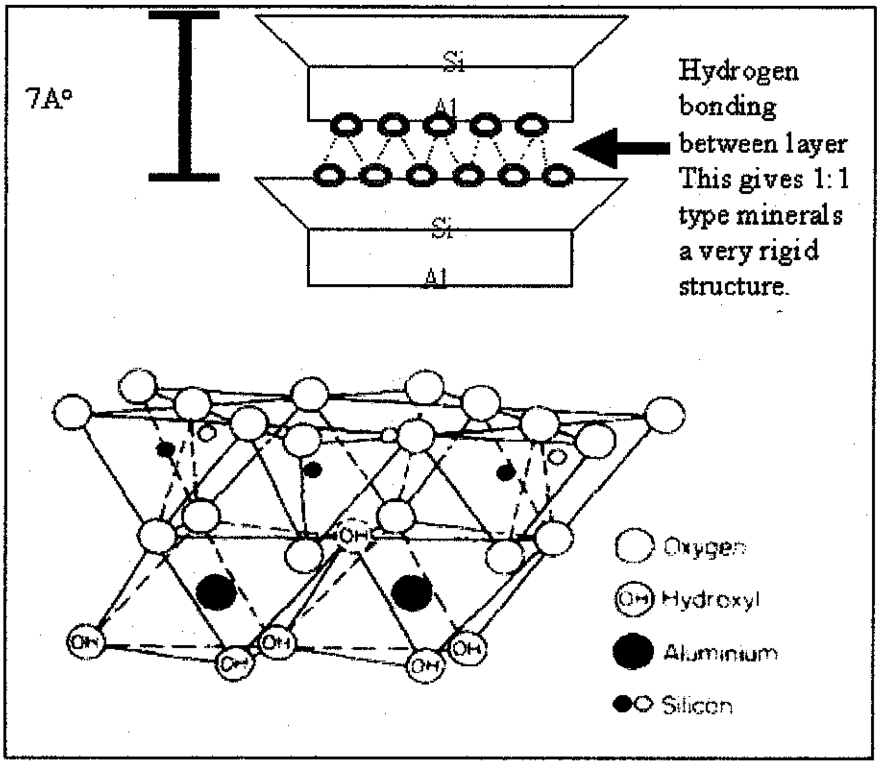


**Figure 1.1**: Kaolinite structure

Kaolinite particle also has a net charge which means kaolinite particle is surrounded by a strongly attracted layer of water. As the dipolar water molecules do not satisfy the electrostatic balance at the surface of clay particles, some metal cations are also adsorbed. The ions are usually weakly held and therefore can be replaced readily by others. Consequently, they are referred to as exchangeable ions. (Fred G. Bell, 1994)

As stated by Fred G. Bell (1994), thickness of kaolinite soil is about 0.3 to 0.1*d* which is the value of *d* is 0.3 to $3^{-3}$. The thickness of the clay soil also influences the soil permeability that is the thicker the layer of clay soil, the lower the permeability. This is because of the greater proportion of pore space is occupied by strongly held adsorbed water.

Besides thickness of kaolinite soil, specific surface is also one of the kaolinite properties that influence the kaolinite behavior. Specific surface can be defined as surface area in relation to the mass. This is also can be explain that the smaller the particle the larger the specific surface. Fred G. Bell (1994) also states that the specific surface provides a good indication of the relative influence of electrical forces on the behavior of particle. The specific value of kaolinite soil is 10 – 20 $m^2$ $g^{-1}$ and can be classified as high specific surface. High specific surface will result in good influence of electrical forces on the behavior of particle. The properties of kaolinite soil are shown in **Table 1.2**.

| Properties | Values |
|---|---|
| Moisture Content | 27% |
| Specific gravity, SG | 2.6 |
| Liquid Limit, LL | |
| - in distilled water | 43% |
| - in seawater | 38% |
| Plastic Limit, PL | |
| - in distilled water | 27.4% |
| - in seawater | 24.4% |
| Surface Area | $14\ m^2 / g$ |
| Swelling Volume | 4 mls / 2g |
| Compression Index, $C_c$ | |
| - in distilled water | 0.558 |
| - in seawater | 0.459 |
| Coefficient of Compressibility, $m_v$ | $0.0013\ m^2 / kPa$ |
| Void Ratio, $e_o$ | 1.02 |
| Plasticity Index, PI | |
| - in distilled water | 38% |
| - in seawater | 30% |
| Permeability, k | $6 - 8 \times 10^{-8}$ cm / s |
| Coefficient of Consolidation, $c_v$ | $6 \times 10^{-9}\ m^2 / s$ |

**Table 1.2:** Properties of Kaolinite soil (Indian Geotechnical Journal, 2002)

**Table 1.2** has indicated values of swelling volume which is 4 mls/2g. Vijayvergiya and Ghazzaly (1973) has developed a method of estimating the amount of potential swell of clay soil from clay natural moisture content and liquid limit as shown in **Figure 1.2**.

**Table 1.2** has indicated values of swelling volume which is 4 mls/2g. Vijayvergiya and Ghazzaly (1973) has developed a method of estimating the amount of potential swell of clay soil from clay natural moisture content and liquid limit as shown in **Figure 1.2.** This method is to predict the percentage of swell for clay. **Figure 1.3** has shown an estimation of the degree of expensiveness of clay soil. This estimation is developed by Van der Merwe (1964) which is based on plotting plasticity against percentage clay fraction.

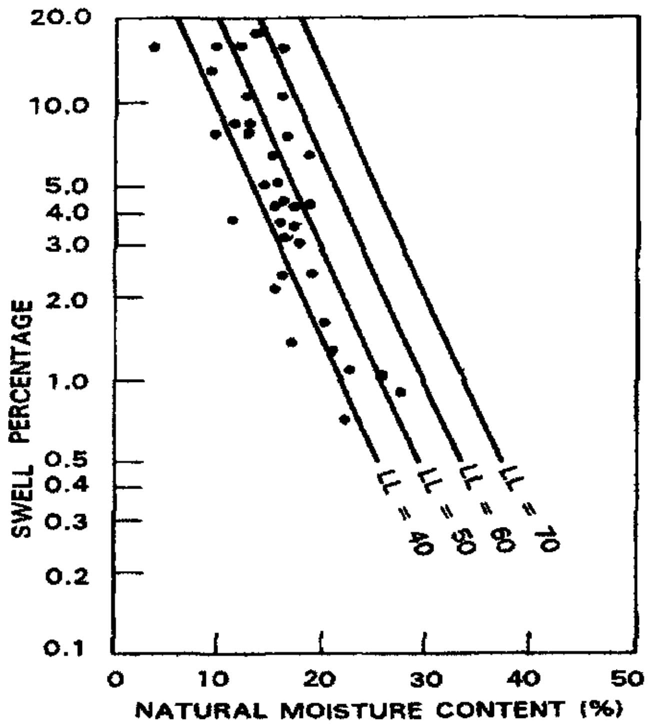


**Figure 1.2**: Prediction of percentage swell for clay, LL = Liquid limit.
(Vijayvergiya and Ghazzaly ,1973)

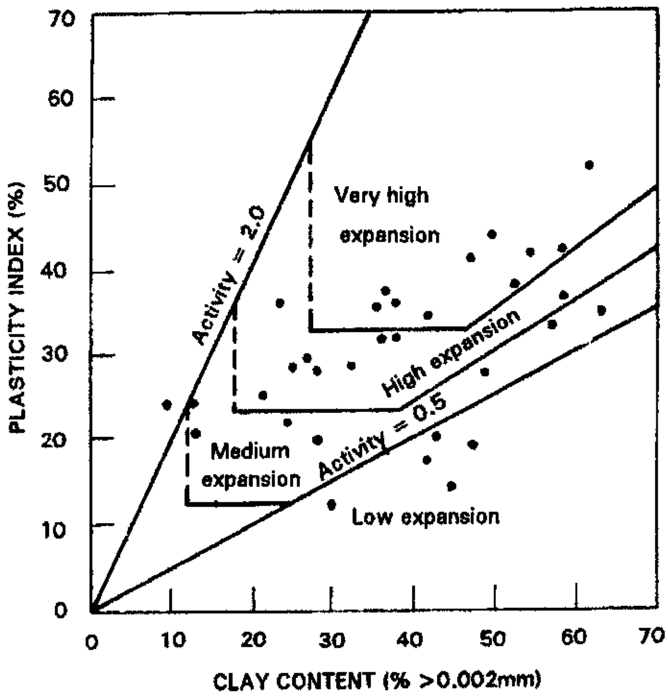


**Figure 1.3**: Estimation of the degree of expansiveness of a clay soil (Van der Merwe, 1964)

## 2.2 Electro-Kinetic

### 2.2.1 Historical Development of Electro-Kinetic

In 1939, Leo Casagrande demonstrated that when electro-osmosis is applied to soils with high water content, the resulting shows an increasing in the effective stress in the soil thus will increase soil shear strength to such a degree. In 1941, Casagrande again utilized electro-osmosis in foundation engineering successfully. This was indicated from Casagrande's practice, that small reductions in water content by electro-osmosis could produce significant increases in soil strength. From then on, electrochemical treatment of soils has been investigated and used in many field projects, such as improvement of excavation stability, electrochemical indurations or hardening, fine-grained soils' stabilization, consolidation and densification. In the late 60's and early 70's, direct current was applied successfully to recover residual oil from deep seated geological formations (Enhanced Oil Recovery) Waxman (1967),Smits (1967).

The electro-kinetic phenomena in porous medium are based on the relative motion between a charged surface and the bulk solution at its interface. The formation of electric double layer at the charged surface of clay particles explains these electro-kinetic phenomena of interest which are electro-osmosis, electrophoresis, and electro-migration.

### 2.2.2 The Diffuse Double Layer

The double layer model is used to visualize the ionic environment in the vicinity of a charged surface. This phenomenon can be either a metal under potential or due to ionic groups on the surface of a dielectric.

The diffuse double layer occupies the space between the clay surface and the soil solution and the thickness is less than one-millionth of a centimetre ($10^{-6}$ cm). The thickness of the diffuse double layers decreases with an increase in the electrolyte concentration and this condition also called as the compression of double layer. The diffuse double layer is thinner when calcium ions (with a double positive charge) balance the negative charge rather than ions such as sodium that have a single positive charge. **Figure 2.1** indicated a model of electric double layer of clay particles.

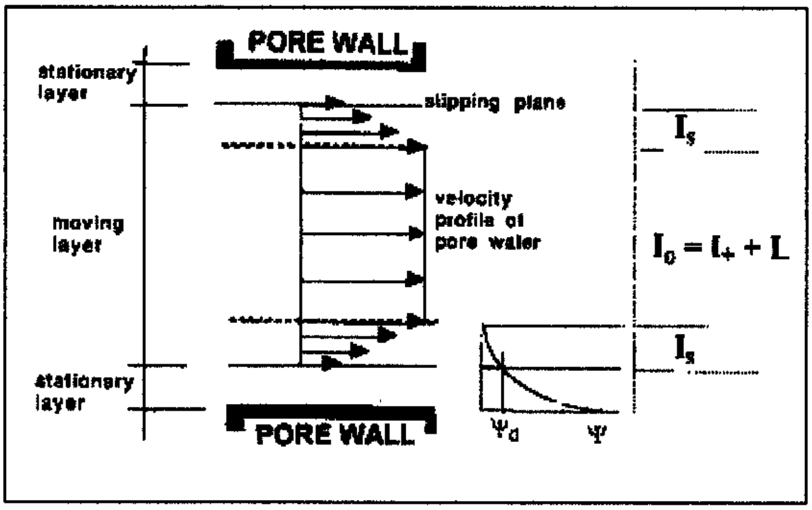


**Figure 2.1:** Schematic model of electric double layer of clay particles (Acar and Alshawabkeh, 1993)

### 2.2.3 Electro-Osmosis

Electro-osmotic flow was shown to be independent to the pore size distribution or the presence of macro-pores (Acar and Alshawabkeh, 1993). Therefore electro-osmosis is an efficient method to generate a uniform fluid and mass transport in clayey soils. Relative contribution of electro-osmosis and ion migration to the total mass transport varies according to soil type, water content, types of ion species, pore fluid concentration of ions and processing conditions. Electro-osmotic advection is most useful for transporting contaminants in clays and low permeability soils, since the their hydraulic conductivity. Electro-osmotic advection is able to transport non-ionic and non-polar as well as ionic species through soil pores toward the cathode. This is best achieved when the state of the material (dissolved, suspended, emulsified, etc.) is suitable for the flowing water to carry it through the tight pores of soil without causing an immovable plug of concentrated material to accumulate at some distance from the electrode.

## 2.3 Electro-Osmosis and Electrochemical Stabilization

### 2.3.1 Relation of Electro-Osmosis and Electro-Chemical

Based on Casagrande (1952) and Lo et al. (1991), Electro-osmosis was originally developed as a means of dewatering fine-grained soil. This process consists of passing a direct current from anodes to cathodes positioned at predetermined locations in the soil to be stabilized. As the current pass through the soil, water will migrate from the anodes towards the cathode where it is collected and then removed.

The mechanism responsible for bringing about migration is not completely understood but it is appear that absorbed water is removed from clay particles, and that ion transfer through the pore water causes it to flow. Not only does electro-osmosis reduce the water content of the soil but it also directs seepage forces away from the surface of an excavation as well as developing pore-water tension in the soil Perry (1963). More over, base exchange occurs in the soil during electro-osmosis, thereby enhancing strength. In addition, ion migration, electrolysis and chemical reactions occur leading the information of new irreversible compound. Indeed, chemicals such as Calcium Chloride and Sodium Silicate are sometime added to ensure the growth of cementations material in the pore space.

Where electro-osmosis method alone has proven successfully, an introduction of chemical injection into the soil either through anode solution or by direct electrolyte replacement have been studies to see the effectiveness of this electro-osmosis method. This improves the stability of the soil either by ionic replacement occurring in the clay mineral content, or by cementitious material being deposited in the pore space. This adaption of electro-osmosis is known as electro-chemical stabilization.

Unlike the coefficient of soil permeability, $k$ the coefficient of electro-osmotic permeability, $k_e$ and the rate of electro-osmotic permeability flow are independent of the size of the capillaries. Hence, the electro-osmotic permeability is more or less independent of the soil pore size.

### 2.3.2 Consolidation Process in Electro-Osmosis

Due to Mitchell (1977) and Wan (1977), consolidation may occur as a result of the development of negative pore-water pressure under controlled electro-osmotic drainage. This has lead to changes in the stress strain and strength characteristics of the soil concerned. The Terzaghi Equation of consolidation for homogenous material also applies to electro-osmotic consolidation where the voltage distribution remains constant with time. Like ordinary consolidation under direct loading, electro-osmotic consolidation is a mass flow process in response to pressure of potential gradient. The rate of consolidation is controlled by the coefficient of consolidation which in turn is governed by the hydraulic conductivity and not by the electro-osmotic permeability.

### 2.3.3 Ion Exchange in Electro-Chemical Process

The mechanical properties of clay mineral vary particularly those belonging to the smectite family, according to the type of cations associated. If a clay mineral contains a significant amount of weakly bonded cations such as sodium or lithium, then this clay has tendency to absorb and retain large quatities of water. Accordingly, clay possesses low shear strength. By contrast, if cations have higher bonding strength such as calcium or magnesium or more especially iron or aluminium, the clay material absorbs less water and has a more stable structure. F. G Bell (1993).

As cations associated with the clay minerals are exchangeable, the introduction of solutions containing an excess of cations with higher bonding strength gives rise to ion exchange, thereby enhancing the soil properties in term of strength.

Electrochemical stabilization due to anode solution results from initial base exchange reactions on the surface of the clay minerals. Weakly bonded cations being replaced by strongly bonded cations and the formation of soil cementing compounds has been produced by reaction between the electrolyte and dissolved anode solution. Thus a lattice-like structure is built-up around the clay particles. According to research that have been done by F. G Bell (1993), addition of additives to the anode (in addition to the dissolved electrode material) can increase the base exchange reaction, act as a catalyst in the formation of cementitious material, and improve the quality and quantity of cemitatious material. To increase the base exchange reaction, most of the additives used are organic and inorganic compound such as aluminium or calcium, while iron normally being presents in the form the electrode material. Out of these three chemicals, the most used compound in electro-osmosis test is $CaCl_2$.

## 2.4 Chemical Stabilization of Kaolinite by Electrochemical Injection

Senda Ozkan et al. (1998) have carried out a test of electro-chemical injection by using aluminum and phosphate ions. Sample used in this project is kaolinite soil and a variety of batch tests were conducted to determine the effect of electrochemical injection on the kaolinite strength. A series of laboratory test including mix the kaolinite soil with acidic, basic, aluminum, calcium and phosphate formulations is performed. The primary emphasis of this study is to investigate injection of ionic species to achieve stabilization by homogenous precipitation of the species, pore fluid reconstitution and appropriate ion exchange mechanisms.

A variety of batch tests is conducted by Senda Ozkan et al. (1998) including the study on phosphate ions under an acidic environment for first test. For the second test, aluminum is injected at anode compartment and phosphate at the cathode compartment in order to study simultaneous injection of ions and possible precipitation of them throughout the soil medium. **Figure 2.2** shows the results obtained by Senda Ozkan et al. (1998). From the observation, there is a great improvement of the soil strength contributed by phosphoric acid treatment, $H_3PO_4$. This is because of the ion exchange reaction, ion adsorption and fabric changes. For test that is using the aluminum sulfate, $Al_2(SO_4)$ and $H_3PO_4$ the strength results is lower compared to test one. This is because of the formation of insoluble phosphate compound. According to the results provided by Senda Ozkan, the insoluble ion occur during electro-osmosis process has lead to low strength results.

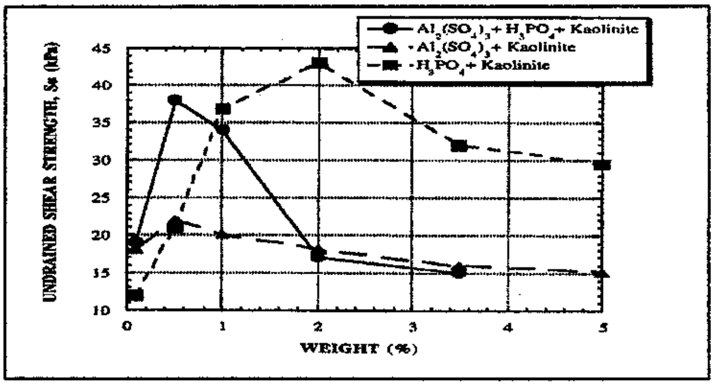


**Figure 2.2**: Shear strength changes of kaolinite mixed with selected chemicals ( Senda Ozkan et al ,1998)

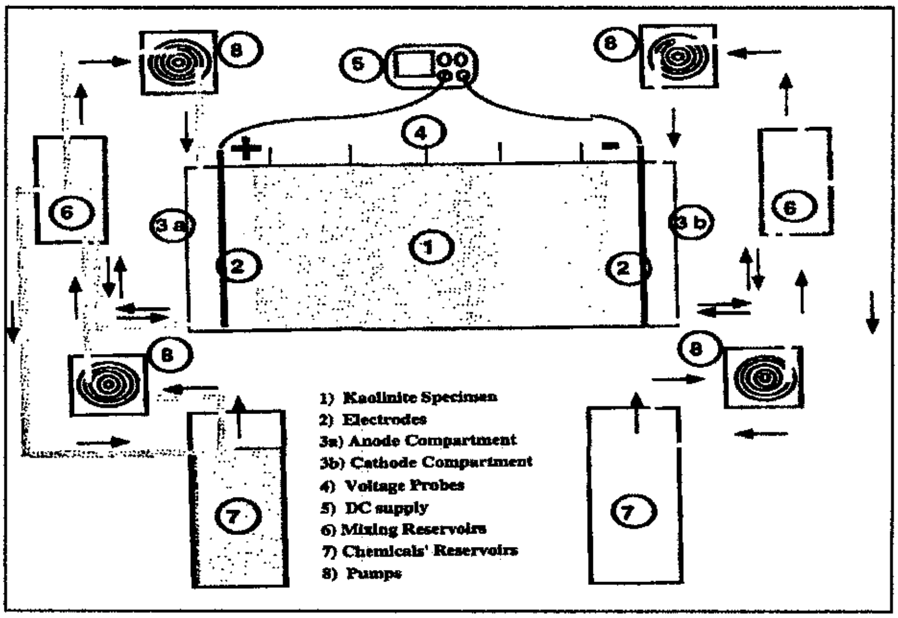


**Figure 2.3**: Schematic diagram of the test setup develop by Senda Ozkan et al, 1998

## 2.5 Voltage and Duration Effects on Electro-osmotic Treatment of Dispersive Soils

J. Sadrekarimi and ASadrekarimi (1993) have investigated the voltage and duration effects on electro-osmosis treatment by using dispersive soil. J.Sadrekarimi (1993) and A Sadrekarimi (1993) applied various of voltage value in range of 3 to 24 Volts and the current flow is measured.

**Figure 2.4** has shown variations of current density with respect to time. From the results obtained the lower the voltage applied, the longer the time required achieving the steady state in current density. For soil with applied voltage 24 Volts the steady state is achieved in less than 180 hours compared to the lowest voltage applied which is 3 Volts. This applied voltage shows that 800 hours is required to achieve the steady state.

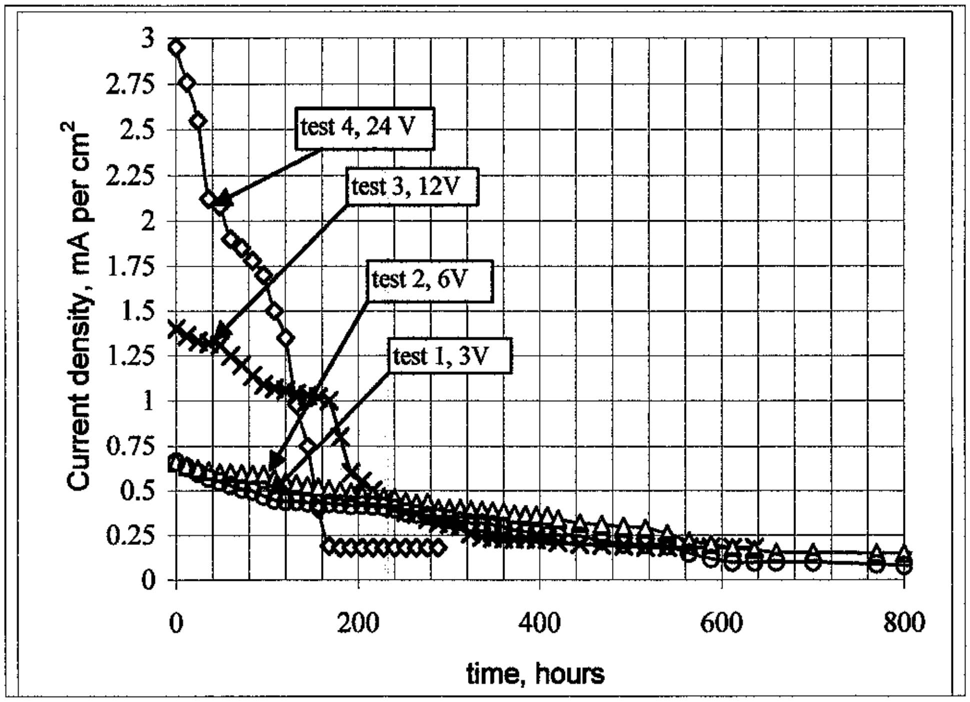


**Figure 2.4**: Variations of current density against time (J. Sadrekarimi and ASadrekarimi ,1993)

## 2.6 Pozzolanic Reaction

The shear strength of the stabilized soil gradually increases with time mainly due to pozzolanic reactions. Due to Diamond and Kinder (1965), Calcium Hydroxide in the soil water reacts with the silicates and aluminates (pozzolans) in the clay to form cementing materials or binders, consisting of calcium silicates and/or aluminates hydrates (principally dihyrates). Calcium ions, $Ca^{++}$ will reacts with ion from clay such as Aluminum and Silicon ion to form CSH (Calcium Silicates Hydrates) and CAH (Calcium Aluminate Hydrates) as stated by the chemical **Equation 2.1**:

$$Ca^{++} + 2(OH)^{-} + SiO_2 \longrightarrow \text{CSH (Calcium Silicates Hydrates)}$$
$$Ca^{++} + 2(OH)^{-} + Al_2O_3 \longrightarrow \text{CAH (Calcium Aluminate Hydrates)}$$

**(eq. 2.1)**

The gel of Calcium Silicates (and/or aluminate hydrates) cements the soil particles in a manner similar to the effect produced by the hydration of Portland cement, but the lime cementing process is a much slower reaction which required considerably longer time than the hydration of cement.

## 2.7 Hydration process

A large amount of heat is released when quicklime (CaO) is mixed with clay. This is due to the hydration of CaO with the pore water of the soil. According to Bromes (1984), the increase in temperature can be so high when the pore water starts to boil. An immediate reduction of natural water contents occur when CaO is mixed with cohesive soil. Moreover, a large amount of pore water evaporates because of the heat release. As the hydration of the quicklime proceeds and the temperature increases, the amount of pore water is reduced. This drying action is particularly beneficial in the treatment of the moist clay. Due to D.T Bergado et. al (1996) application of $Ca(OH)_2$ as the stabilizer will dissociated in the water hence will increasing the electrolytic concentration and the pH of the pore water. This process will dissolve the silicates and aluminates ion from the clay particles and results in ion exchange, flocculation, and pozzolanic reaction. The hydration process is clearly view in **Equation 2.2**

$$CaO + H_2O \longrightarrow Ca\,(OH)_2 + \text{heat}$$
$$Ca\,(OH)_2 \longrightarrow Ca^{++} + 2(OH)^{-}$$

**(Eq. 2.2)**

# CHAPTER 3

# METHODOLOGY

## 3.1 Literature Review

Literature review is needed in order to enhance understanding about the kaolinite soil and electro-osmosis test. Source of literature review are from the internet, books and journals. The study focuses on kaolinite properties, electro-osmosis and also electrochemical reaction.

## 3.2 Laboratory Tests

Several tests will be conducted for soil investigation. Test that will be conducted are listed below:

i. Electro-osmosis test by using cylinder
ii. Electro-osmosis test by using box
iii. Moisture content test
iv. Shear Strength test
   - Vane Shear Test
   - Unconfined Compression Test

### 3.2.1 Electro-Osmosis Test by Using Cylinder

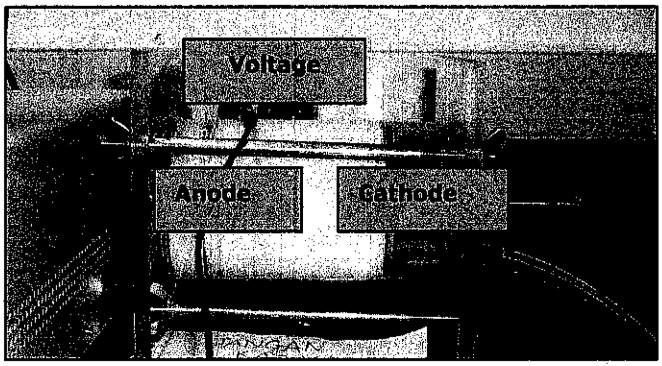


**Figure 3.1**: Electro-osmosis test by using cylinder

For electro-osmosis test, 1000g of kaolinite soil (2mm sieve size) will be blended with 400g of distilled water. Slurry soil is needed in order to see the changes in the results. Certain amount of chemical is added with 100 ml distilled water and will be inject in the electro-osmosis cylinder as shown in **Figure 3.1**. Cylinder is connected to the voltage. Reading is taken every 5 minutes of time interval for the first hour. After that, the logger is used to take the reading automatically for every 30 minutes. The measurement of current, dissipation of water, shear strength, and moisture content of water are recorded.

The tests conducted by using cylinder are:

a) 1 Mol $CaCl_2$, 30 Volts.

   (Test is done for 2 times in order to prove the results obtain for the first test)

b) 1 Mol $CaCl_2$, 100 Volts

c) 1 Mol $Mg(OH)_2$, 30 Volts

d) 2 Mol $CaCl_2$, 30 Volts

### 3.2.2 Electro-Osmosis Test by Using Box

This test is same as electro-osmosis test by using cylinder. This test will be conducted for this semester in order to compare results with electro-osmosis cylinder. By using box, the situation might be similar to the site. 10 kg of kaolinite soil is mixed with 4 kg of distilled water. Chemical will be injected at anode and water will dissipate at cathode according to flow of water from anode to cathode. To avoid flooding at cathode portion due to dissipation of water, drainage at cathode is provided. Similar to electro-osmosis test by using cylinder, current measurement, shear strength test and moisture content test are recorded. The samples taken for shear strength and moisture content tests are shown in **Figure 3.3.**

Sample is taken at different location for the reason to see the effect of current and chemical at different locations. Sample one and three theoretically will give similar result because the location is same. Sample two is taken in order to check the variation of results compared to sample one. While, sample four is assumed as controller sample since the location is not involved current and chemical flow. This sample theoretically shows less strength compared to other samples. Row one and two is provided in order to measure the variation of current value either both row will show similar value or not. Various electro-osmosis tests that are conducted by using box are:

a) 1 Mol $CaCl_2$, 100 Volts
b) Controller, 100 Volts
c) 1 Mol $CaCl_2$, 30 Volts
d) 1 Mol $Mg(OH)_2$, 30 Volts
e) Controller, 30 Volts

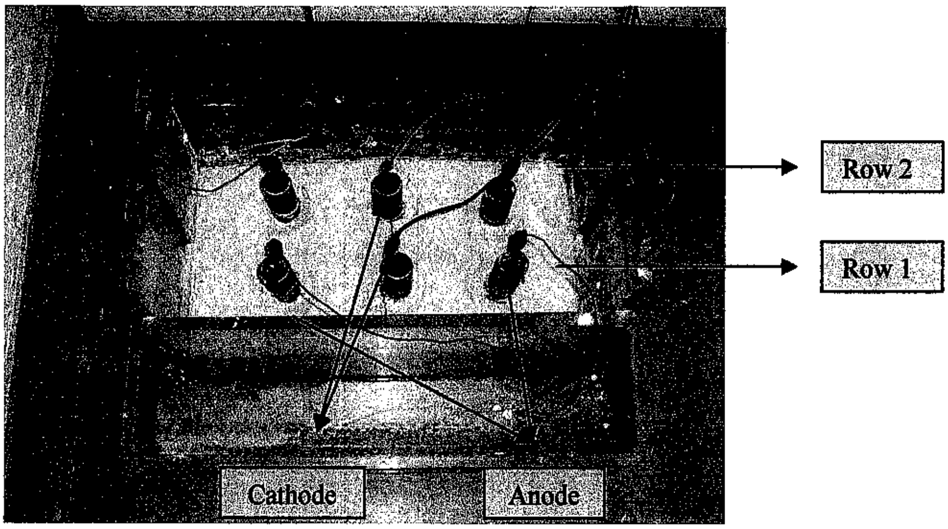


**Figure 3.2**: Electro-osmosis box

### 3.2.3 Moisture Content Test

#### 3.2.3.1 Moisture Content Test for Electro-Osmosis by Using Cylinder

Kaolinite soil that undergone electro-osmosis test will be taken out from electro-osmosis cylinder. Soil from anode and cathode portion is taken. Initial weight and weight after soil is dried for 24 hours is measured. **Equation 3.1** is used to measure moisture content.

$$\text{Moisture content, } W = \frac{(\text{Mass of wet soil + container}) - (\text{Mass of dry soil + container})}{(\text{Mass of dry soil + container}) - \text{Mass of container}}\ 100\%$$

**(eq. 3.1)**

### 3.2.3.2 Moisture Content Test for Electro-Osmosis by Using Box

The soil is taken at different locations as shown in **Figure 3.3**:

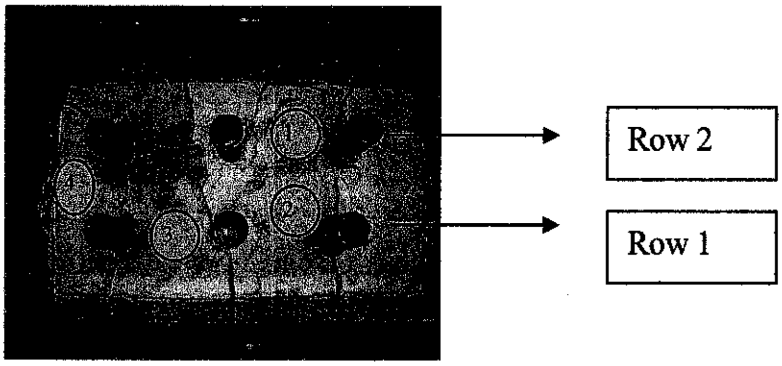


**Figure 3.3**: sample taken for test

The procedure of moisture content test for this sample is similar to moisture content measurement for electro-osmosis test by using cylinder.

### 3.2.4 Shear Strength Test

### 3.2.4.1 Vane Shear Test

This method covers the measurements of the shear strength of a sample of soft to firm cohesive soil. Firstly, the sample container will be attached to the base of the vane apparatus. Then suitable torsion spring is selected to estimate the strength of the soil. For kaolinite soil, spring number four is selected and assembled into the vane apparatus. Pointer and the graduated scale are set on the torsion head to their zero readings. The vane assembly is lowered to push the vane steadily into the sample to the required depth. The top of the vane should be at distance not less than four times the blade width below the surface. Depth of penetration is recorded. The vane shear strength of soil, $\tau_v$ (in kPa) is measured by using **equation 3.2**:

$$\tau_v = (M/4.29)\ kN/m^2 \qquad \text{.................................} \quad \textbf{(eq. 3.2)}$$

### 3.2.4.2 Unconfined Compression Test

The objective of this test is to determine unconfined compressive strength of a sample. Firstly, load frame is ensuring to stands firmly on a solid level bench top or support. The attachment of the load ring to the cross-head of the frame is check out and fit any necessary extension pieces, and the upper platen, securely to the lower end of the ring. Lower platen is placed centrally on the machine platen and the dial gauge post is set vertically upright. Level pf is adjusted at the lower platen to allow enough clearance to insert the test specimen gear position is selected which will give a platen speed between 0.05% and 2% of the specimen length per minute. To prepare the specimen, sample is cut into rectangular shape since this sample cannot be taken by using cylinder test tube. Size of sample is measure and placed at the centre of the machine.

## CHAPTER 4

## RESULTS AND DISCUSSION

The results of the analysis are measured in different parameters which are current, shear strength and moisture content. These parameters are closely related to each other.

### 4.1. Current vs Time

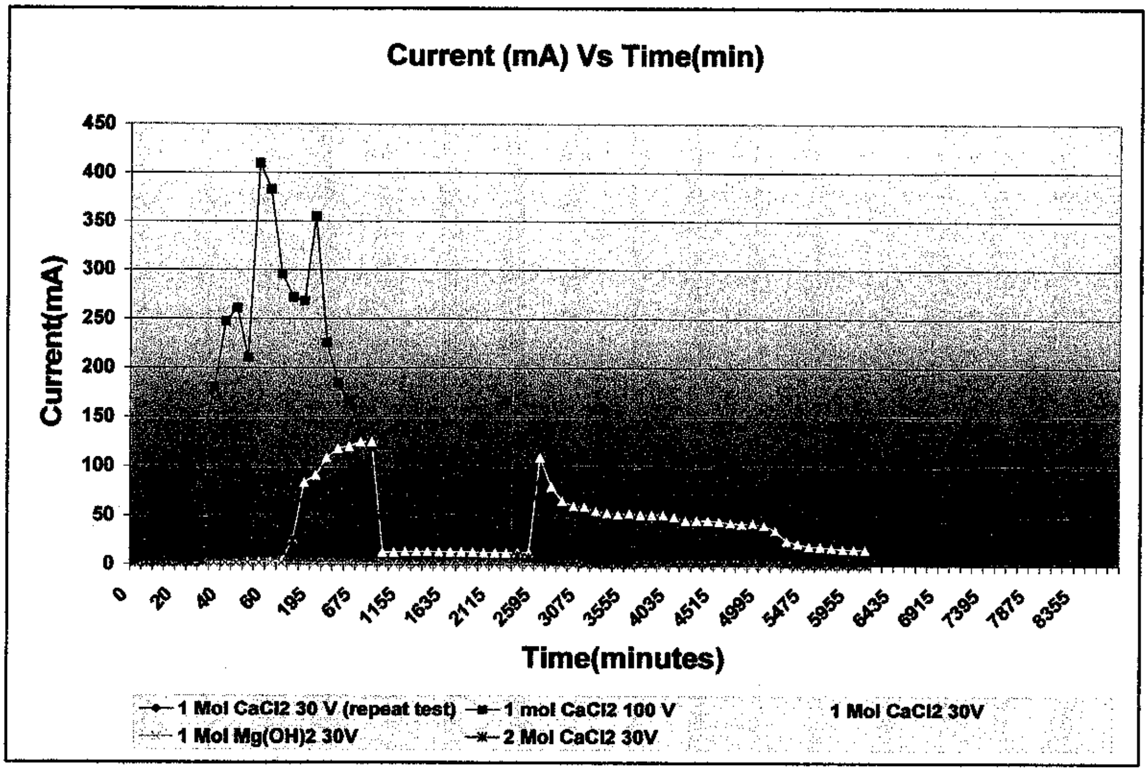


**Figure 4.1**: Current vs Time results for cylinder cell

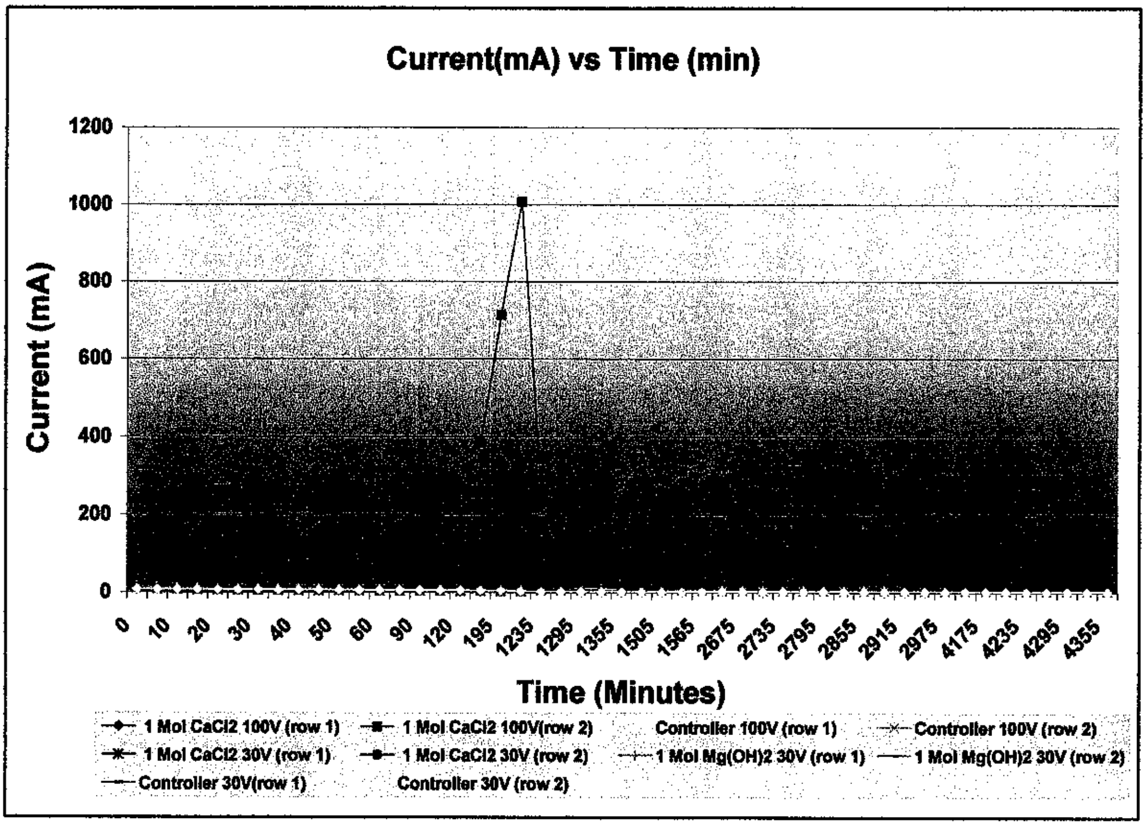


**Figure 4.2**: Current vs Time results for box cell

**Figure 4.1** and **Figure 4.2** are the current results for cylinder and box. The objective of measuring this parameter is to see the effect of different chemical and voltage on the current value. Current value influences the amount of water dissipation. Analysis of current shows the similarity in current patterns for both tests. The current values have shown fluctuation patterns due to increasing and decreasing of current. The increasing in current is because of the time for chemical traveling through the whole soil. When chemical travel, there will be chemical reaction between clay ions and chemicals ions. Chemicals that are injected through the electrodes have caused erosion at the electrodes. This erosion has disturbed the flow of current and gives low current results.

For electro-osmosis test by using cylinder, the highest current value is achieved by sample 1 Mol $CaCl_2$ 100 Volts with the value is 410mA. The less effective chemical is $Mg(OH)_2$ since the value is between 0.5mA to 1.81mA. Similar to electro-osmosis test by using box, the highest current value is enhanced by 1 Mol $CaCl_2$, 100 Volts. This value reaches 1008mA. Test with 1 Mol $Mg(OH)_2$, 30 Volts and controller, 30V experienced low current values with the range between 2mA to 8mA only. $Mg(OH)_2$, is less effective maybe due to the precipitation that took place during electro-osmosis process. The precipitation is observed during the test when the white precipitate of chemical balance is found inside anode tubes. $Mg(OH)_2$ is less effective also might be because of the chemical reaction that weakens the bonding of the clay particles.

## 4.2 Shear Strength Results

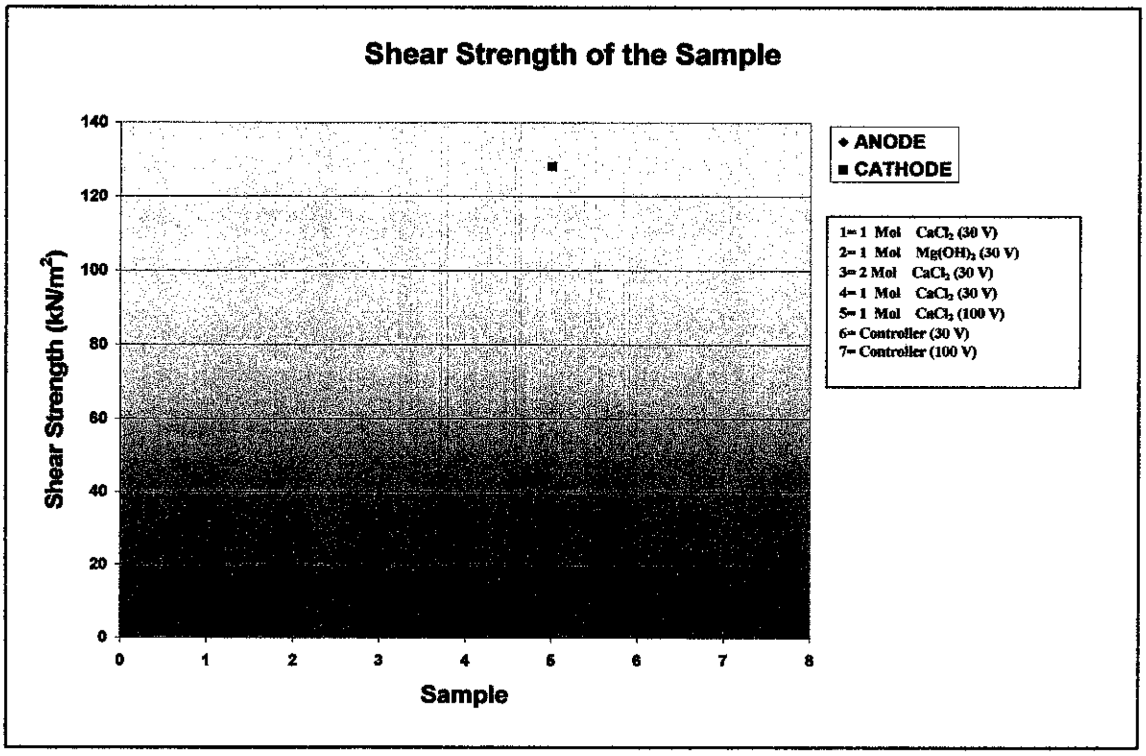


**Figure 4.3** Shear strength value for cylinder cell

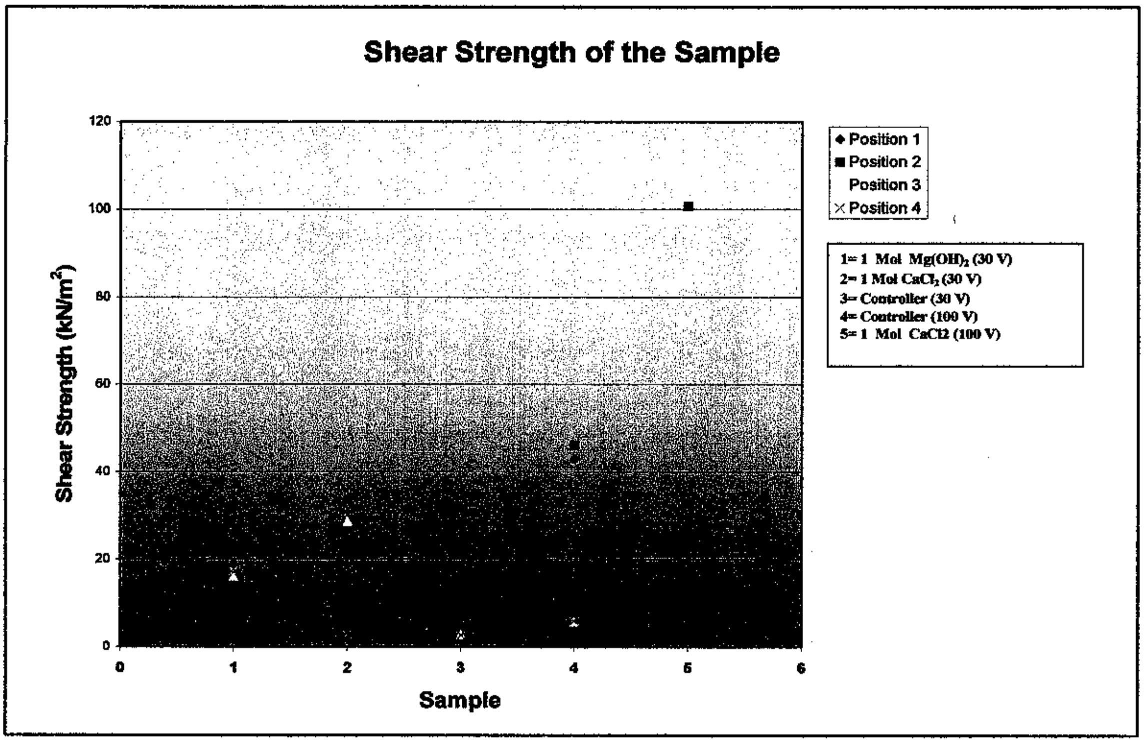


**Figure 4.4** Shear strength value for box cell

The shear strength is to measure the hardness of soil after electro-osmosis test has been carried out. Both of these results shown in **Figure 4.3** and **Figure 4.4** indicate that the highest strength value is obtained from sample using 1 Mol $CaCl_2$. For electro-osmosis by using cylinder cell, the shear strength of sample 1 Mol $CaCl_2$ 100 Volts is 128.2 $kN/m^2$. However, the sample only can be measured at cathode portion since the sample at anode portion has been cracked after test carried out. For electro-osmosis by using box, the highest strength value is 100.68 $kN/m^2$ that obtained from sample 1 Mol $CaCl_2$ 100 Volts. This sample is measured by using unconfined compression test because the soil is too hard to measure with vane shear test.

The lowest shear strength results for electro-osmosis by using cylinder is sample by 1 Mol $Mg(OH)_2$, 30 Volts which indicated the value is 8.6 kN/m$^2$. Magnesium hydroxide gives less strength maybe because of two factors. One is because of the precipitation and the other one is because of the chemical reaction that weakens the clay bonding.

For electro-osmosis test by using box, the sample at position one and three should give similar results because the location is similar, but observation that is made from the graph shows that not all of the samples act upon to this theory. Position four should give low strength value compared to other position since no current and chemical flow is assumed at this position. But sample with 1 Mol $Mg(OH)_2$, 30 Volts has shown that the strength value at position four is higher compared to other position. This is maybe because of the errors such as parallax error during shear strength measurement. The value taken might be wrong. The strength at position two should less than position one because position one that is located in the middle of electrodes will experience more current and chemical flow compared to position two. All of the results satisfy the theory except sample of controller, 100 Volts. This phenomenon is maybe because of the error during the measurement or the unknown process that happened inside the soil.

## 4.3 Moisture Content Results

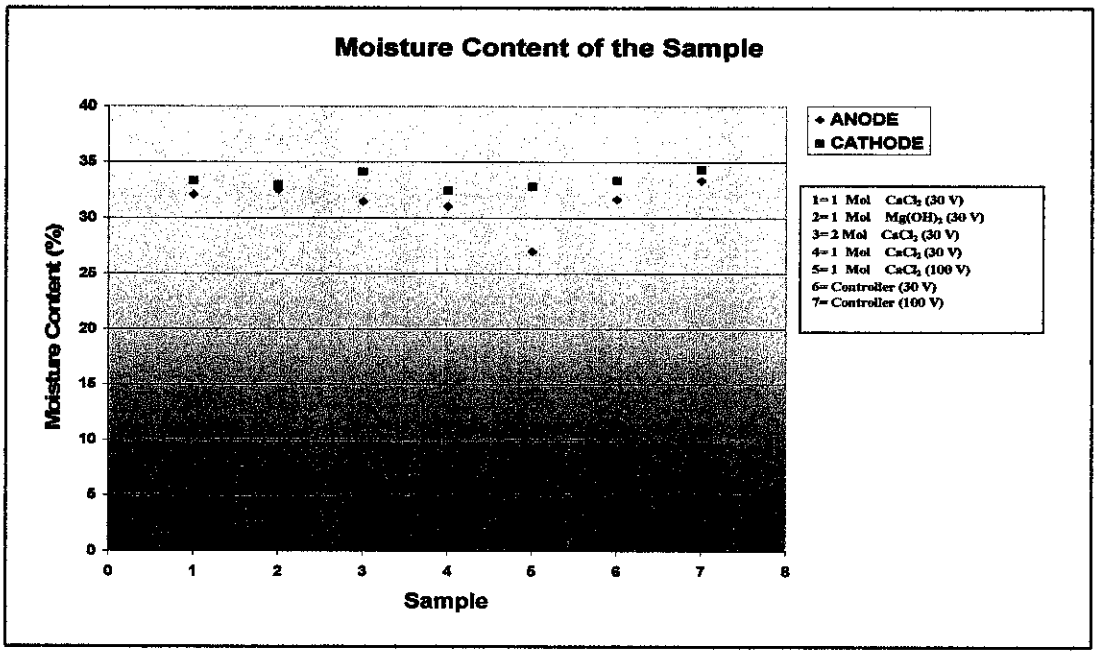


**Figure 4.5** Moisture content values for cylinder cell

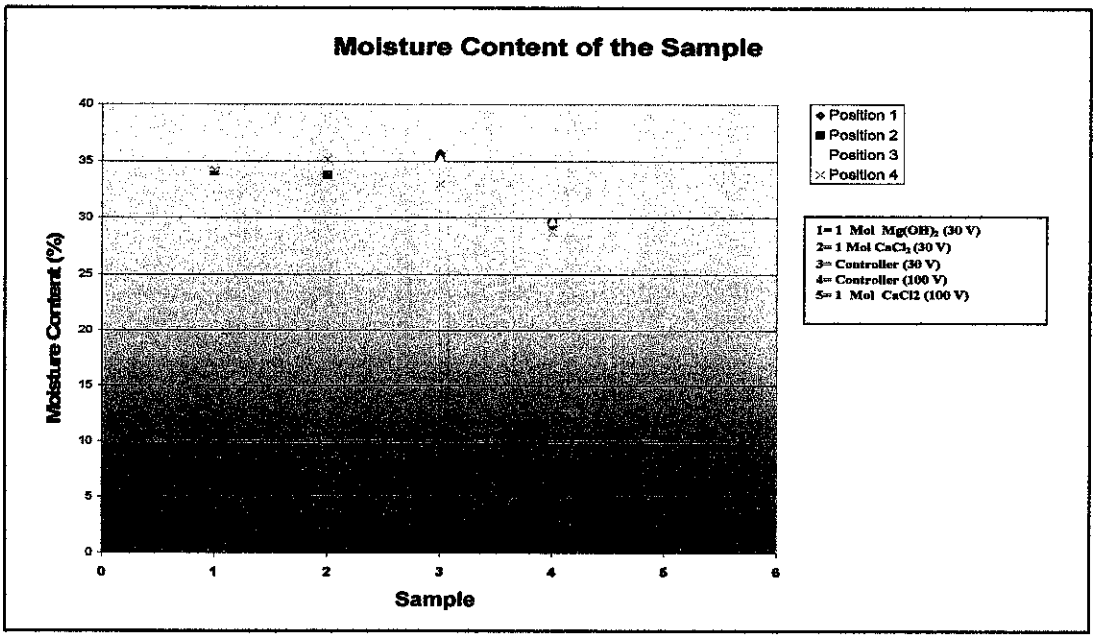


**Figure 4.6** Moisture content values for box cell

The moisture content is measured to observe the reduction in water content. For electro-osmosis by using cylinder, the moisture content at anode should be less than cathode because water will flow from anode to cathode. Similar pattern results in moisture content are shown in **Figure 4.5** and the value of moisture content is in the range of 27% to 33%. The initial moisture content is 50% and after the test, the moisture content is reduced about 17% to 23%.

For electro-osmosis by using box as shown in **Figure 4.6,** Electro-osmosis test with 1 Mol $CaCl_2$ 100 Volts has shown lowest moisture content that is 10.33 %. Initial moisture content is 45% and reduced to 10.33%. The water loss in kaolinite soil is approximately 34.67%.

## 4.4 Relation of Shear Strength and Moisture Content

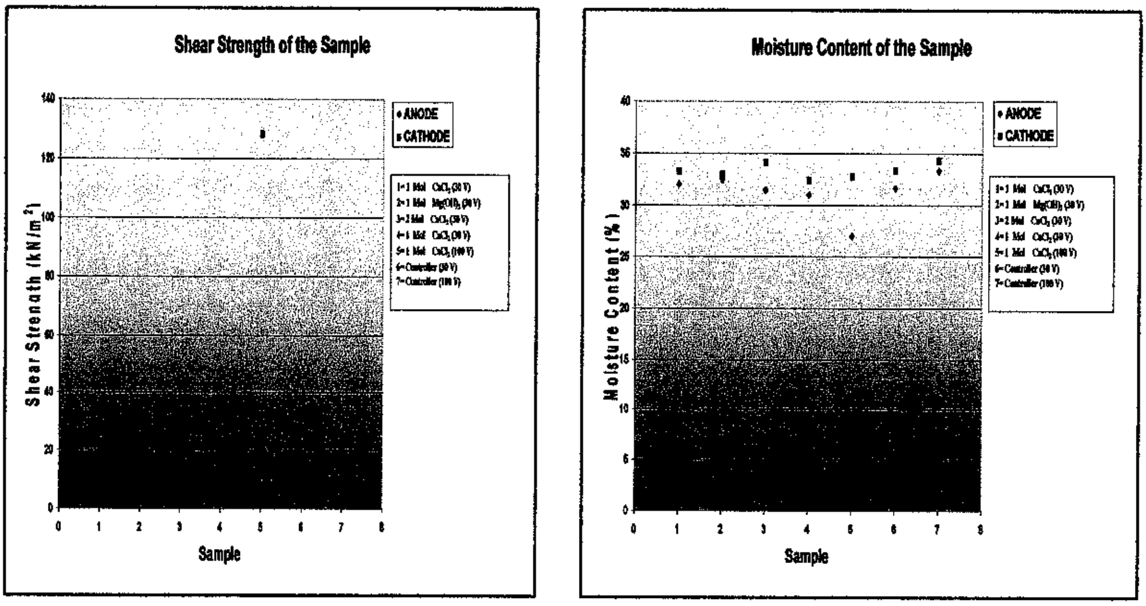


**Figure 4.7** Shear strength and moisture content values for cylinder cell

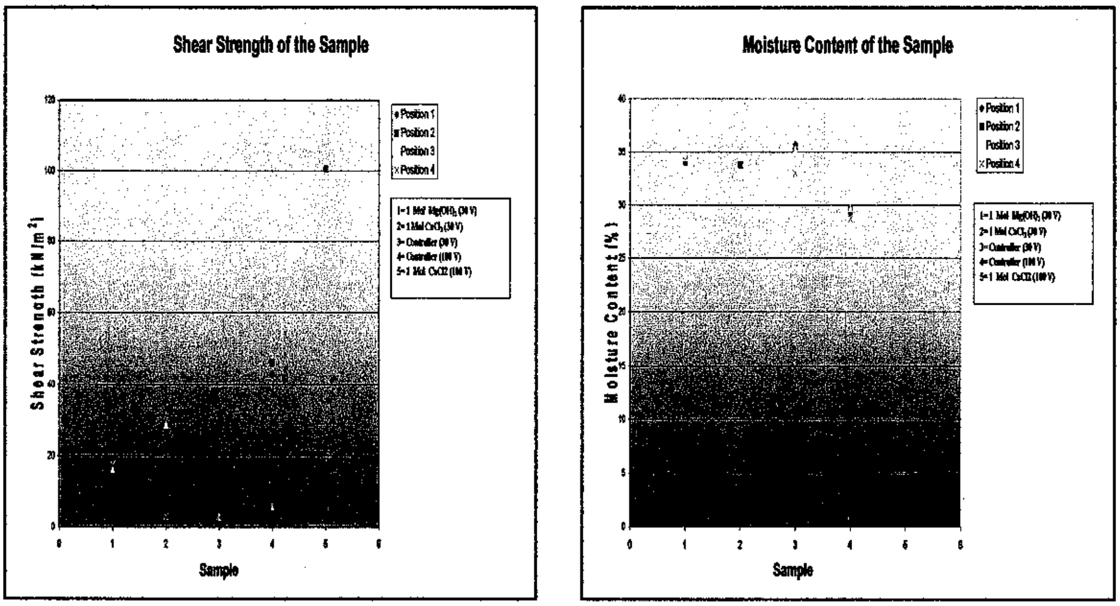


**Figure 4.8** Shear strength and moisture content values for box cell

**Figure 4.7** and **Figure 4.8** shows the relation between moisture content and shear strength of the soil. Theoretically, low water content will results in high strength values. Observation made from **Figure 4.7** shows that even though moisture content values are similar for all samples but it is not the case in sample 1 Mol $CaCl_2$. The sample of 1 Mol $CaCl_2$ shown very high strength values compared to other samples. It is because of the dissipation of. Another reason that probably would have taken place that contributes to this high strength is the cementation process that may have taken place. This is because from the observation, the sample after test is hard and cemented. From the theory, the existence of calcium ions, $Ca^{++}$ will react with dissolves ions from kaolinite such as silicon and aluminum to form the cementation product. Compared to $Mg(OH)_2$

that does not contain $Ca^{++}$ ions, this chemical less effective when reacts with kaolinite soil because this chemical cannot form cementation products.

For electro-osmosis by using box, the high value is achieved in sample 1 Mol $CaCl_2$. This is due to the both processes such as dissipation of water and cementation process that may have taken place during the electro-osmosis process. Compared to sample of controller, 100 Volts that not contain any chemicals have given high moisture content and low strength. From this observation, existing of calcium ions, $Ca^{++}$ produced cementation product and also enhance the water dissipation.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

This experiment is conducted in order to find out the best chemical and applied voltage that will give best effect to kaolinite soil properties in term of the strength. Chemicals that are used in this experiment are $CaCl_2$ and $Mg(OH)_2$. Voltage applied on this soil is 30 Volts and 100 Volts. Only $CaCl_2$ used both voltage which are 30 Volts and 100 Volts. $Mg(OH)_2$ used 30 Volts only since this chemical has shown less effective chemical in this project.

Electro-osmosis is tested with 2 types of apparatus which are cylinder and box. The objective of this box is to have the similarity with site condition. Initial moisture content of the soil is about 50% and the reduction in moisture content is measure with moisture content test. Shear strength is measured by using vane shear test and unconfined compression test. From this experiment, the effective chemical is $CaCl_2$ since this chemical give high value for current and strength. This chemical is effective because of the existing calcium ion ($Ca^{++}$) and this ion will react with dissolve kaolinite ion to form CSH (calcium silicates hydrates) and CAH (Calcium aluminum hydrates) as shown in chemical equation below:

$$Ca^{++} + 2(OH)^{-} + Al_2O_3 \longrightarrow CAH$$
$$Ca^{++} + 2(OH)^{-} + SiO_3 \longrightarrow CSH$$

$Mg(OH)_2$ is not effective because this chemical is a precipitate chemical and might be because the reaction between $Mg(OH)_2$ and clay has weaken the clay bonding. Due to this precipitation, the amount of ion dissolve is less so fewer ions react with kaolinite ions. Between 30 Volts and 100 Volts, 100 Volts give better performance on the current value, shear strength and moisture content. High voltage will increase the current value and hence will increase the temperature. Increasing in current value and temperature will enhanced the acceleration of water and hydration process. In conclusion from this project, the best chemical is $CaCl_2$ with 100 Volts

### 5.2 Recommendation

This experiment is the basic experiment in order to find out the best chemical that is suitable to improve strength of the soil. In the future, various amounts of chemicals and voltage should be investigated. For this experiment only 1 Mol and 2 Mol of chemical with 30 Volts and 100 Volts is considered. From this test $CaCl_2$ has shown very effective results, in the future work, the test can be focused only with this chemical by varying value of chemical concentration and voltage applied. The X-ray Diffraction (XRD) and X-Ray Fluorescence (XRF) test should also be carry out in order to prove the existence of cementation products in the soil which are CSH and CAH.

Since there were several numbers of errors during the measurement and also time constraint, repeated test is needed in future in order to obtain the precise results. To implement this investigation on site, future investigation can be made on equipment that is suitable for site condition.

# CHAPTER 6

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# CHAPTER 7

# APPENDICES

## 7.1: Flow of activities

| No. | Detail/ Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | Study week | Week After Final | Within 2 weeks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Discussion with lecturer | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| 2. | Submission of Progress Report I | | | ● | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| 3. | Project work continue | | | Lab 1 | Lab 2 | Lab 3 | Lab 4 | Lab 5 | | | | | | | | | | |
| | -Practical/Laboratory Work | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| 4. | Submission of Progress Report 2 | | | | | | | | ● | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| 5 | Project work continue | | | | | | | | Lab 6 | Lab 7 | Lab 8 | | | | | | | |
| | Practical/Laboratory Work | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| 6. | Submission of Dissertation 1st Draft | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | ● | | |
| 7 | Submission of Dissertation Final Draft | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| 8 | Oral Presentation | | | | | | | | | | | | | | | | ● | |
| | | | | | | | | | | | | | | | | | | |
| 9 | Submission of Project Dissertation | | | | | | | | | | | | | | | | | ● |

**Table 1.1:** Flow of activities

## 7.2: Equipments

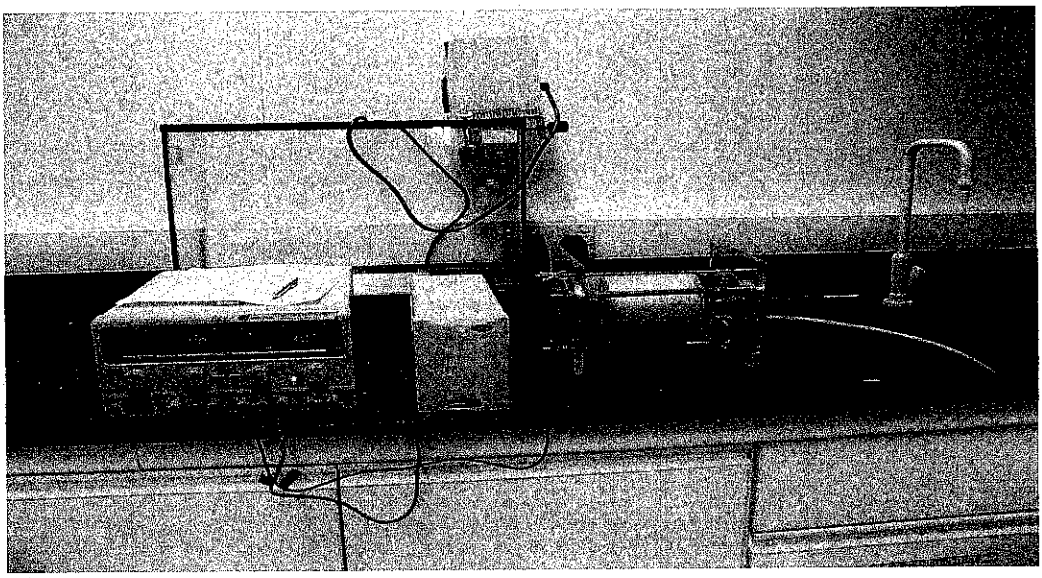

**Figure 7.1**: Equipment setup for electro-osmosis cell

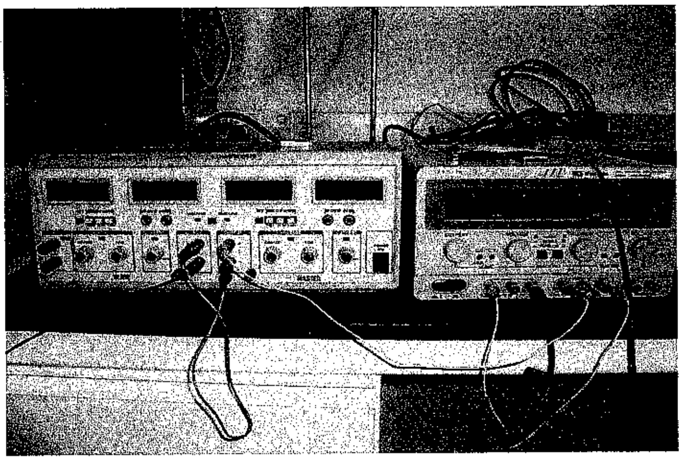

**Figure 7.2**: Power supplied