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ENGINEERING PROPERTIES OF CONTAMINATED COMPACTED CLAY LINERS

A Thesis
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in Civil Engineering

By

Basim Mohammed Abdullah
(B.Sc. in Civil Engineering, 2012)

Supervised by

Asst. Prof.Dr. Khalid Rassim Mohmood Al-Janabi

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SUPERVISORS CERTIFICATE

I certify that this thesis entitled **"Engineering properties of contaminated compacted clay liners"** was prepared by **Basim Mohammed Abdullah** under my supervision at the Civil Engineering Department, College of Engineering, University of Anbar, as a partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering.

<u>Supervisor</u>

Signature:

Name: Asst. Prof. Dr. Khalid Rassim Mahmood Al-Janabi

Date: / / 2017

Report of Language Advisor

I certify that this thesis titled **"Enginerring properties of contaminated compacted clay liners"**, which was prepared by **Bassim Mohammed Abdullah** at the University of Anbar, College of Engineering, Civil Engineering Department has been revised linguistically by me and thus the thesis is now ready for discussion as far as language and style are concerned.

Signature:

Name: Dr. Ali Sabah Jameel

Date: / / 2017

Report of the Head of the Civil Engineering Department

According to the recommendation presented by the supervisors and chairman of the postgraduate studies, I forward this thesis for discussion.

Signature:

Name: Assist. Prof. Dr. Akram S. Mahmoud

Date: / / 2017

Abstract

Compacted clay liners are widely used as liners in the engineering landfills because of their low hydraulic conductivity, high contaminant attenuation and cost effectiveness. To construct clay liners, processed and natural clays are widely used to create impermeable liners in solid waste disposal landfills. The engineering properties of clay liners can be significantly affected by the leachate from the waste mass.

In this study, the effect of different inorganic salt solutions will be experimentally investigated. Different inorganic salt solution will be used at different concentrations. Two type of inorganic salt $MnSO_4$ and $FECL_3$ are used at different concentration 2%,5%, 10%. Clay used in this study was the CL- clay (kaolinite) .The test will be conducted after permeation of salt solutions will be completed. The result show that the liquid limit, plastic limit and plasticity index increased as the salt concentration increased. Also, the unconfined compressive strength increased as the concentration of salts increased. While the permeability tend to decrease as salt concentration increased. The finding of this study indicated that the salt in pore fluid reduce the compression index as the concentration increased from 2% to 5% , after that the C_c nearly constant. The swelling index tend to increase slightly as the concentration of $MnSO_4$ increased, while its decrease as the concentration of $FeCL_3$ increased. The study proved that the CL- clay (kaolinite) can be used as liner material for the construction of the MSW landfill site. Furthermore, according to these results, the CL-clay suitable for using as a compacted clay liner to be used in construction of landfill in Baghdad city.

Acknowledgment

In the Name of Allah, the All –merciful, the All-compassionate.

Praise be to Allah, the All-Powerful, the All-Knowing, the All-wise, the All-Generous, the Noble and the compassionate, for giving me the strength and persevernace to complete this work in pursuit of my dreams. And pray, and gave the envoy mercy to the worlds of Prophet Muhammad by the best prayer and delivery and on his family and companions.

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Basim Mohammed ABDULLAh 2017

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Notation and Abbreviations

Abbreviation	Full Terms
CCL	Compacted Clay Liner
MSW	Municipal Solid Waste
C_C	Comperssion index
C_e	Swelling index
USCS	Unified Soil Classfication System
CL	Low plasticity clay
CH	High plasticity clay
k	Permeablity coefficient
L.L	Liquid Limit
P.L	Plastic Limit
P.I	Plasticity Index
O.M.C	Optimum Mositure Content
ρ_{dmax}	Maximum dry density
UCS	Unconfined Comperssive Strength
GS	Specific gravity
w	Water content
GCL	Geosynthtic Clay Liner
C_v	Coefficient of consolidation
C	Cohesion
$\varnothing$	Angle of internal fraction

Introduction

1.1 General

Landfills are used as an engineering system for the disposal of waste and prevention its impact on the environment and the health of human. Modern landfill barriers consist of impermeable layers called compacted clay liner (CCL), which may be defined as a layer of clay used as a hydraulic barrier to prevent the transport of pollutants into the soil and ground water, as well as prevent the emission of gas into the atmosphere.

There are many types of soil can be used in construction of compacted Clay liner (CCL), such as natural clay, glacial till, residual soil, shale, mud, bentonite , kaolinite or any available of mixture soil. In general the soil should be classified (CH, CL, SC) in order to be suitable for used as a Compacted clay liner (CCL). The material when used for compacted clay liner should be stacked in order to increase bulk density and homogeneity of soil **Nayak et al., (2014)** Many organizations require that the thickness of Compacted Clay Liner (CCL) must not be less than 0.6m and that the material used in the creation of compacted clay liner has a permeability of less than or equal $1x10^{-7}$ cm/s. These are essential requirements to prevent percolation of leachate into the ground water and surrounding environment.

When waste placed in a landfill, pollutants may generated leachate from the interaction of water with waste material in landfill, as well as by squeezing of waste material by self weight of wastes **(Saleh, 2005)**.

Xuede et al.,(2002) showed that even in the absence of water, the leachate will be generated due to the many biological and chemical processes occurs in many of the substance found in pollutants such as organic material, inorganic material, heavy metals and other materials. **Mahdi,(2015)** in his study of ground water for three random landfill sites in Baghdad found that the Leachate generated containing a high proportion of sulfates and manganese above the allowable limit.

The impact of Leachate on the clay liner varies from city to city and from country to country depending on the type of pollutants that are received at the landfill.

1.2 Aim of the study

The overall objective of this research is to investigate the performance of compacted clay liner which exposed to the certain chemicals that generated by the leachate and their effects on the Geotechnical properties of compacted clay liner such as consistency limits, permeability coefficient, compressibility characteristics and unconfined compressive strength are investigated.

1.3 Thesis outline

This thesis is divided into four chapters in addition to the introduction. They can be summarized as follows:

Chapter two is a brief collection of information from different kinds of literature about the environmental effect on landfill sites, particularly describing the effects of inorganic salt that is generated in a landfill on the Geotechnical properties of clay. The literature review has been done to wining an insight into relevant researches activities that related to landfill waste management in many countries. This chapter incorporates all the data required to set reasonable justification for the subject under study.

Chapter three describes the methodology used in preparing and testing the engineering properties of compacted clay exposed to certain inorganic salt.

Chapter four discusses the results obtained from the experimental programs.

Chapter Five presents conclusions and recommendations for future work.

Literature Review

2.1 Introduction

The ideal way to deal with the waste generated from human activities are disposal in landfill. every city around the world owns an area of land dedicated to landfill pollutant left over from the population and activities that lead to the creation of many the problems that must be dealt with.**(McDougall et al., 2008**).

The waste disposal in landfill randomly leads to contaminate the soil and losing of soil fertility which need a long time to retrieve it and also lead to contaminating the ground water, thus there is a persistent need to study their effect on soil and ground water**. (Thiruvenkatacharie et al., 2008).**

2.1.1 Landfill history

Due the increase in population around the world, and the increase of pollutants that are generated as a result the use of landfill become essential to get rid of these pollutants and prevent the impact on the environment.

Solid waste is a growing problem in many countries, both developed and developing countries. For example :between 1970-1990 the production of solid waste in developing countries increased by 90% in eastern Europe, the production of solid waste up to 1 kg/person/ day and it is much bigger in the south east Asian countries **(Selah,2005).**

The disposal of waste is a major problem in most developing countries, the landfill is the best way to get rid of this problem,this method is also used in developed countries .In spite of policies that encourage the re-use or reduce the amount of waste within the European Union, still more than half of the member state get rid of 75% of waste by landfill and the Ireland as well as the 92% of waste is disposed of in this way **(Thiruvenkatachari et al., 2008).**

The modern landfill waste uses layers made of impermeable material to prevent the transmission into soil and ground water. At the present time new type of landfill use air to encourage biodegradation, this type of landfill called bio-reactors .This type allow storing larger amount of waste than the conventional landfills,**(Di Bella et al., 2011)** pointed that methane gas that produced by the biodegradation of organic waste in the bio-reactors may be used as an energy source.

2.1.2 Type of landfills

Landfill may be classified into four groups, such as a sanitary landfill, municipal solid waste (MSW) landfill, construction and demolition waste landfill, and industrial waste landfill.

2.1.2.1 Sanitary landfill

Sanitary landfilling is the most common way to eliminate solid urban waste. In this type, the uses of clay liner isolate the trash from the environment. **(Milosevic et al., 2012).** This type of landfill is used where waste isolated from the environment until its safe. **(Diamantis, 2013)** suggested that the waste is considered safe when it is completely degraded: chemically, physically,and biologically.

Sanitary landfill use technology to contain the waste and prevent the leaching of potentially hazardous substance. There are two main types used in sanitary landfill :trench method and area method .(**Di Bella et al., 2011**).Both methods used principles of cell to cover compacted waste (**Thomsen et al., 2012**). Both methods are illustrated in figure 2.1

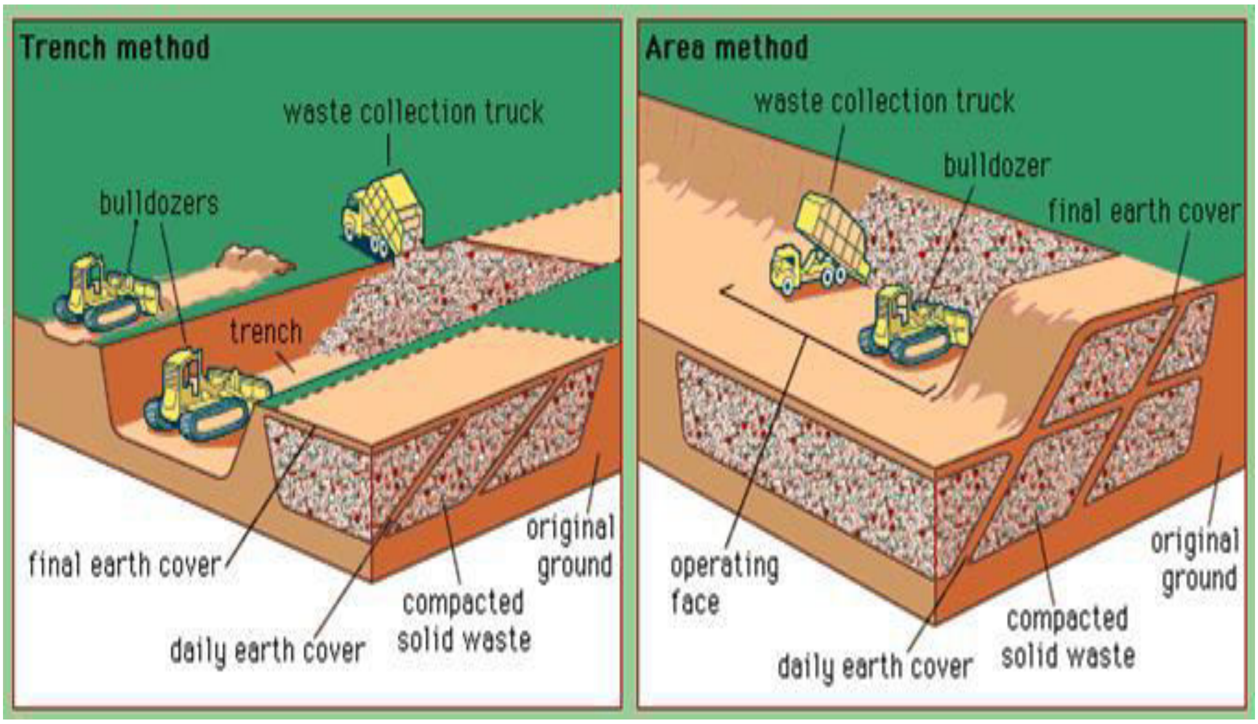

Figure 2.1:Sanitary landfill (Nijrabi,2010)

2.1.2.2 Municipal solid waste (MSW) landfill

Municipal solid waste landfill uses a synthetic (plastic) liner to isolate the trash from the environment. This type of landfill collects household waste and it is regulated by the local and state governments **(Geismar, 2014)**. The environmental Protection Agency (EPA) has established minimum criteria that these landfills must meet some material may be banned from disposal in municipal solid waste landfills (MSW) .These items include paints, cleaners, motor oil , batteries, and pesticides which are some of the common items that are banned from MSW's **(Al-Jarallah and Aleisa, 2014)**. However,some household appliances can be turned into MSW's for disposal, but dangerous wastes such as bulk liquids or waste that has free liquids, yard waste and scrap tires are not **(Thomsen et al., 2012).**

2.1.2.3 Construction and demolition waste landfill.

Landfills used for storage the waste consist of debris generated during the construction, renovation and demolition of buildings, road, and roads .these waste include brick, concrete and other masonry material ,wood, gypsum, asphalt, soil, rock, glass, and trees**(Geismar, 2014)**. These add to contamination of earth, and when smoldered can transmit dangerous gasses.**(Thomsen et al., 2012)** suggested that there should be recycling these types of waste to help in saving money and also help to reduce the amount of waste disposal of in landfills.

2.1.2.4 Industrial waste landfill

The industrial waste created particularly by manufacturing companies generated methane **(Gallas et al., 2011)**, which consider to be normal after-affect, the decomposition of which can produce clean and serviceability energy .However, if these squanders were reused as opposed to dumped, they could likewise be utilized to make helpful item **(Milosevic et al., 2012)**

2.2 Compacted Clay Liner

Compacted clay liners are materials that can be used to isolate waste from natural ground and prevent the leachate generation from these wastes to reach into ground and ground water. The material when used in Compacted Clay Liner (CCL) should be compacted to increase bulk density and homogeneity to minimize seepage through them. **Rahman,(2000)** found the compacted clay liner when used in landfill received the extreme prominent attention in recent times. The main reason for using compacted clay liners is their low hydraulic conductivity and their ability to maintain this characteristic in the long term chemicals, biological and moisture condition at the base of landfill. Subsequently, compacted clay liner is utilized as a part of mix with extera mineral layer and gemombranes to form a compelling defensive layer.

2.2.1 Application of Clay Liner

Clays can be used as liner materials, both in municipal and hazardous solid waste site, such as canal linings **(Holtz, 1953),** sewerage lagoons, landfill surface impoundment **(Daniel and Wu, 1993)** mine tailin, chemical liquid storage ponds and evaporation ponds**(Daniel, 1984)**.

There are three components of liner materials, these components are base liner, side liner, and cover liner **(Rahman, 2000)**.These functions and component are illustrated in figure 2-1 and discussed below:

►Base liner: These materials are found at the base of landfill to prevent leachate migration into the ground, prevent bio-gas escaping into the environment and to assist in providing mechanical support for the waste mass.

►Side liner: These materials found at the side of the landfill to reduce and prevent the Leachate migration into the soil, provide mechanical resistance to external water pressure and prevent lateral migration of landfill gas.

►Top liner : These materials are found at the top of the landfill (cover of the landfill) to prevent the precipitation and surface water infiltration into the landfill, as a result to reduce Leachate generation and prevent gas generation to travel into atmosphere.

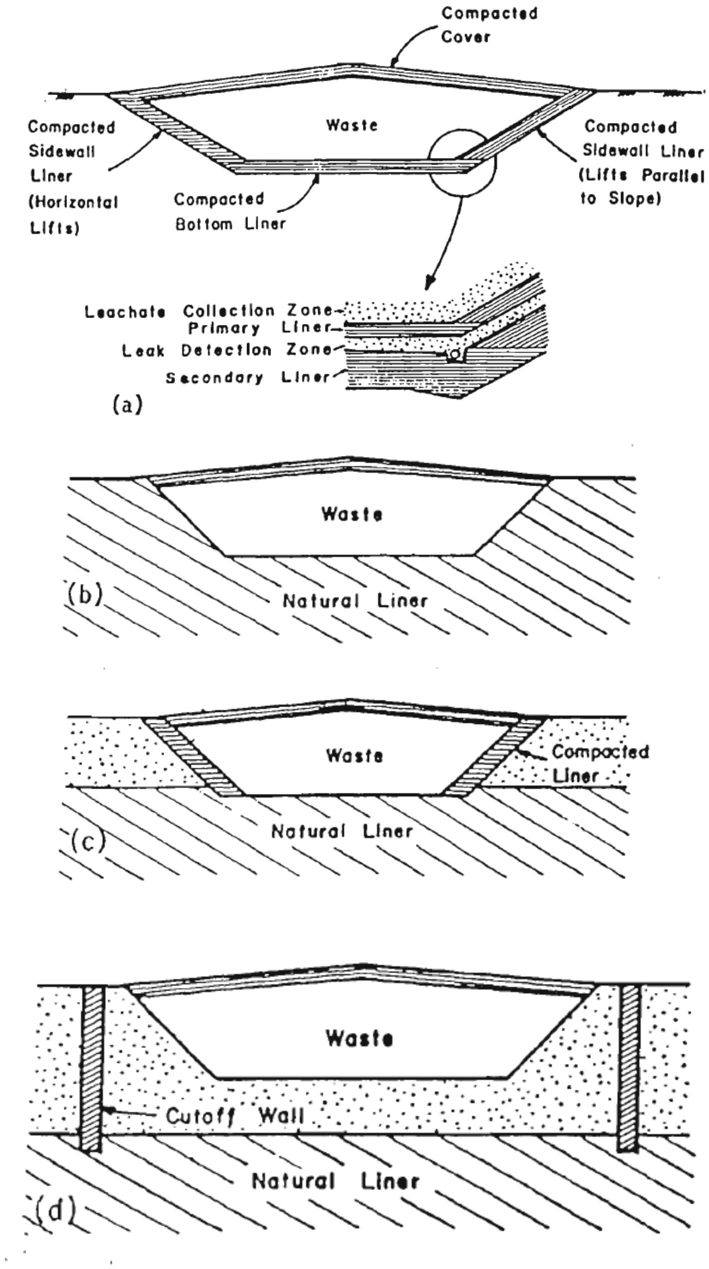

Fig 2-2 Clay Liners: (a) Compacted; (b), (c) and (d) Natural
(Source: Daniel, 1997)

2.2.2 Requirement of compacted clay liner material

In general, there are various important properties must be the material satisfied before used as a liner. For example,(**Daniel and Wu, 1993)** recommended that the clay liner should, maintain the following characteristics

1- **It must be durable and resistant to weathering:** compacted clay liners must be resisting the weathering change such as the force resulting from wet/dry and freeze/thaw cycle that whill cause the cracking that will lead to the migration of pollution to the ground water and the other surrounding environment.

2- **The material must be constructible:** It is the capacity of the material to be workable as far as the situation and compaction under field condition. Hence, the soil must be mixed with water above than optimum moisture content and should be compacted using heavy rollers.

3- **Low diffusivity**: It is the transportation of pollutants from the high concentration area to lower concentration area. This process occurs when the transport of pollutants through CCL, in simple term, the pollutants flux rate, depends on the concentration gradient and the diffusion coefficient. Hence, as far as the liner eligible characteristics are concerned, low diffusivity may be achieved by maintaining a low diffusion coefficient within the liner.

4- **Low hydraulic conductivity:** hydraulic conductivity is the important factor that can be used for selection of material and suitability for use as a liner. In general, the permeability is immediately proportional to the rate of drainage flow of pollutants liquid through the liner. Hence low permeability will minimize the rate of pollutants liquid release /or release of pollutants through liquid flow from the waste pollutants facility and, consequently, the effect on the natural environment would be lessened.

5- **Grain size distribution:** when the materials have a high percentage of clay fraction, these tend to reduce the permeability percentage. In general, when the material used as a compacted clay liner should be have percentage of fines ≥30% and the percentage of clay ≥10%

6- **High attenuation potential:** the term (attenuation) refers to many processes such as adsorption, precipitation, biological processes, redox reaction, acid-base reaction by which liner materials reduce the quantity of pollution leachate within the landfill.

7- **Low freeze/thaw effects**: compacted clay liners should resist the seasonal change in temperature (freezing and thawing of pore fluid).This change in temperature may have effect on the structure of the clay liner leading to cracking of the liner. While it may be important to keep these effects to a minimum CCLs constructed in very cold climates, this case may not stratify to CCLs constructed in countries with temperate or tropical climates.

8- **Ductility**: the compacted clay liner should resist the amount of force before fracturing or breaking. The foreword of tensile stress on barrier materials during different settlement may result in cracking on them which lead to seepage.

9- **Stability**: the material when used as liner must be bear its desirable properties throughout its service life and such should not degrade with time. Processes that facilitate in the degradation of the liner include; its reaction while Leachate and creep. Creep can lead to long term distortion, and if differential settlement were to occur, they can menace the integrity of the liner. If the potential for chemical reaction leading to degradation of liner properties is low, it is then deemed that liner soil is "compatible" with the waste to be contained.

10-Adequate strength and compressibility: compacted clay liner should characteristic adequate strength and low compressibility in order to effectively result as barrier for pollutant release. These characteristics are fundamental to maintain the Trafficability of construction equipment during the construction phase. These are also wanted to maintain the integrity of the liner against the overburden stress imposed by the material above it, and produce the liner stable when employed on a slope, for example, in the side wall of a waste containment facility.

2.3 Solid waste in Baghdad

Waste in country rises as result of the natural growth of the population and developing standard of living**.**(Alsamawi et al. 2009) had been estimated that there were more than(1330393ton) generated per year of municipal solid waste (MSW) produced annually in the city of Baghdad with a per capita rate of about 0.63 Kg/person/day.

The most important system for disposal of waste is the landfilling, that used in Baghdad municipality for all types of waste .The landfilling are used by Baghdad municipality do not meet the minimum required environmental standards condition in terms of the site selection, design and management. The geological and environmental conditions of the site are not adequately regulated ,and random landfill techniques without proper waste separation are often used **(Alsamawi et al. 2009)**.

2.4 Landfill Leachate

2.4.1 Landfill Leachate Generation

Leachate generation is a an outcome of the interaction of waste mass with liquid from rainfall or other forms of precipitation onto the buoyant part of the landfill site and by a series of physical, Hydrolytic and Fermentative degradation of organic matter, inorganic ions and heavy metals existing in the landfill body (**Ince et al., 2013**). It is noticed that, in a zone of low precipitation (parched and semi-bone –dry areas) moderately high moisture content of thewaste can assume the principal part in the Leachate generation (**Safari and Baronian, 2002**).

Chiang et al.,(1995) found that the increase level of leachate occur with increased precipitation, such as during the wetter seasons. **(Renou et al., 2008)** Show that the level of contamination leachate that is more through the waste affected by the type of waste. Also, it was found that the Leachate from biodegradable waste may carry a significant quantity of natural material, including alkali nitrogen and chlorinated natural and inorganic salts. All these materials are poisonous to a number of organic entities, specially to sea life, and can result in damage to human health.

Many factors may affect to the leachate creation, frost, rain and snow greatly affect to leachate creation. Another factor that affect the leachate creation like ground water penetration if the site is constructed below the water table. Aside from precipitation and atmospheric situation, the water content and level of compaction is little that can give increase to more leachate due to the minimize permeation rate(**Deng and Englehardt, 2006**).

2.4.2 Landfill Leachate Composition:

Location and condition of the landfill are the most important factors that affects the composition of Leachate, these factors, including the type of waste stored and how old the landfill is. Many of research investigated the type of pollutants likely to be found in landfill Leachate, one of these researches ,(**Al-Salem and Lettieri, 2009)** who reported that there are four groups of the pollutants found in landfill Leachate :

1-Dissolved organic matter, including methane, measured by COD and Toc

2-Heavy metals

3-Particular compounds

4-Inorganic compounds

(Arasan & Yetimoğlu 2008) summarized typical data on the composition of leachate suggested by different researchers as shown Table 2-2 below:

Table 2-1 typical compositional properties of leachate in landfills(Arasan & Yetimoğlu 2008)

		Robinson and maris(1979)	Ehrig (1988)	Hohl (1992)	Tchobanglous et al (1993) New landfill landfill Less than 2year than	Mature (greater 10 Year)	Kruse (1994)	Timur (1996)	Kjeldsen et al (2002)
PH		6.2-7.6	4.5-9	4.5-9	4.5-7.5	6.6-7.5	6.2-8.3	7.3-7.8	4.5-9
Constituent					Concentration mg\L				
Organic Carbon constituent	COD BOD_5 TOC	66-11600 2-8000 21-4400			3000-60000 2000-30000 1500-2000	100-500 100-200 80-160	(460-40000) (20-27000) (150-1200)	(14900-19980) (6900-11000) (4550-6000)	(140-152000) (20-57000) (30-29000)
Nitrogen constituent	Org-N NH_3-N	0.9-160 5-730	10-4250 30-3000	- 30-3000	10-800 10-800	80-120 20-40	- -	- (1120-2580)	14-2500 50-2200
Anions	CL^- PO_4^{2-} $SO4^-_4$	43-2800 0.02-4.4 55-460	50-4000 - 10-1750	- - 10-1750	200-3000 5-100 50-1000	100-400 5-10 20-50	(315-12400) - 20-2500	(5620-6330) - 142-352	(150-4500) 0.1-23 8-7750
Metals	Na Mg K Ca	43-2500 12-480 20-650 130-1200	50-4000 40-1150 10-2500 10-2500	- - - 10-2500	200-2500 50-1500 200-1000 200-3000	100-200 50-200 100-200 100-400	1-6800 25-600 (170-1750) 49-2300	- (363.8-640) - 97-787.5	70-7700 (30-15000) 50-3700 10-7200
Heavy metals	Mn Fe Cr Ni Cu Zn Cd Pb	0.19-26 0.09-380 0.005-0.14 0.02-0.16 0.004-0.15 0.02-0.95 0.002-0.13 0.003-0.22	0.03-60 3-2100 0.03-1.6 0.02-2.05 0.04-1.4 0.03-120 (0.0005-0.14) 0.008-1.02	- 3-2100 30-1600 20-2050 4-1400 0.03-120 0.5-140 8-1020	- 50-1200 - - - - - -	- 20-2000 - - - - - -	- 2-500 (0.002-0.53) 0.01-1 (0.005-0.56) 0.05-16 (0.0007-0.525) (0.008-0.4)	0.11-5.3 14.2-4 0.02-0.78 0.32-0.45 0.02-0.13 0.38-1.06 0.01 0.04	0.3-1400 3-5500 0.02-1.5 0.015-13 (0.005-10) (0.03-1000) 0.001-5

2.5 Soil Contamination:

Soil contamination comes from solid or liquid hazardous substance mixing with the natural local soil **(Ismail et al., 2008).(Sunil et al., 2009)** noticed that the Leachate pollutants may affect the properties of soil due to chemical reaction between the soil mineral particles and pollutants.

Mahdi, (2015) studied the chemical characteristics of landfill Leachate for three locals of landfill location. The result showed high concentrations of sulfate as (SO_4) about (1040 mg/l) and (2560 mg/l) and (2320 mg/l) with an average (1973.3 mg/l) compared with standard concentration (200 mg/l)

2.6 Effect of Contaminants on the Engineering Properties of Soil:

2.6.1 Consistency Limits:

The consistency limits (Atterberg limits) have been repeatedly shown to be useful indicators of clay behavior **(Jefferson and Rogers, 1998)**.

Most of researches showed that the consistency limit increased when the concentration of salt solution increased for CL-clay **(Arasan and Yetimoglu,2006,2008; (Sivapullaiah and manju, 2005) other researchers (sridharan et al,1988,(Bowders Jr and Daniel, 1987);(Daniel et al., 1988);(Gleason et al., 1997);(Petrov and Rowe, 1997);(Lin and Benson, 2000);(Sridharan and Prakash, 2000); (Schmitz et al., 2004)** stated that the effect of salt on the liquid limit decrease when salt concentration was increased for CH-clay.

Alhassan, (2012) studied the contaminated soil by leachate from MSW, he showed that the contaminated soil generally has relatively lower consistency limits than the than uncontaminated soil.

Sheela & Ann,(2010) studied the effect of Acitic acid and calcium chloride solution as to leachate on different type of Bentonite. They show that the liquid and plasticity index decreased with an increase of concentration of Acitic Acid and calcium chloride for all type of Bentonites.

Dimension,(2013) study the presence of inorganic salt such as NaCl , $CaSO_4$ and $KNO_3$with different concentration added with subsoil , he shows that after the soil was contaminated with these salts, both plastic limit and liquid limits decrease due to the presence of NaCl and KNO3, on the other hand they increase due to presence CaSO4.

George, (2011) carried out liquid limit and plastic limit tests on latrite soil, which was mixed with leachate from municipal solid waste at increament of 0%, 25%, 50%, 75% and 100% by weight. It was found the decreases in liquid limit and plastic limit.

Sunil et al.,(2009) stated that the liquid limit and plasticity index of leachate contaminated soil sample increase as the nature of the pore fluid change. Also, he shown by an increase in the clay content of specific surface area of the soil these may be cause to high adsorption of water that changes the limit value.

2.6.2 Strength Characteristics

Sunil et al.,(2009) conducted a study to examine the effect of leachate on lateritic soil at different concentration 5%,10%,20% by weight of soil. They show that there slight increase in cohesion and a decrease in friction angle.

Ayininoula al et., (2009) showed that the increase in friction angle and cohesion when subsoil saturated with $CaSO_4$ at different concentration.

Singh and Prasad, (2007) studied the effect of inorganic and organic chemical on geotechnical properties Bentonite soil. He indicated that with the addition of inorganic chemicals (aluminum hydroxide), the cohesion (C) decrease by about 50%, while the angle of internal friction (Ø)remained unchanged, with the addition of organic chemical (Acetic acid) the behavior of bentonite was almost same as that with inorganic chemicals (Aluminum hydroxide).

Naeini and Jahanfar, (2011) studied the effect of inorganic salt on the shear resistance of clay. The used different solution concentrations of NaCl. It was found the salt solution sharply increases the undrained shear resistance of compacted up to 2% NaCl, due to changesin chemical structure of clay and then decreases up to 10% NaCl slightly owing to salt flocculation

Also, **Al-Fares,(2011)** studied the effect of landfill leachate on natural soil in Kuwait. It was found that the cohesion increase from 10 kpa to 17 kpa for uncontaminated soil, due to increase of leachate concentration up to 5% by weight of dry soil with no significant change in the angle of fraction. However, when the concentration of leachate increased up to 15% by weight of dry soil the cohesion decreased to closely reach the cohesion of the clean soil with no noticeable change in the angle of friction.

Vanda,(2014) showed that the unconfined compressive strength increased as the NaCl and $CaCl_2$ salt concentration increased. The failure strain increase in NaCl added specimens ,the becoming more ductile, on the other hand in $CaCl_2$ is observed to makes specimens more brittle.

Ayininoula al et.,(2009) studied the behavior of subsoil saturated with $CaSO_4$ at different concentration. It was shown that the increase in salt concentration may lead to increase in fraction angle and cohesion parameters.

2.6.3 Compressibility:

Ojuri and Akinwumi,(2012) studied the effect of high concentrations of heavy metals in the landfill leachate on the behavior of clayey soil in Nigeria. He showed that the compression index and swelling index(C_c and C_e) decreased with an increase in the degree of nitrate concentration.

Similarly, **Resmi et al.,(2011)** studied the effect of artificially fed lead nitrate on uncontaminated clayey soil, they show that the values of the coefficient of consolidation(C_v) increased of the with the increasing concentration of lead.

In a study conducted on fine grained soil the study showed that any increase in saline concentration may cause reduction in compression index and swelling index **(Ajalloeian et al.,2013)** .

Alawaji ,(1999) shown that the swell potential, swell pressure and pressure and volume compressibility when evaluated by oedometer test using various concentration of $Ca(NO_3)$ and $NaNO_3$, these study indicated that the compressibility decreased with increased of salt concentration.

Also,**Shackelford et al.,(2000)** and **Jo et al.,(2001)** noticed that the swelling index of Bentonite was sensitive to the cation valence and/ or electrolyte concentration in a manner that was consistent with change in the thickness of the adsorbed layer of cation.

Shariatmadari et al.,(2011) investigated the effect of three different inorganic salts (NaCl, $CaCl_2$ and $MgCl_2$) solution on some geotechnical properties of soil Bentonite mixtures as barriers, they concludes that the compression index (Cc) decrease with the increase in salt concentrations.

Vanda, (2014) studied the effect of inorganic salts($NaCl_2$and $CaCl_2$) on consolidation parameter of clay when clay is mixed with these salt, it was concludes that there is a decrease in consolidation parameter when salt concentration increased

2.5.4 Permeability Characteristics

Mitchell, (1993) showed that the mechanicals and hydraulic behavior of clay soil can be strongly affected by the clay –fluid system interaction. For this reason to properly use the compacted raw clay as impermeable liners, more theoretical and experimental study is needed to investigate the variation of hydraulic conductivity with chemicals.

Arasan & Yetimoğlu, (2008) study the effect of five different inorganic salt solution (NaCl, NH_4Cl,KCl,$CaCl_2$,$FeCl_3$) and they found that for CH-Clay, the hydraulic conductivity increased when the concentration of the salt solution was increased. And for CL-Clay, the hydraulic conductivity decreased when the concentration of the salt solution was increased, this was observed for all salt solution.

Many researchers have studied the hydraulic conductivity of higher activity clays such as Bentonite or geosynthetic clay liner(GCL) with affected by salt solution .the reported that the hydraulic conductivity increase when the concentration of salt solution was increased **(Petrov and Rowe, 1997); Jo et al (2000); Jo et al (2005);Shacklford et al(2000); Lee et al(2005))**

Nayak et al.,(2007); sunil et al.,(2008); AL Fares(2011); Resmi et al.,(2011) noticed that the hydraulic conductivity of leachate contaminated soil increased when the leachate concentration increased

Alhassan, (2012) conducted a study on contaminated soil by leachate from MSW, the results showed that the contaminated soil has higher values of coefficient of permeability than the uncontaminated soil.

Sujatha et al.,(2013) studied the effect of dumping municipal solid waste on hydraulic conductivity of soil sampled from different locations below the landfill, the result shown that there is a decreases in hydraulic conductivity.

(Yilmaz et al. 2008) studied the effect of inorganic salt on hydraulic conductivity of CL –Clay,it was concluded that the hydraulic conductivity decrease with increase salt concentration.

2.6 General comments:

► The main reasons for choosing these two types of inorganic salts ($FeCl_3$ & $MnSO_4$) because these types were a high concentration of leachate generated in Baghdad city landfill with comparing with other types.

► The table 2-3 include a summary of researches related to investigate the effect of leachate composition on different engineering propertirs of different types of soil:

Table 2-2 A review show the effect of leachate compositions on clay

Author	Soil type	Salt used	Salt concentration	Soil properties		Parameter under study	Effect of salt on parameter
(Arasan & Yetimoğlu 2008)	CL-CLAY	$FeSO_4.7H_2O$-$CUSO_4.5H_2O$-KCL-NH_4CL	0.0001-0.01-0.05-0.1-0.2-0.5-1M	G.S	2.76	Liquid limit	Increase with increase salt concentration
				L.L%	26	Plastic limit	
				P.L	19	Plasticity index	
				P.I%	7		
	CH- CLAY	$FeSO_4.7H_2O$-$CUSO_4.5H_2O$-KCL-NH_4CL	0.0001-0.01-0.05-0.1-0.2-0.5-1M	G.S	2.79	Liquid limit	Decrease with increase salt concentration
				L.L%	113	Plastic limit	
				P.L%	38	Plasticity index	
				P.I%	75		
(Yilmaz et al. 2008)	CL-CLAY	NaCL-KCL-NH_4CL-$CaCL_2.2H_2O$-$FECL_3.6H2O$	0.01-0.10.25-0.5-1M	G.S	2.77	Permeability (K)	Decrease with increase salt solution
				L.L%	40		
				P.L%	23		
				P.I%	17		
				K cm/s	6.974×10^{-7}		
				OMC%			
				Maximum dray density	$18.3KN/m^3$		
	CH-CLAY	NaCL-KCL-NH_4CL-$CaCL_2.2H_2O$-$FECL_3.6H2O$	0.01-0.10.25-0.5-1M	G.S	2.79	Permeability (k)	Increase with increase salt solution
				L.L%	113		
				P.L%	38		
				P.I%	75		
				K cm/s	7.6421×10^{-9}		
				OMC%	36		
				Maximum dray density	$12.2KN/m^3$		

Table 2.3 (continued)

(Sheela & Ann 2010)	Various type of Bentonite	Type I	Acitic acid and calcium chloride	0.25-0.5-1-2M	L.L%	234			L.L, P.L, P.I, Permeability	Decrease with increase salt solution
					P.L%	54				
					P.I%	180				
		Type II	Acitic acid and calcium chloride	0.25-0.5-1-2M	L.L%	448			L.L, P.L, P.I, Permeability	Decrease with increase salt solution
					P.L%	69				
					P.I%	379				
		Type III	Acitic acid and calcium chloride	0.25-0.5-1-2M	L.L%	400			L.L, P.L, P.I, Permeability	Decrease with increase salt solution
					P.L%	52				
					P.I%	348				
		Type IV	Acitic acid and calcium chloride	0.25-0.5-1-2M	L.L	315			L.L, P.L, P.I, Permeability	Decrease with increase salt solution
					P.L%	65				
					P.I%	250				
		Type V	Acitic acid and calcium chloride	0.25-0.5-1-2M	L.L%	260			L.L, P.L, P.I, Permeability	Decrease with increase salt solution
					P.L%	60				
					P.I%	200				
(Naeini & Jahanfar 2011)	Clay with different plasticity		NaCL	2%-5%-10%		Clay1	Clay2	Clay3	Un drained shear strength	Increase with increase salt solution and plasticity
					L.L%	30.4	39.5	58.8		
					P.L%	20.5	22.8	26.1		
					P.L%	9.9	16.7	32.7		
					Maximum dray density KN/m^3	18.5	17.4	16.9		
					OMC%	12.9	15.2	16		

Con

<table>
<tr><td rowspan="6">(Alawaji 1999)</td><td rowspan="6">Two types of Bentonite mixture with pure silica sand (High quality (HQB)and low quality Bentonite (LQW))</td><td rowspan="6">$Ca(NO_3)_2$ and $NaNO_3$</td><td rowspan="6">0-0.1-0.5-1-4M</td><td colspan="2">HQB</td><td colspan="2">LQB</td><td rowspan="6">L.L, P.L, swell, swell pressure, compressibility</td><td rowspan="6">Decrease with increase salt concentration</td></tr>
<tr><td>G.S</td><td>2.68</td><td>G.S</td><td>2.61</td></tr>
<tr><td>L.L%</td><td>505</td><td>L.L%</td><td>316</td></tr>
<tr><td>P.L%</td><td>459</td><td>P.L%</td><td>254</td></tr>
<tr><td>CLay%</td><td>89</td><td>Clay%</td><td>78</td></tr>
<tr><td>Silt%</td><td>11</td><td>Silit%</td><td>22</td></tr>
<tr><td rowspan="6">(Shariatmadari et al. 2011)</td><td rowspan="6">The materials used in this study were commercially available Bentonite clay supplied by Iran Barit Falat Company and the typical clay which was collected from Varamin town mixed with them</td><td rowspan="6">Nacl, CaCL2 ,MgCL2</td><td rowspan="6">0-0.1 -1M</td><td></td><td colspan="2">Bentonite</td><td>Varamine clay</td><td rowspan="5">Compression index(Cc), swell index(Cs), liquid limit, MDD, OMC</td><td rowspan="5">Decrease with increase salt solution</td></tr>
<tr><td>G.S</td><td colspan="2">2.53</td><td>2.67</td></tr>
<tr><td>L.L%</td><td colspan="2">199.4</td><td>34.2</td></tr>
<tr><td>P.L%</td><td colspan="2">157.9</td><td>13.66</td></tr>
<tr><td rowspan="2">OMC(%)/MDD(g/cm^3)</td><td rowspan="2" colspan="2"></td><td rowspan="2">14/1.86</td></tr>
<tr><td>Hydraulic conductivity</td><td>Increase with increase salt concentration</td></tr>
<tr><td rowspan="7">(Ojuri & Akinwumi 2012)</td><td rowspan="7">Tropical clayey soil collected from different depth</td><td rowspan="7">KNO_3</td><td rowspan="7">0-30-60-120-200mg/L</td><td>L.L%</td><td colspan="3">56-29</td><td rowspan="3">Permeability , C_V</td><td rowspan="3">Increase with increase salt</td></tr>
<tr><td>P.L%</td><td colspan="3">23.3-6.2</td></tr>
<tr><td>G.S</td><td colspan="3">2.75-2.6</td></tr>
<tr><td>$C_V \times 10^{-4}$</td><td colspan="3">6.04</td><td rowspan="4">C_C -C_S</td><td rowspan="4">Decrease with increase salt concentration</td></tr>
<tr><td>C_C</td><td colspan="3">0.46</td></tr>
<tr><td>C_S</td><td colspan="3">0.063</td></tr>
<tr><td>$K \times 10^{-11}$ cm/s</td><td colspan="3">6.38</td></tr>
</table>

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Table 2.3 (continued)

(Endene, 2015)	Clay samples used in the study were collected from Mfensi and Afari, both towns in the Ashanti Region of Ghana.	leachate was collected from an active aerobic cell at the Kumasi Engineered landfill site			Afari	Mfensi	L.L, P.I, UCS	Increase with increase salt concentration
				G.S	2.68	2.72		
				L.L%	81.65	47.31		
				P.L%	22.43	19.62		
				P.I%	59.22	27.69	P.L, permeability	Decrease with increase salt concentration
				L.I	0.12	0.68		
				Activity	1.2	0.6		
				$K\times10^{-7}$	1.005	2.27		
(Vanda 2014)	Swell soil	Nacl, $CaCL_2$	0.5M -1M	L.L%	61		LL, PI, swell potential, swell, C_C, C_S	Decrease with increase salt concentration
				P.L%	30			
				P.I%	31			
				G.S	2.62			
							K, UCS, PL	Increase with increase salt concentration
				OMC%	25			
				Dray density KN/M^3	1.451			
(George 2011)	Lateritic soil	Leachate was collected from municipal solid waste	0%-25%-50%-75%-100%	Lateritic soil properties			L.L%, P.L%, Shrinkage limit, GS	Decrease with increase leachate
				LL%	20			
				PL%	18			
				GS	2.64			
				Van shear strength kg/cm2	0.0142			
				Permeability	$2.7\times^{-5}$ cm/s		Van shear strength, permeability	Increase with increase leachate
				Plastic limit	21.31			
				Liquid limit	29.98			
				Plasticity index	8.67			

Table 2.3 (continued)

(Ajalloeian et.al.2013)	Fine-grained soil	Saline water	0-Half saline water-saline water	Plastic limit	21.31	PL, LL ,P.I,C_C, C_S	Decrease with increase saline water
				Liquid limit	29.98	Shear strength(Cu, Ø)	Increase with increase saline water
				Plasticity index	8.67		
(Petrov & Rowe 1997)	GCL	Nacl	0.01-0.1-0.6-2M	Specified to contain a minimum of 350g/m^3 of essentially dray natural Na-bentonite		Hydraulic conductivity	Increase with increase salt solution
(Mosavat & Nalbantoglu 2013)	Silty clay with high plasticity (CH-MH)	Ethylene glycol-r toluene- sea water	(20%, 40%,6o%, 100%)ethylene glycol-pour toluene-pour sea water	LL%	63.3	LL, PL, PI. C_C . C_S, UCS	Decrease with increases pour fluid
				PL%	31.9		
				PI%	31.4		
				GS	2.54		
				Clay %	60		
				Silt %	34		
				Sand %	6		
				Linear shrinkage %	16.8		
				OMC%	27		
				Dray density	1.47		

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Table 2.3 (continued)

(Lee & Shackelford 2005)	Two geosynthetic clay liner (GCL-HQB, GCL-LQB)	$CaCL_2$	5-10-20-50-100-500 mM		GCL-LQB	GCL-HQB	Hydraulic conductivity	Increase with increase salt solution
				G.S	2.74	2.78		
				L.L%	430	589		
				P.L%	393	548		
				Swelling index(ml/2g)	27.5	30		
(Arasan et al. 2010)	Two type of clay (CL- clay-CH-clay)	Nacl- NH_4CL – KCL- $CaCL_2$ – $FECL_3$ -DW	0.01-0.1-0.25-0.5-0.75-1		CL-clay	CH-clay	Swelling for CL- clay	Increase with increases salt solution
				G.S	2.77	2.79		
				L.L%	40	113		
				P.L%	23	38		
				P.L%	17	75		
				OMC%	15	36		
							Swelling for CH-clay	Decrease with increase salt solution
				Maximum unit weight	18.3	12.2		
				K cm/s	$6,974\times10^{-7}$	7.641×10^{-7}		
				Swelling pressure	71	281		
(Matthew & Akinyele 2014)	Soil samples for this study were taken from two burrow pits in Ibadan South-western Nigeria.(soil A and soil B)	NaCL ,$CaSO_4$	0-10-30-50-70g/dm^3		Soil A	Soil B	Soil Permeability with NaCL	Increase with increase salt concentration and time for both soil
				L.L%	36	42		
				P.L%	22	19.6		
				K cm/s	5.688×10^{-6}	5.243×10^{-6}		
							Soil permeability for $CaSO_4$	Decrease with increase $CaSO_4$ and time

Experimental work and material

3.1 Introduction

This chapter is devoted to describe the experimental work, materials used, sample preparation, testing procedures, and testing program conducted in this work to achieve the purpose of the study. The experimental work includes a series of laboratory tests to investigate the geotechnical properties of a clay soil contaminated with different concentration of inorganic salts solution.

3.2 Material

A commercial clay (kaolinite clay) CL-clay was used in this study. It was brought from Anbar governorate (quarries in the western desert). The main specifications of this clay have been represented in Table 3.1

Table 3.1: Chemical Compositions of Kaolin.(as provided by the *General Company of Geological Survey and Mining*).

Chemical Element	Percent (%)
SiO_2	50
Al_2O_3	32
CaO	1.1
Fe_2O_3	1.4
MgO	0.24
K_2O	0.24
Na_2O	0.24
TiO_2	1.6
L.O.I*	13

*L.O.I (Loss of Ignition)

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Distilled water as well as two salt solutions, $MnSO_4$ and $FeCl_3$ have been used. The properties of these two salts are given in Table 3.2

Table 3.2:The properties of salts used

Salt	Chemical Formula	Density(g/cm^3)	Molecular Wight(g/Mol)
Manganese	$MnSO_4$	3.25	169.01
Iron(III) chloride	$FeCl_3$	2.898	162.2

3.3 Experimental Works and Testing Program

Standard tests were performed to determine the properties of the clay used, the results are presented in table (3.3),

Table 3.3:The properties of clay used

Soil properties	Index	Standards
Specific gravity (GS)	2.66	ASTM:D- 854
Liquid limit (L.L %)	35.6	ASTM:D- 4318
Plastic limit (P.L %)	17.4	ASTM:D- 4318
Plasticity index (P. I%)	18.2	ASTM:D- 4318
Maximum dry density,(ρ_{dmax} g/cm^3)	1.665	ASTM:D- 698
Optimum moisture content(O.M.C)	18.74%	ASTM:D- 698
Particle size distribution		ASTM:D- 422

Figure (3.1) shows the result of the compaction test for the clay used; it is Apparent that the maximum dry unit weight is 1.665 g/cm^3 and the optimum moisture content is 18.74% as shown in figure 3.1

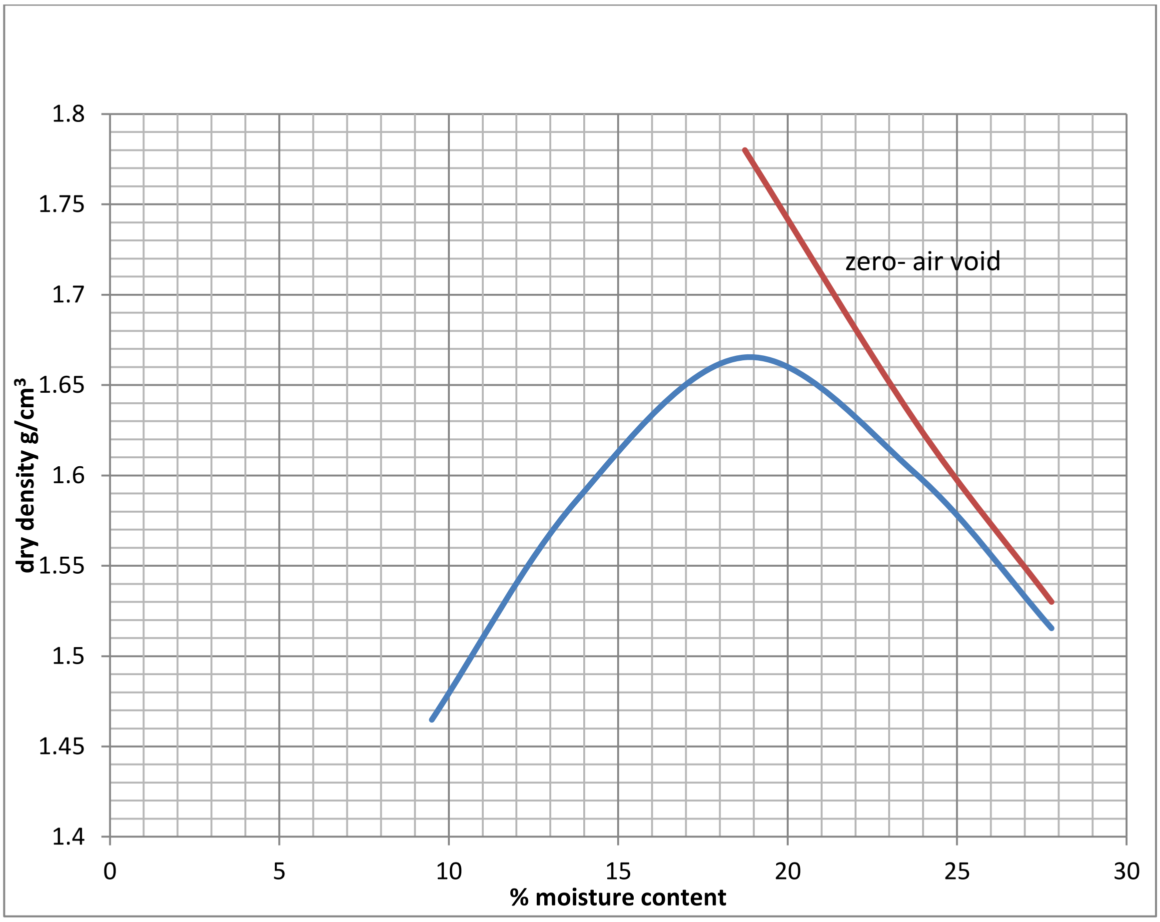

Figure (3.1): Moisture -Density Relationship for clay used.

The grain size distribution curve is shown in Figure (3.2). The soil is classified as **CL** according to the Unified Soil Classification System (USCS).

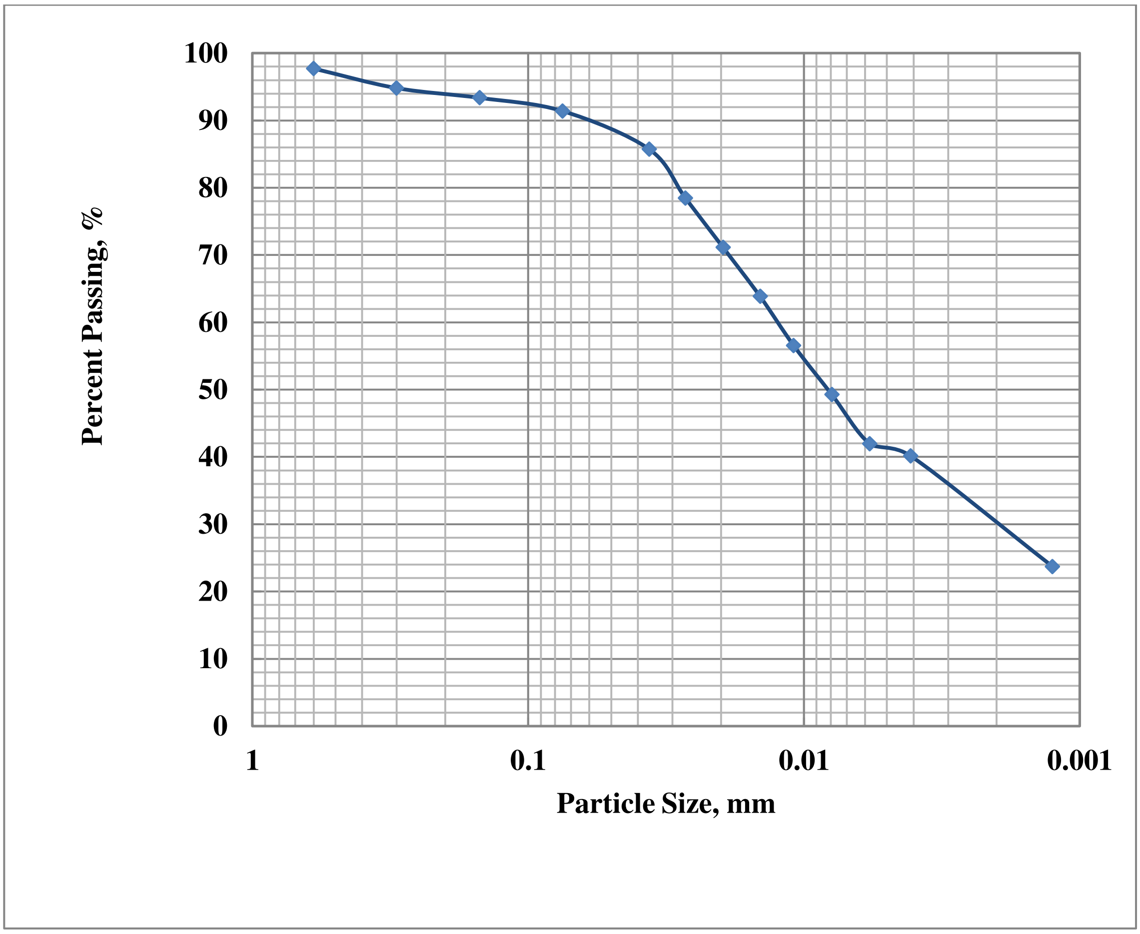

Figure (3.2): Grain size distribution of clay used

The laboratory tests undertaken in this study can be categorized under three series of testsas shown in the form of a flow chart in Figure 3.3.

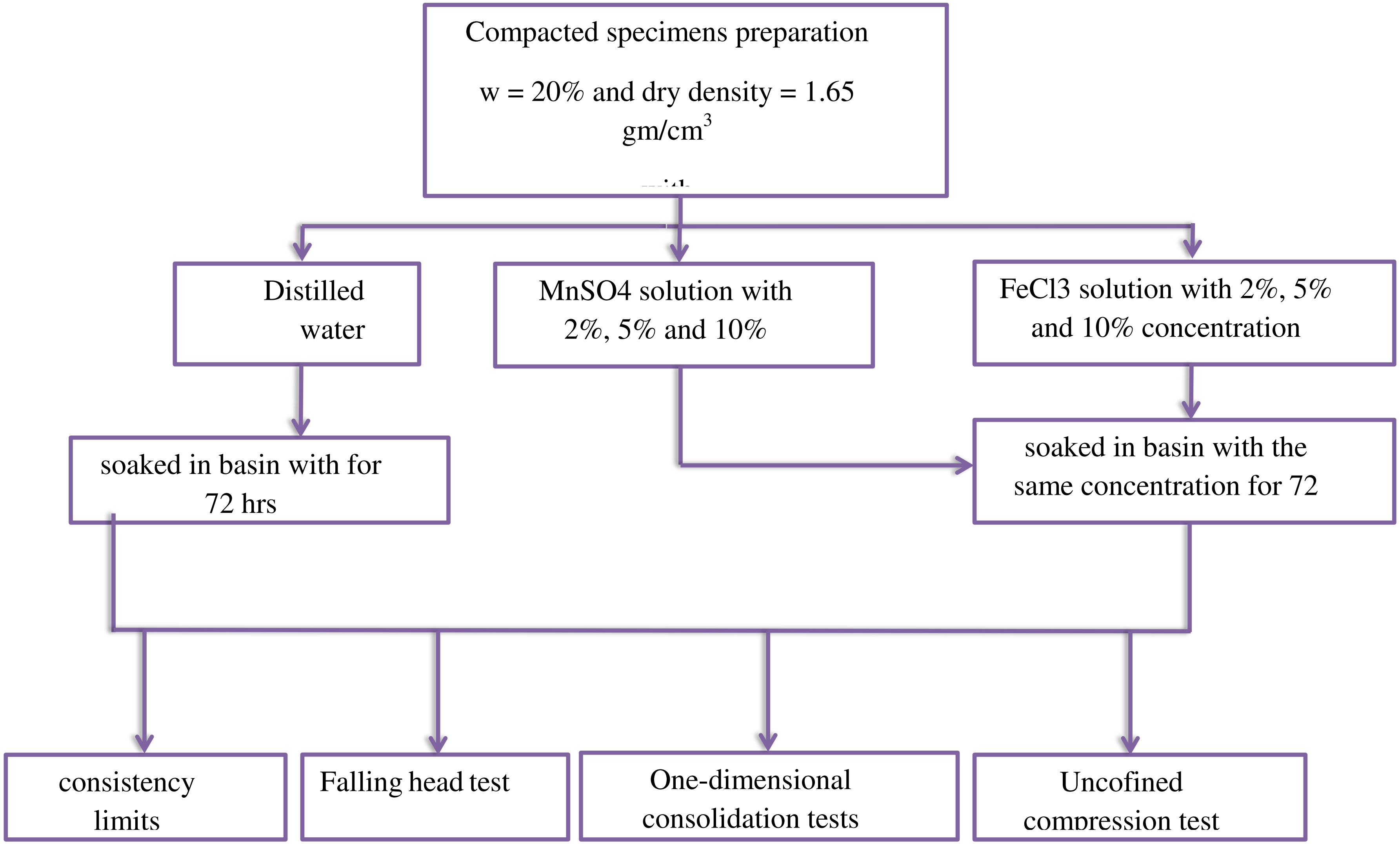

Figure 3-3:Overview of experimental program

3.4 Preparation of Specimens

Samples were prepared by blending with distilled water or salt solutions with different concentration (2% ,5% ,10% M.) at moisture content w =20% then the samples were compacted with dry density 1.65 g/cm^3. The compacted mold immersed in a basin contains of distilled water or the salt solution with the same concentration that was prepared with it for a period of 72hours to reach moisture /chemicals equilibrium before conducted the tests. Table 3.4 shows the various engineering tests conducted in each series of test.

Table 3.4:The engineering tests.

Soil properties	Standards
Liquid limit (L.L%)	ASTM:D- 4318
Plastic limit (P.L%)	ASTM:D- 4318
Plasticity index(P.I%)	ASTM: D- 4318
Falling head permeability test	ASTM: D- 5084
One-Dimensional test	ASTM: D- 2435
Unconfined compressive strength	ASTM:D- 2166

Results and Discussion

4.1 Introduction

This chapter presents the result of tests that were conducted to study the effect of the inorganic salt (from leachate) on geotechnical properties of the soil. The result from the geotechnical properties tests are used to understand the behavior of soil-located system.

4.2 Consistency limits:

The consistency limits of clay mixed with water and inorganic limits ($MnSO_4$ and $FECL_3$ are presented in figure

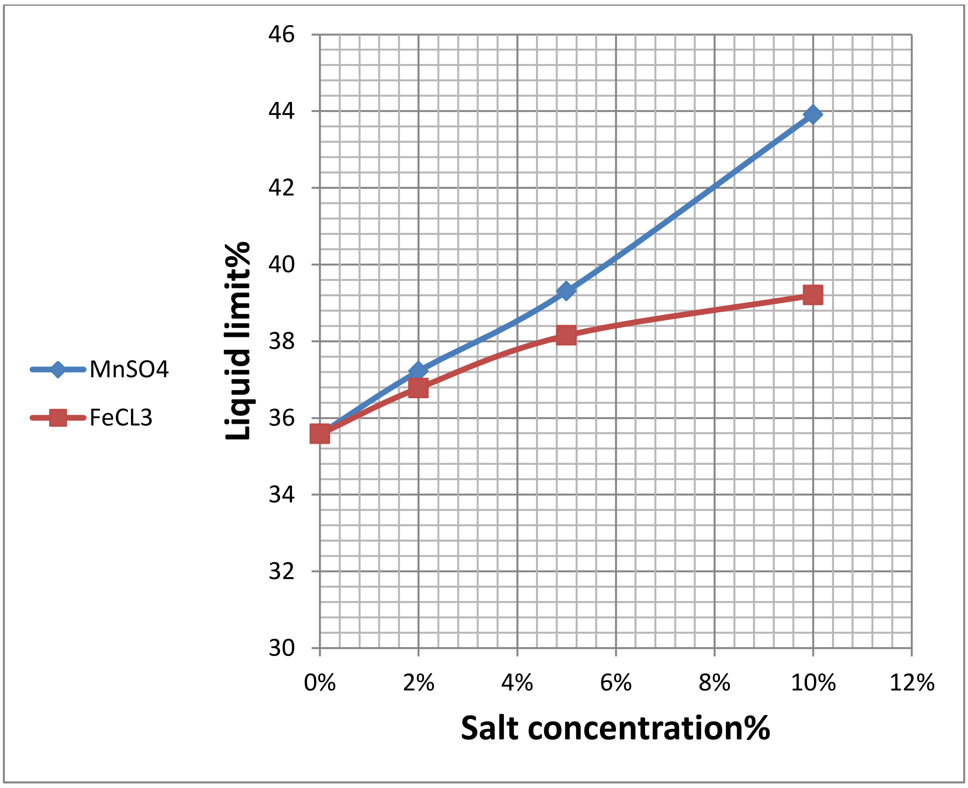

Figure 4-1 Effect of salt concentration on liquid limit

Figure 4-1 shows that liquid limit increases as the concentration of inorganic salt was increased. Beside, the consistency limits are higher under the effect of $MnSO_4$ rahter than $FeCl_3$. The figure 4-2 below described the effect of salt concentration ($MnSO_4$ and $FeCl_3$) on plastic limit. It can be seen that the plastic limit increases as the concentration of salt increases following the same trend observed for liquid limit.

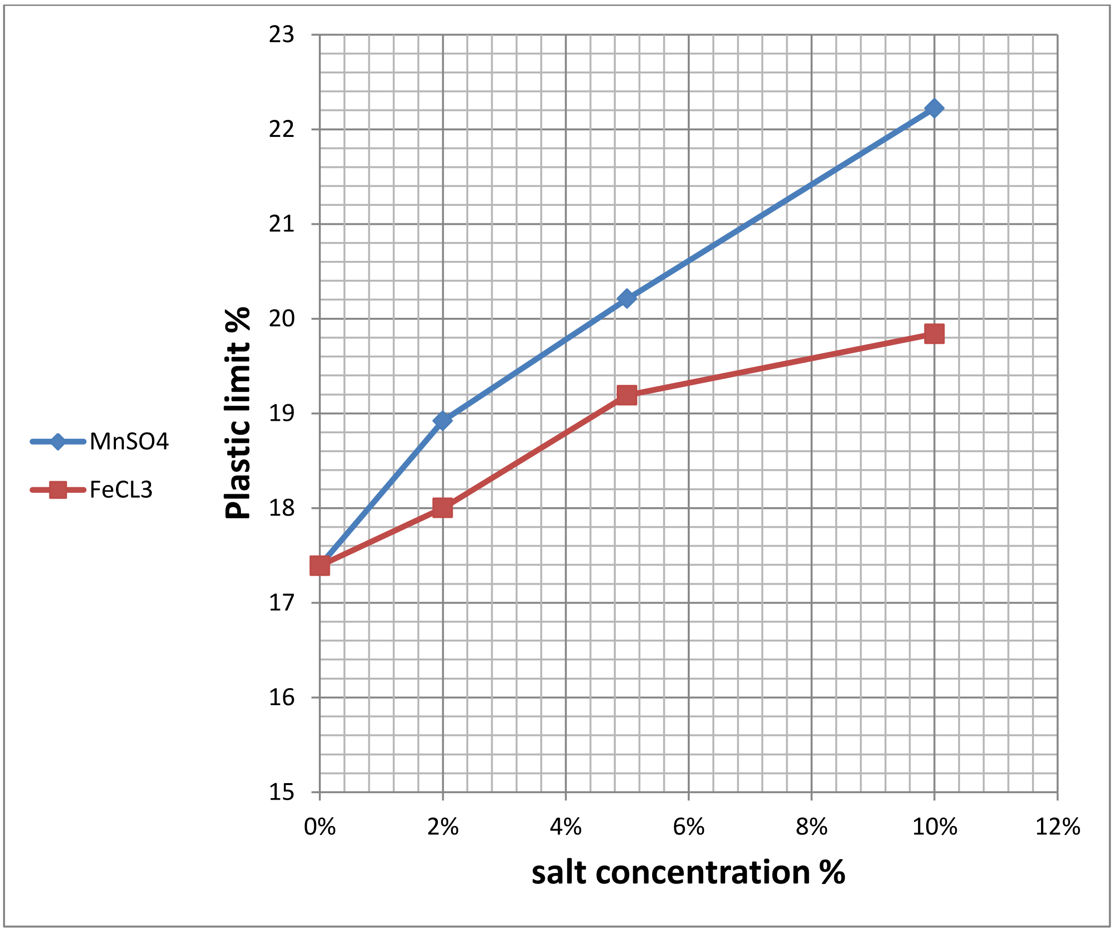

Figure 4-2 Effect of salt concentration on plastic limit

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Figure 4-3 presents the effect of salt concentration the plasticity index

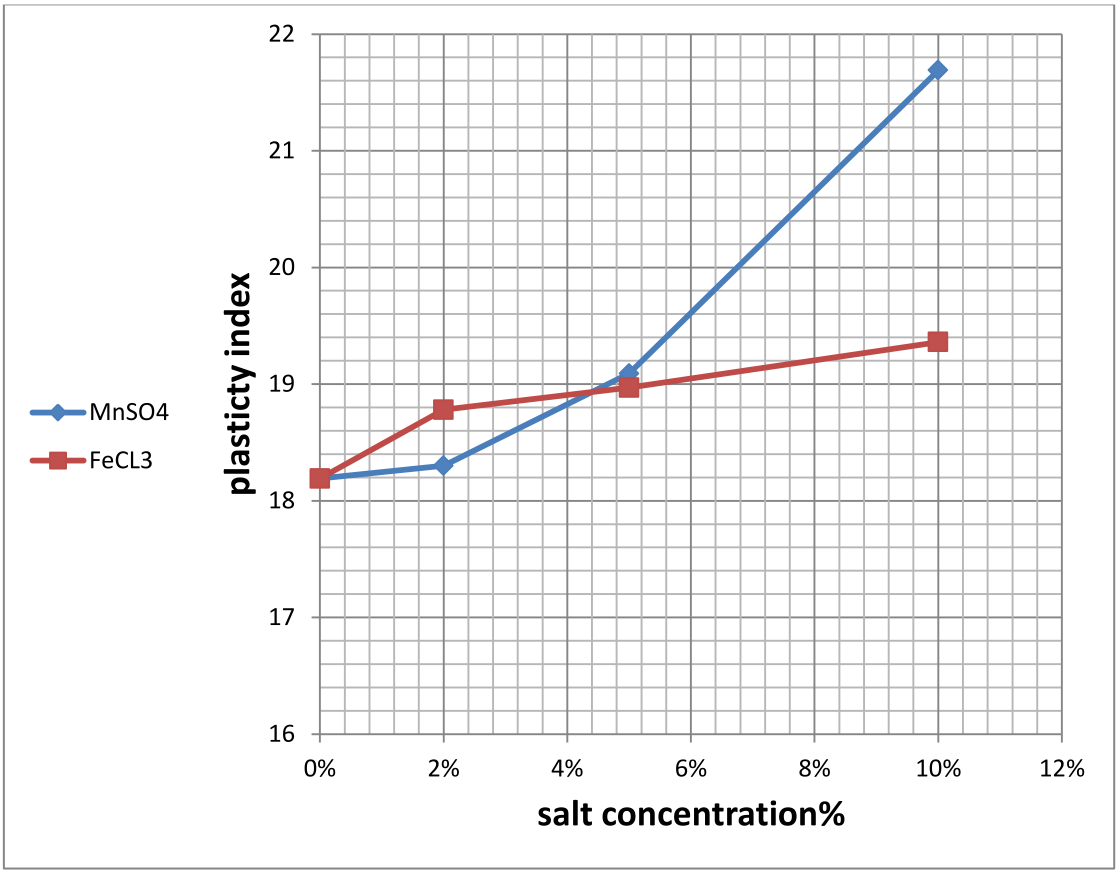

Figure 4-3 Effect of salt concentration on plasticity index

Consequatly, the plasticity index increased as the salt concentration increased as shown in figure (4-3). The effect of $MnsO_4$ is more pronounced than the effect of $FeCl_3$.

These results are in line with the requirements specified by **(Lawal and Abdullahi., 2010)** who indicated that, the higher the liquid limit of a sample, the higher its water retention capacity. Based on the results, the consistency limits of clay for both inorganic salts meet the requirement for use as clay liner. The behavior of clay when permeated with salt was explained by the flocculation mechanism of client (non swelling) clays and diffuse double layer (DDL).

Similarly, **Bowders Jr and Daniel., (1987)** related that the use of chemicals tends to decrease the thickness of the diffuse double layer (DDL), causing the soil skeleton to shrink and decrease in repulsive forces, thus encouraging flocculation of clay particles, and to the dehydrated interlayer zone of expandable clays, which thereafter became a gritty or granular. Moreover, **(Sharma and Lewis., 1994)** stated that the net electrical forces between clay mineral layers were affected by the concentration valence of cations. They specified that increasing cation concentration or cation valence would result in a reduction in net repulsive forces, hence causing clay particles to flocculate.

Sivapullaiah and Manju,(2005) stated that when using the salt solution may cause the formation of new swelling compounds and this new compound causing increased the liquid limit of clay.

4.3 Strength Characteristics of the Clay:

It can be seen that the clay tends to be soft as the salt concentration increased to 2%, there is tend to be harder. From figure 4-4 it can be seen that the unconfined compressive strength increased as the salt concentration increased for both salt. These increased is a result of interaction of clay with salt, the increase in the salt concentration cause increase in the ion concentration of pore water followed by a reduction in the diffuse double layer. Furthermore, this cause a lessening in the antiparticles repulsion and an increase in the attraction.

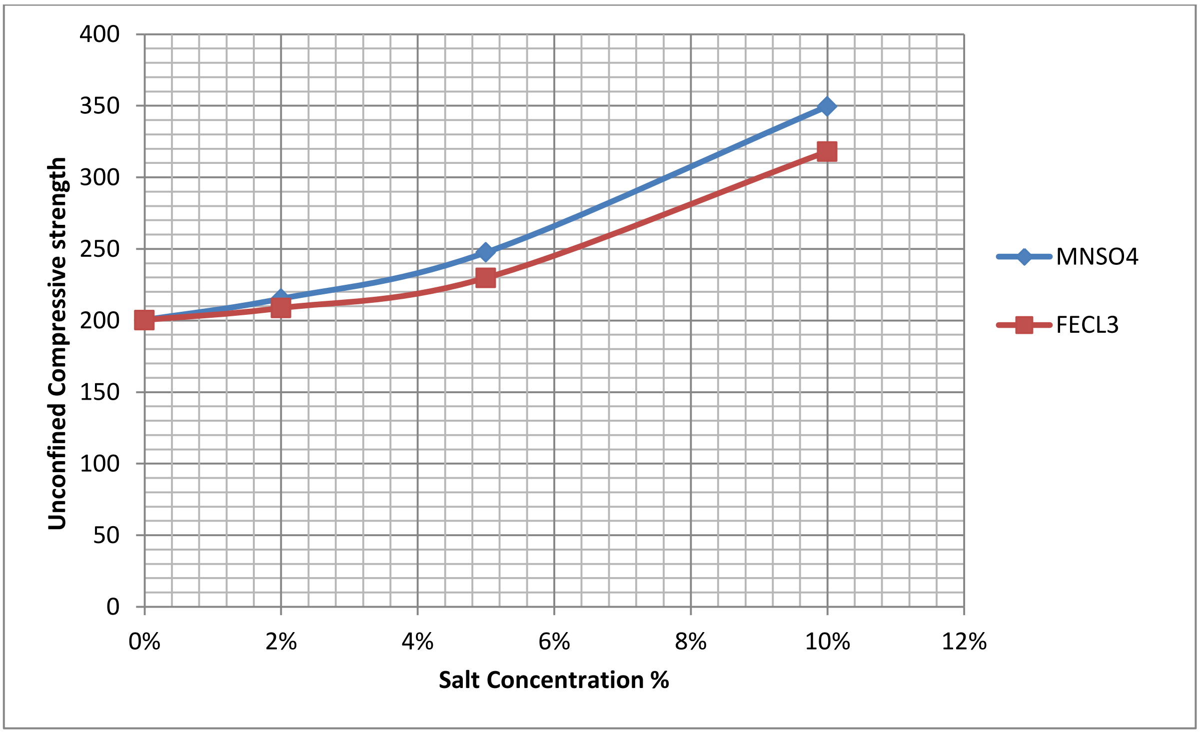

Figure 4-4 Effect of salt concentration on unconfined compressive strength

Figures (4-5) and (4-6) show the stress –strain relationship of the clay as the salt concentration ($MnSO_4$ and $FeCl_3$) increased.

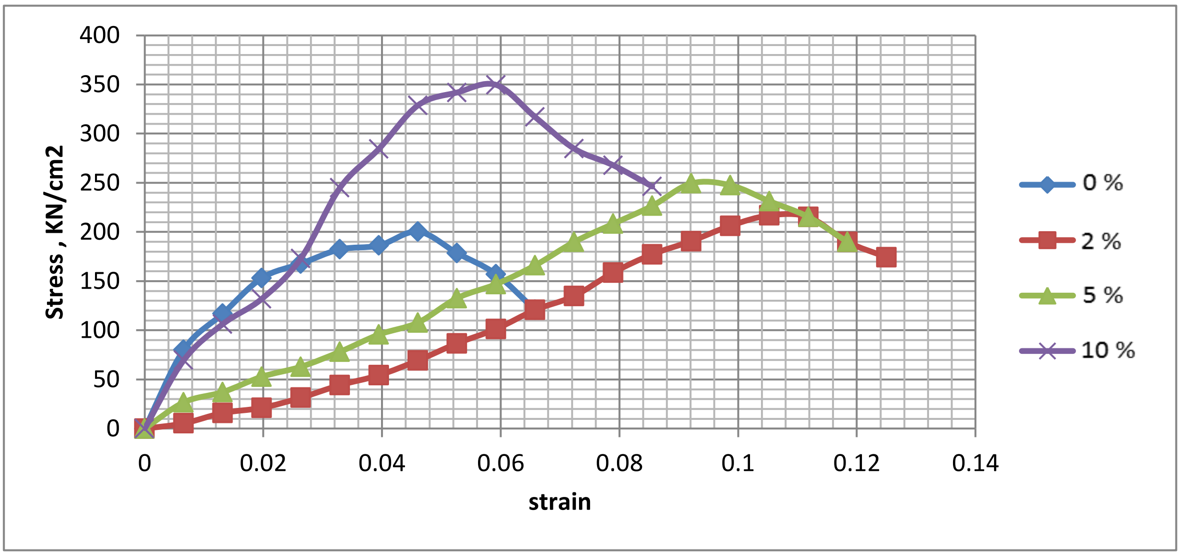

Figure 4-5 Effect of $MnSO_4$ concentration on stress-strain relationship

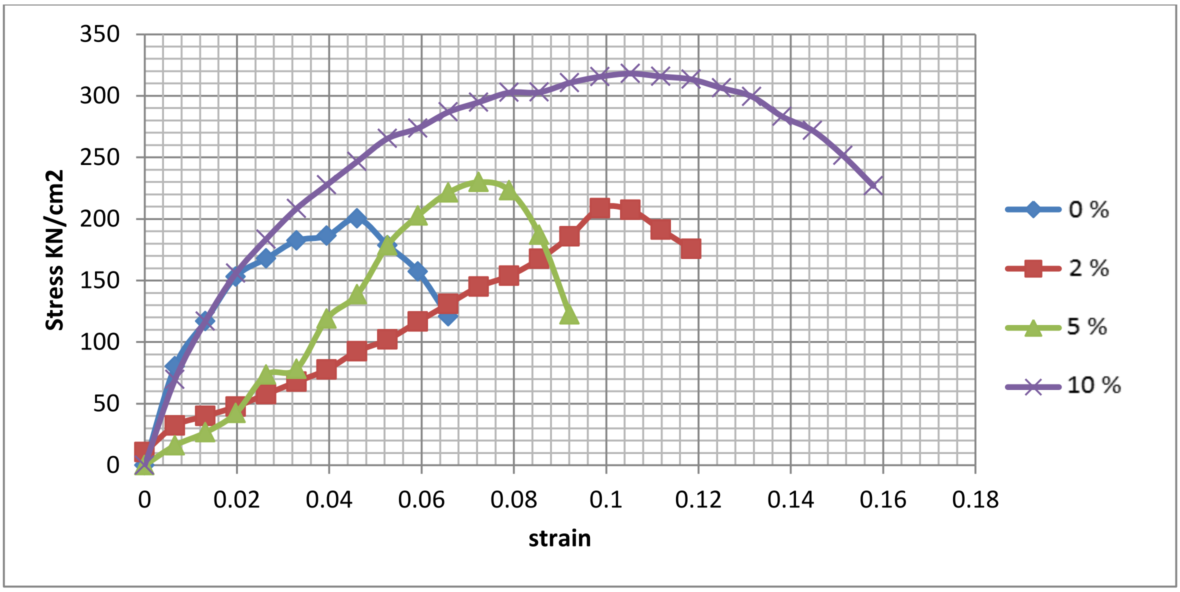

Figure 4-6 Effect of $FeCl_3$ concentration on stress- strain relationship

Table 4-1 Percent increase in unconfined compressive strength with salt concentration.

Salt concentration	$MnSO_4$	$FeCl_3$
0%	0%	0%
2%	7.4%	4.17%
5%	23.4%	14.69%
10%	74.5%	58.73%

Table 4-1 showing the effect of salt concentration. It can be seen the maximam effect on unconfiened comperessive strength at 10% concentration from salts. The effect of $MnsO_4$ is more pronounced than the effect of $FeCl_3$. The strength characteristics of clay depends on cohesion which is the ability of particles to stick together as such porosity is being decreased and density increased. From the result one can conclud that, the clay permeated with both salt solution was meet the strength requirement of not less than 200kPa **(Daniel and Wu., 1993)** recommended for using as the clay liner when tested with water and inorganic salt. Figure 4.7 shows the aligned specimen before test commenced, as well as a failed one after the test was completed.

Figure 4-7:(a) unconfined penetration test set up,(b) and (c) type of failure

4.4 Comperssibility Characteristics:

Figure (4-8) &(4-9) show the e-log pressure of the clay obtained from odeometer test with different inorganic salt concentration of $MnsO_4$ & $FeCl_3$ respectively. It can be seen that as the salt concentration increased the comperssibilty of the soil decreased. This is as a result of the decease of the electrical double layer surrounding the clay particles (Arsan 2010)

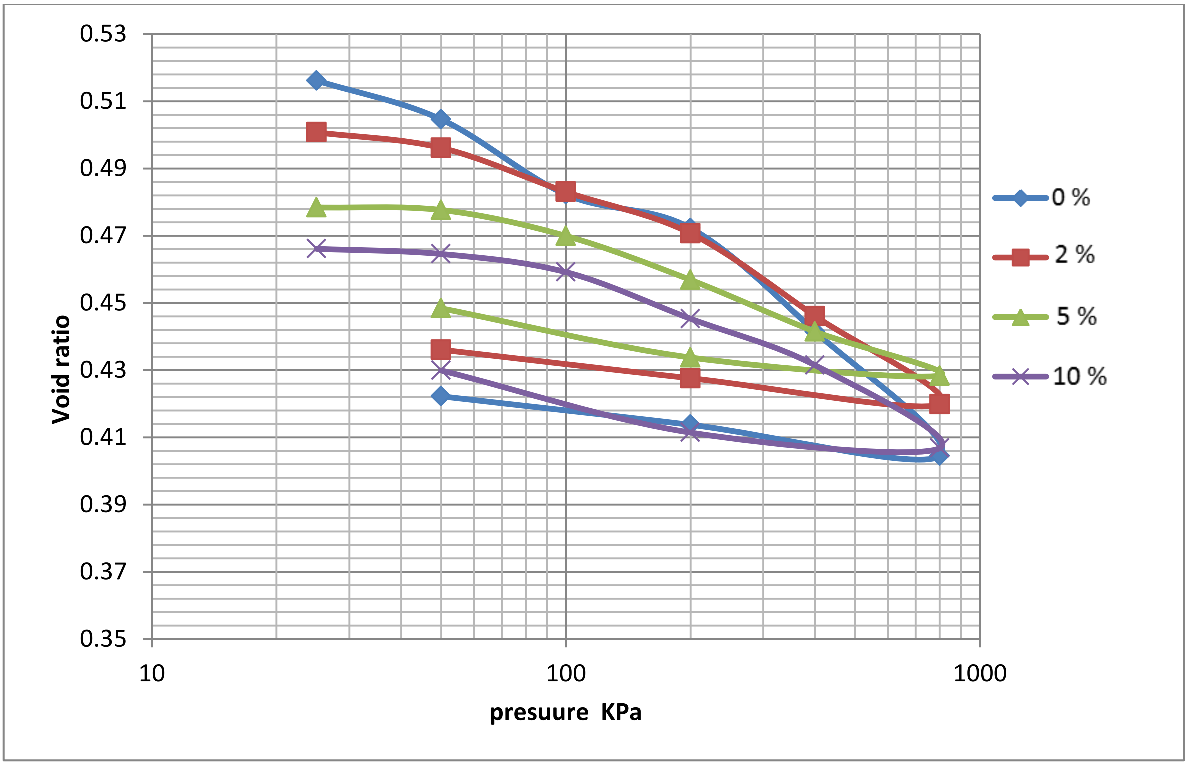

Figure 4-8 Effect of $MnSO_4$ concentration on void ratio-log pressure relationship.

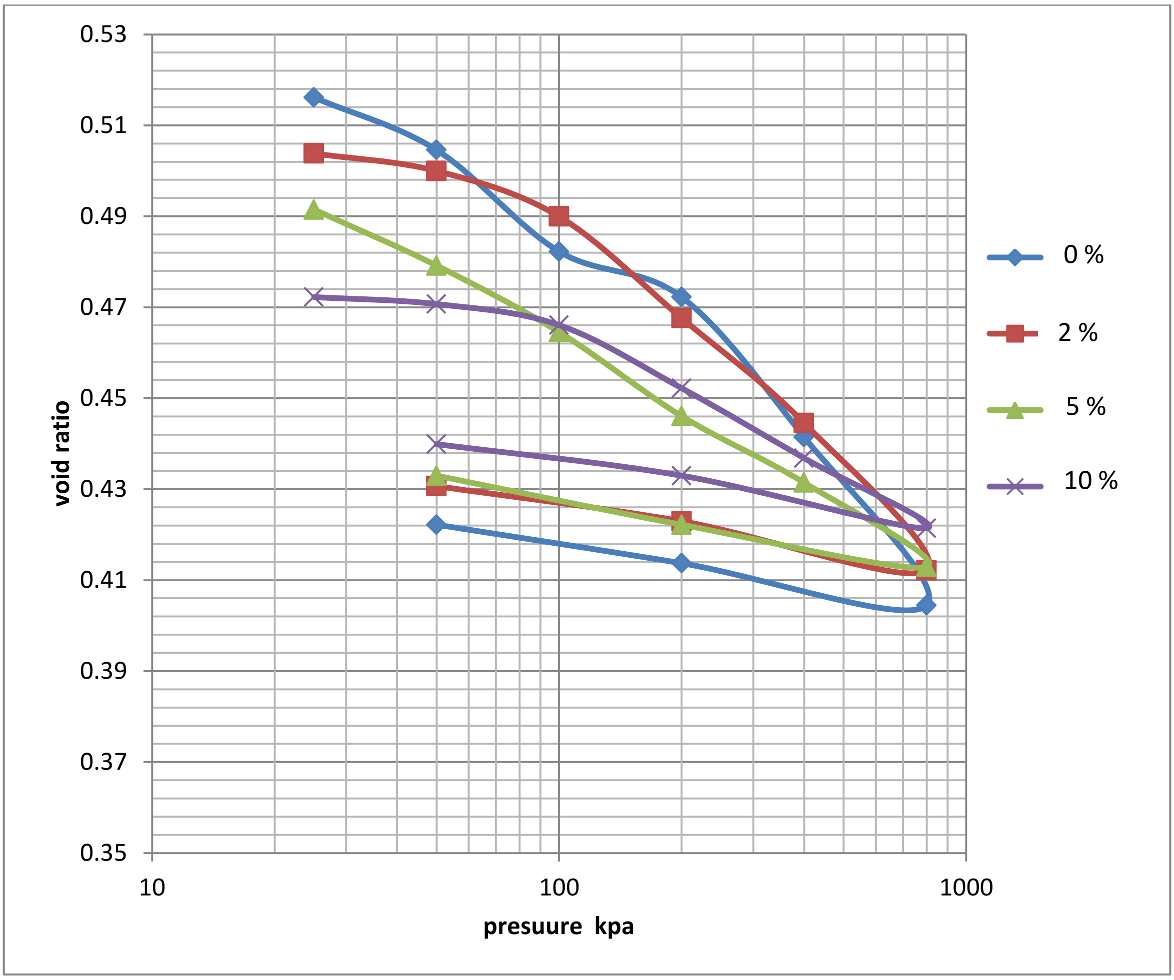

Figure 4-9 Effect of $FeCl_3$ concentration on void ratio-log pressure relationship.

Figures 4-10 and 4-11 present the effect of salt concentration on void ratio of clay mixed with $MnSO_4$ and $FeCl_3$ respectively. It can be seen that the void ratio decreased as the salt concentration increased for stresses up to 400 kpa while under 800 kpa the void ratio tends to increase then decreased to value nearby to initial value with $MnSO_4$ salt, and increased slighty with $FeCl_3$.

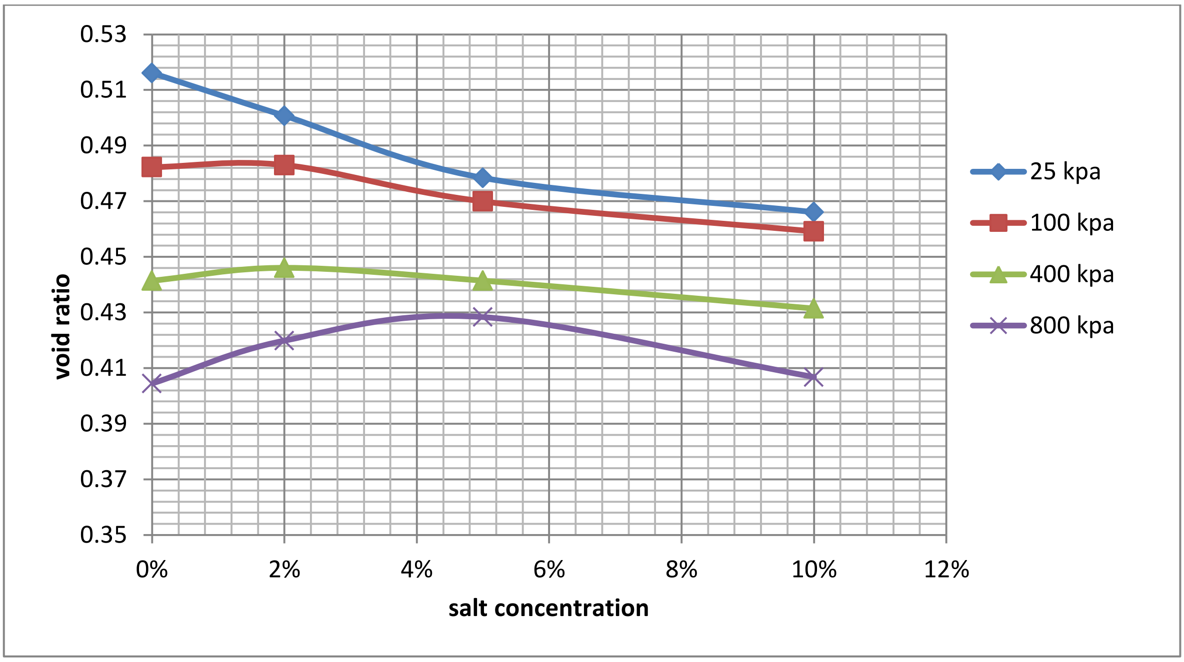

Figure 4-9Effect of $MnSO_4$ concentration on void ratio

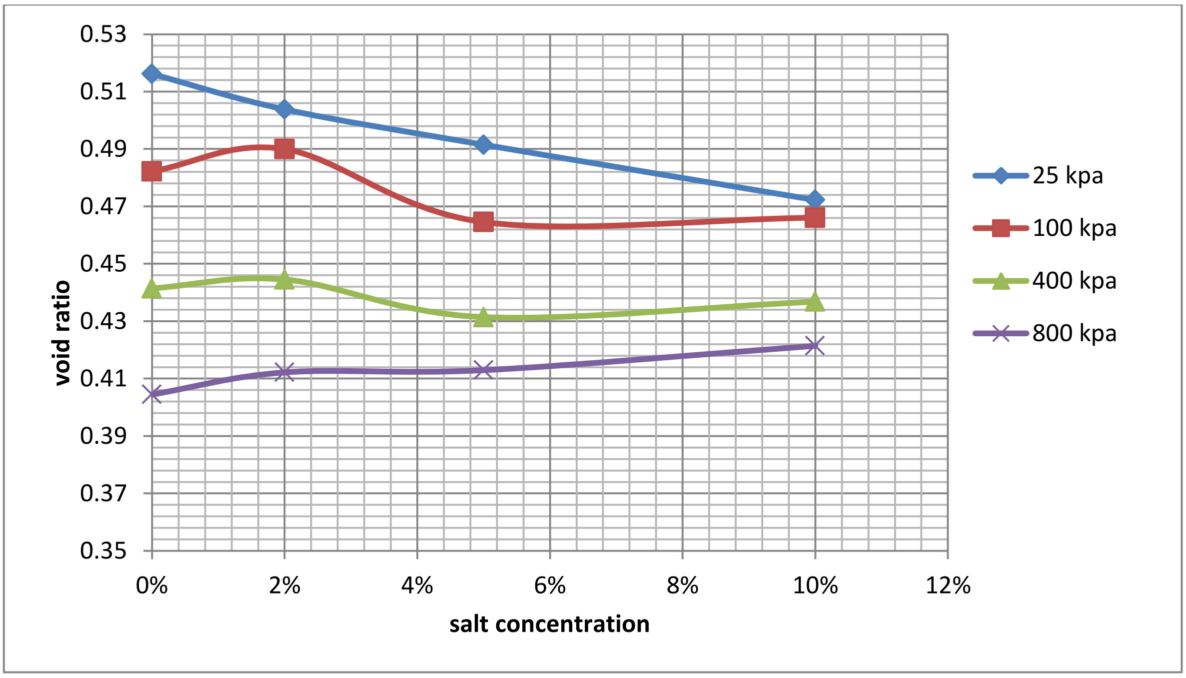

Figure 4-11 Effect of $FeCl_3$ concentration on void ratio

There are many reasons that lead to decrease the compressibility characteristics. **Lee et al., (2005)** stated that increases in the chemical concentration shrink the diffuse double layer, causing the flocculation of the clay particles and reduction compressibility characteristics.

Also, **Bowders Jr and Daniel., (1987)** stated that the chemical concentration tended to decrease the thickness of the diffuse double layer, resulting the soil skeleton to shrink and causing a reduction in repulsive forces, thus promoting flocculation of clay.

Figures 4-12 and 4-13 describ the effect of salt concentration on compression indices and swell indices respectively:

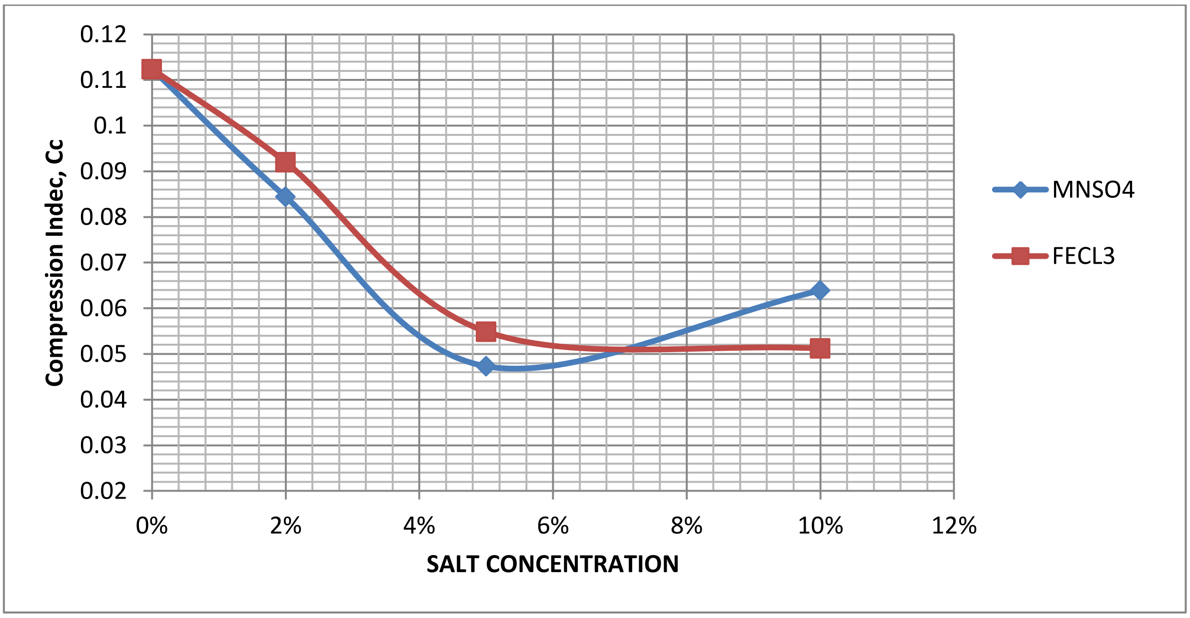

Figure 4-12 Effect of salt concentration on compression index

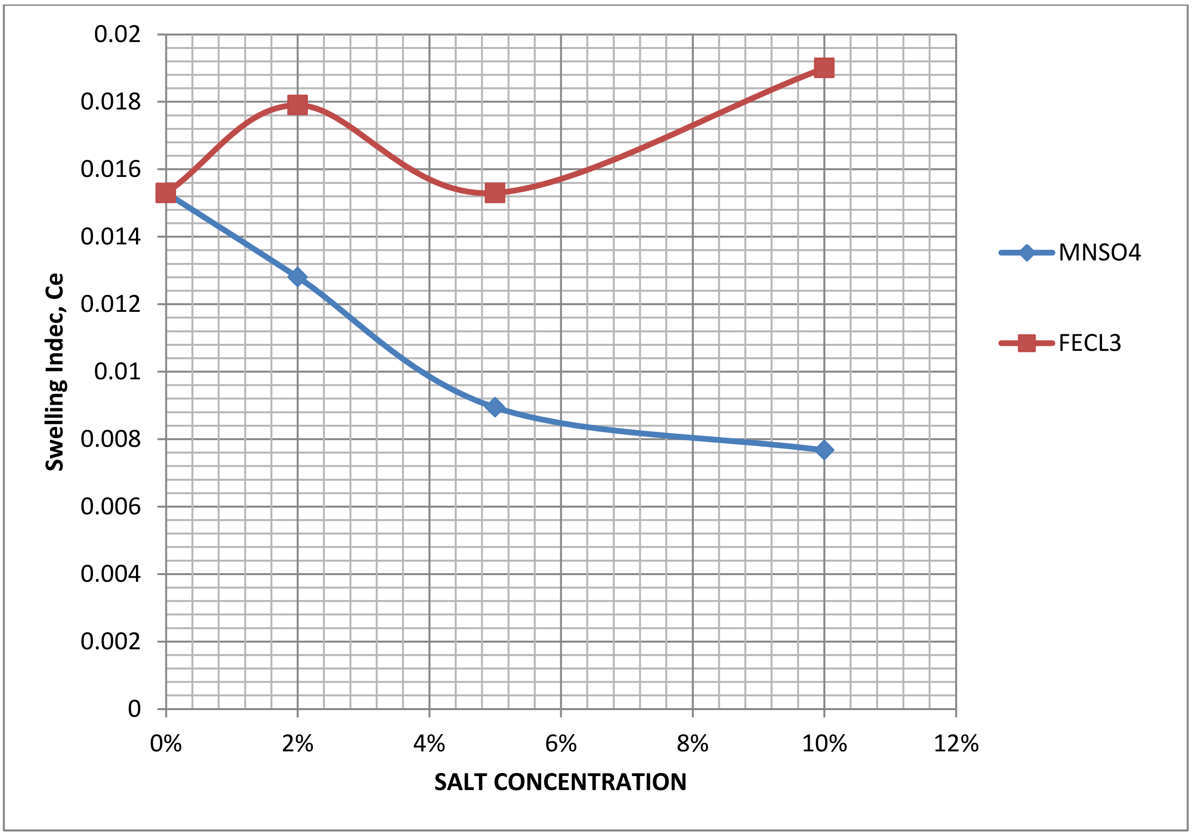

Figure 4-13 Effect of salt concentration on swelling index

From figure 4-13, it is obvious that the compression index for clay mixed with $MnSO_4$ and $FeCl_3$ decrease as salt concentration increase these observed for all concentration. Also from figure 4-13 it is noticed that the swelling index decrease as salt concentration increase for clay mixed with $MnSO_4$, while the swelling index for clay mixed with $FeCl_3$ increase slighty.

4.5 Permeability Characteristics:

The variation of permeability coefficient of clay permeated with different concentration of $MnSO_4$ and $FeCl_3$ is presented in figure 4-14.

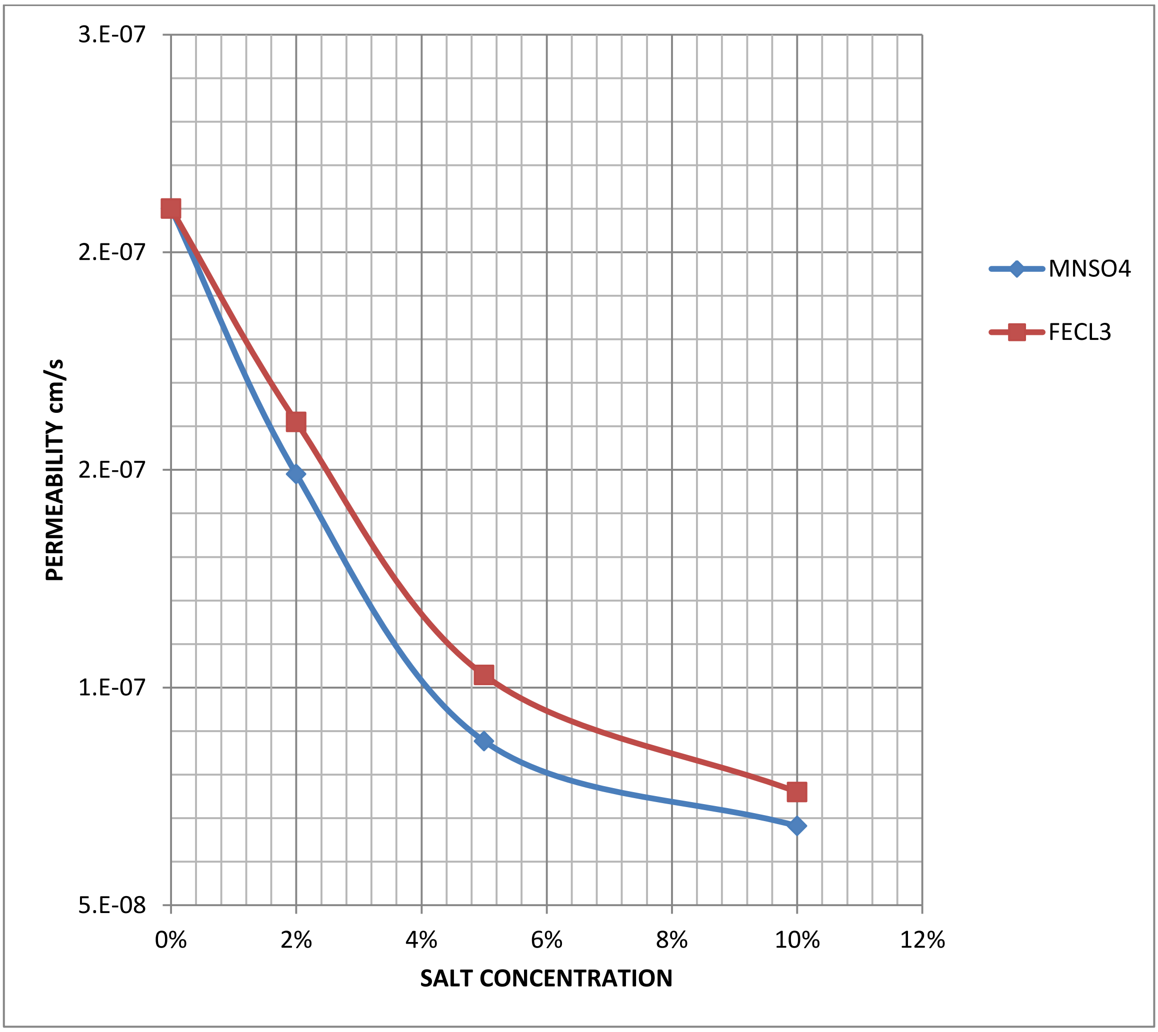

Figure 4-14 Effect of $MnSO_4$ and $FeCl_3$ concentration on permeability

Figure 4-14 shows that the permeability coefficient of clay permeated with $MnSO_4$ and $FeCl_3$ decrease as salt concentration increase. These was observed for all salt concentration. This result agrees with results reported by (**Alhassan, 2012) and (Yilmaz et al .,2008**).

The permeability of clay permeated with $MnSO_4$ decrease from $2.1\times^{-7}$ cm/s to reaches 6.82×10^{-8} cm/s at 10% concentration. When the same clay sample was permeated with $FeCl_3$ there was a decrease in the permeability of 2.1×10^{-7} cm/s to reaches 7.6×10^{-8} cm/s as shown in figure 4-14. Hence, the reduction in permeability can be attributed to the dispersion of the clay particles when low plasticity clay permeated with salt solution. **Sivapullaiah and manju(2005)** explained that the reason for the reduction permeability due to the formation of a new swelling type of compounds.

Park et al., (2006) after conducting the laboratory study of low plasticity kaolinite clay, indicated that the permeability reduced due to pore clogging and the high viscosity of the solutions. Similarly, **Petrov and Rowe (1997)** stated that the permeability of Geosynthetic Clay Liners (GCL) decreased as used the ethanol for less than 50% concentration, due to the increase in viscosity.

CONCLUSIONS AND RECOMMNDATIONS

5.1 Conclusions:

Compacted Clay Liners (CCL) are very important elment in constructing landfills. They have been used as for environmental protection purpose in many waste disposal facilities including municipal waste landfill. In landfill environmental, CCL are exposed to various surrounding environmental conditions and these conditions affect the chemical, physical and mineral properties. This study investigates the effect of different inorganic salt solutions on geotechnical properties of a soil system at the laboratory scale. The conclusion derived from this study can be listed as follows:

1- The study proved that the CL- clay (kaolinite) can be used as liner material for the construction of the MSW landfill site. Furthermore, according to these results, the CL-clay suitable for using as a compacted clay liner to be used in construction of landfill in Baghdad city.
2- The consistency limits increased as the concentration of inorganic salt increased. This is mainaly due to the effect of inorganic salt on the difuse double layer.
3- The Unconfined compressive strength increased as the concentration of $MnSO_4$ & $FeCl_3$ increased.
4- As the concentration of $MnSO_4$ &$FeCl_3$ increased from 2% to 5%, the compression index decreased ,after that the C_c nearly constant .

5- Swelling index tend to increased slighty as the concentration of $MnSO_4$ increased, while it decreased as the concentration of $FeCl_3$ increased.

6- Permeability coefficient tend to decreased as the concentration of $MnSO_4$ & $FeCl_3$ increased, this is a good recipes for material that are used a CCL.

5.2-Recommendations:

1- Studies should be conducted on clays after mixing with Leachate they may obtain from the landfill (Leachate generation in landfill contained different materials such as organic salt, inorganic salt, heavy metals and other materials).

2- Conducting mathematical modeling to study the stress and heat acting on the liner material since both factors do have an effect on the liner breakthrough time flow rate.

3- Conducting study to determine of the unsaturated permeability coefficient and the water storage function so as to obtain real experimental data for effective validation of the models.

References

Alawaji, H. A., 1999. Swell and compressibility characteristics of sand-Bentonite mixtures inundated with liquid. Appl. clay Sci., 15:411-430.

AL-Fares, R. 2011. Effects of Leachate-Soil Interaction on Shear Strength, Permeability, Compaction, and Chemical Characteristics. Journal of Environmental Systems, 33, 1.

Alhassan, M., 2012. Effect of Municipal Solid Waste on Geotechnical Properties of of soil. International Journal of Environmental Science, Management and Engineering Research, Vol.1 (5),pp.204-210.

AL-Jarallah, R. & AleIsa, E. 2014. A baseline study characterizing the municipal solid waste in the State of Kuwait. Waste Management, 34, 952-960.

AL-Salem, S. & Lettierei, P. 2009. Life cycle assessment (LCA) of municipal solid waste management in the state of Kuwait. European Journal of Scientific Research, 34, 395-405.

Alsamawi, A.A., Zboon, A.R.T. & Alnakeeb, A., 2009. Estimation of Baghdad Municipal Solid Waste Generation Rate.Journal science and technology,vol. 27, No.1, 2009.

Ajalloeian, R.2013, Effect of Saline Water on Geotechnical Properties of Fine-grained Soil. EJGE Vol.18, Bund.G

Arasan, S. & Yetimoğlu, T., 2008. Effect of inorganic salt solutions on the consistency limits of two clays. Turkish Journal of Engineering and Environmental Sciences, 32(2), pp.107–115.

Arasan, S. & Yetimoğlu, T., 2008. Effect of inorganic salt solutions on the consistency limits of two clays. Turkish Journal of Engineering and Environmental Sciences, 32(2), pp.107–115.

Arasan, S. 2010. Effect of chemicals on Geotechnical properties of clay liners: a review. Research Journal of Applied Sciences, Engineering and Technology, 2, 765-775.

Arasan, S. and T. Yetimoglu, 2006. Effect of Leachate Components on the Consistency Limits of Clay Liners. 11. National Soil Mechanic and Foundation Engineering Congress, Trabzon, Turkey, pp: 439-445 (In Turkish w ith an English summary).

ASTM standard.2007a. D 422-63 Standard test methods for particles-size analysis of soils. west Conshohocken, PA: ASTM international.

ASTM standard.2010a D 4318-00 Standard test methods for liquid limit, plastic limit and plasticity index of soil. West Conshohocken, PA:ASTM international.

ASTM standard.2003.D 5084 Standard test methods for measurement of hydraulic conductivity of saturated porous materials using a flexible wall Permeameter. West Conshohocken, PA:ASTM international.

ASTM standard. 2000.D 698 Standard test methods for laboratory compaction characteristic of soil using standard effort. West Conshohocken, PA: ASTM international.

ASTM standard. 2011b. D2435 -02 Standard test methods for one – consolidation properties of soil. West Conshohocken, PA:ASTM international.

ASTM standard.2002. D 854-02 Standard test methods for specific gravity of soil solids by water pycnometer. West Conshohocken, PA : ASTM international.

ASTM Standard.2002. D2166-00 Standard test method for unconfined compressive strength of cohesive soil. West Conshohocken, PA: ASTM international.

Rasoul Ajalloeian, Hadieh Monsouri and Amir Hossein Sadeghpour. Effeect of saline water on geotechnical proprteis of finr – grained soil. EJGE, vol.18(2013).

Ayininuola, G. M., O.A. Agbedeand S.O. Franklin, 2009. Influence of calcium sulphate on subsoil cohesion and angle of friction J. Appl. Sci. Rci.,, 5(3):297-304.

Ayininuola, G.M., & O.A. Agbede, 2013. Influence of Inorganic Salts on Soils Liquid and Plastic Limits.civil engeneering Dimension , 15(1), pp.51–60.

Bowders JR, J. J. & Daniel, D. E. 1987. Hydraulic conductivity of compacted clay to dilute organic chemicals. Journal of Geotechnical Engineering, No 113, 1432-1448.

Chiang, L.-C., Chang, J.-E. & WEN, T.-C. 1995. Indirect oxidation effect in electrochemical oxidation treatment of landfill leachate. Water Research, 29, 671-678.

Daniel, D. E. 1984. Predicting hydraulic conductivity of clay liners. Journal of Geotechnical Engineering, ASCE, 110, 285-300.

Daniel, D.E.,H.M. Lilijestrand, G.P. Broderick and J.J. Bowders,1988. Interaction of earthen liner material with industrial waste leachate .Hazard. waste Hazard mater.ASCE, 5(2):93-107.

Daniel, D. E. & Wu, Y.-K. 1993. Compacted clay liners and covers for arid sites. Journal of Geotechnical Engineering, 119, 223-237.

Deng, Y. & Englehardt, J. D. 2006. Treatment of landfill leachate by the Fenton process. Water research, No 40, 3683-3694.

Diamantis, V. 2013. Wastewater disposal to landfill-sites: A synergistic solution for centralized management of olive mill wastewater and enhanced production of landfill gas. Journal of environmental management, 128(1), pp.427-34.

DI Bella, G., DI Trapani, D. & Viviani, G. 2011. Evaluation of methane emissions from Palermo municipal landfill: Comparison between field measurements and models. Waste management, No 31, 1820-1826.

Endene, C. E. 2015. Engineering geological evaluation of Mfensi and Afari clay deposits for liner applications in municipal solid waste containment systems. ". M.Sc.Thesis,College of Engineering, University of Geological Engineering, Kwame Nkrumah University of Science and Technology.

Gallas, J. D. F., Taioli, F. & Malagutti Filho, W. 2011. Induced polarization, resistivity, and self-potential: a case history of contamination evaluation due to landfill leakage. Environmental earth sciences, 63, 251-261.

Geismar, J. H. 2014. Landfill and Health, a Municipal Concern or, Telling it Like it Was. Northeast Historical Archaeology, 16, 3.

George, M., 2011Geotechnical characteristics of leachate-contaminated lateratic. , Proceedings of Indian Geotechnical Conference. (Paper No.L-325.).

Gleason, M. H., Daniel, D. E. & Eykholt, G. R. 1997. Calcium and sodium bentonite for hydraulic containment applications. Journal of Geotechnical and Geoenvironmental Engineering, 123, 438-445.

Holtz, W.G.(1953), Construction of compacted soil linings for canals. proceedings of Third International conference on soil mechanics and foundation engineering. Vol 1-pp.142-146

Ince, M., Senturk, E., Onkal Engin, G. & Keskinler, B. 2013. Landfill leachate treatment in jet-loop membrane bioreactor operated under different organic loading rates. International Journal of Environmental Research, 7, 727-734.

Ismail,R.,Al-mattarneh, H., Sidek, l.,Zain, M. and Taha, M. 2008-Dielectric properties of soilcontaminated by solid waste leachate in the frequency range of 100kHZ to1000KHZ.ICCBT, 35, PP.373-80

Jefferson, I. & Rogers, C. D. F. 1998. Liquid limit and the temperature sensitivity of clays. Engineering geology, 49, 95-109.

Jo, H. Y., Katsumi, T., Benson, C. H. & Edil, T. B. 2001. Hydraulic conductivity and swelling of nonprehydrated GCLs permeated with single-species salt solutions. Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 127, 557-567.

Jo,H.Y., Katsumi, T., C.H.Benson, C.D, Shackelford, J.M. Lee and T.B. Edil, 2005. Long- term hydraulic condactivity of geosynthtic clay liner permeated with inoraganic salt salution-J. Geotech. Geoenviron.Eng, 131(4):405-417.

Lawal, A. & Abdullahi, Y. 2010. Evaluation of industrial potentials of alluvial clays from the confluence of rivers Niger and Mimi. Science World Journal, 5.No3.pp.17-20

Lee, J. & Shackelford, C.D., 2005. Impact of Bentonite Quality on Hydraulic Conductivity of Geosynthetic Clay Liners.ASCE , 131(1), pp.64–77.

Lee, J.-M., Shackelford, C. D., Benson, C. H., JO, H.-Y. & Edil, T. B. 2005. Correlating index properties and hydraulic conductivity of geosynthetic clay liners. Journal of Geotechnical and Geoenvironmental Engineering, 131, 1319-1329.

Lin, L.-C. & Benson, C. H. 2000. Effect of wet-dry cycling on swelling and hydraulic conductivity of GCLs. Journal of Geotechnical and Geoenvironmental Engineering, 126, 40-49.

Mahdi, S. A. 2015. Enviromental Impact Assessment of Virtual Sanitary landfill site". M.Sc.Thesis,College of Engineering, University of Technology.

McDougall, F. R., White, P. R., Franke, M. & Hindle, P. 2008. Integrated solid waste management: a life cycle inventory, John Wiley & Sons.

Mitchell J. K. 1993. Fundamentals of soil behavior.2nd Edn., Johan wiley and Sons Inc., New York.

Matthew, A. & Akinyele, A., 2014. Sodium and Calcium Salts Impact on Soil Permeability. Journal of Earth Sciences and …, 4(3), pp.37–45. Available at: http://www.scienpress.com/Upload/GEO/Vol 4_3_3.pdf

Mosavat, N. & Nalbantoglu, Z., 2013. The impact of hazardous waste leachate on performance of clay liners. Waste management & research : the journal of the International Solid Wastes and Public Cleansing

Milosevic, N., Thomsen, N. I., Juhler, R. K., ALbrechtsen, H.-J. & Bjerg, P. L. 2012. Identification of discharge zones and quantification of contaminant mass discharges into a local stream from a landfill in a heterogeneous geologic setting. Journal of Hydrology, 446, 13-23.

Ojuri, O. O. & Akinwumi, I. I. 2012. Influence of Nitrate Contamination on the Swell and Compressibility Characteristics of a Tropical Clayey Soil. European Journal of Scientific Research, 87, 585-595.

Naeini, S.A. & Jahanfar, M.A., 2011. Effect of Salt Solution and Plasticity Index on undrain Shear Strength of Clays. International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering Vol:5, No:1, pp.982–986.

Nayak, S., Sunil, B.M. & Allamaprabhu, K., 2014. Assessment of Blended Lithomargic Clay as Landfill Liner Material. , 2(4), pp.102–117.

Nayak, S.,Sunil, B.M & Shrihari, J.2007. Hydraulic and compaction characteristics of leachate –contaminated lateritic soil .Engineering Gelogy, 94,pp.137-34

Park, J., Vipulanandan, C., KIM, J. W. & OH, M. H. 2006. Effects of surfactants and electrolyte solutions on the properties of soil. Environmental geology, 49, 977-989.

Petrov, R. J. & Rowe, R. K. 1997. Geosynthetic clay liner (GCL)-chemical compatibility by hydraulic conductivity testing and factors impacting its performance. Canadian Geotechnical Journal, 34, 863-885.

Petrov, R.J. & Rowe, R.K., 1997. Geosynthetic clay liner (GCL) – chemical compatibility by hydraulic conductivity testing and factors impacting its performance. Canadian Geotechnical Journal, 34, 863-885.

Rahman, F. 2000. Hydraulic conductivity and chemical compatibility of some victorian soils used as liners for waste containment. "M.Sc.Thesis,College of Engineering, University of victordv university of technology.

Renou, S., Givaudan, J., Poulain, S., Dirassouyan, F. & Moulin, P. 2008. Landfill leachate treatment: review and opportunity. Journal of hazardous Materials, 150, 468-493.

Renou, S., Givaudan, J., Poulain, S., Dirassouyan, F. & Moulin, P. 2008. Landfill leachate treatment: review and opportunity. Journal of hazardous materials, 150, 468-493.

Resmi, G., Thampi, S. G. & Chandrakaran, S. 2011. Impact of lead contamination on the engineering properties of clayey soil. Journal of the Geological Society of India, 77, 42-46.

Robinson, H.D and P.J Maris, 1979. Leachate from domestic waste: Generation, composition and treatment. A review . water research center(WRC) Technical Report TR 108.p.p: 38

Saleh, A. A. 2005. The suitability of the Libyan soils for use as engineered landfill liners. ", M.Sc.Thesis,College of Engineering, University of loughborough,

Salah,M.J.& Ahmed.I.A,2010, The "analysis of the proplem of waste transportation using the model of transport in the city of Baghdad(case study)".

Safari, E. & Baronian, C. 2002. Modelling temporal variations in leachate quantity generated at Kahrizak landfill. International Environmental Modelling and Software Society (IEMSS) Switzerland. pp. 482- 485.

Safari, E. & Baronian, C. 2002. Modelling temporal variations in leachate quantity generated at Kahrizak landfill. International Environmental Modelling and Software Society (IEMSS) Switzerland. pp. 482- 485.

Schmitz, R. M., Schroeder, C. & Charlier, R. 2004. Chemo–mechanical interactions in clay: a correlation between clay mineralogy and Atterberg limits. Applied clay science, 26, 351-358.

Sanjeev.S.& Arun .P.2007. Effect of chemicals on compacted clay liner.EJGE Vol.12 , Bund .D

Shackelford, C. D., Benson, C. H., Katsumi, T., Edil, T. B. & Lin, L. 2000. Evaluating the hydraulic conductivity of GCLs permeated with non-standard liquids. Geotextiles and Geomembranes, 18, 133-161.

Sharma, H. D and Lewis, S. P. (1994), Waste Containment System. Waste Stabilization and Landfill, design and evaluation. John Wiley and sons Inc., Canada. 588pp.

Sivapullaiah, P. V. & Manju, A. 2005. Kaolinite–alkali interaction and effects on basic properties. Geotechnical & Geological Engineering, 23, 601-614.

Sridharan, A. & Prakash, K. 2000. Percussion and cone methods of determining the liquid limit of soils: controlling mechanisms.Geotech. Test .J.,23(2):263-244.

Sridharan, A., S.M . Rao and N.S. Murthy, 1986. Compressibility behavior of homoionized bentonites. Geotechnique, 36(4): 551-564.

Sunil, B., Shrihari, S. & Nayak, S. 2009. Shear strength characteristics and chemical characteristics of leachate-contaminated lateritic soil. Engineering Geology, 106, 20-25.

Sunil, B., Shrihari, S. and Nayak, S. 2008. Soil-Leachate Interaction and Their Effects on Hydraulic Conductivity and Compaction Characteristics. In International Association for Computer Methods and Advances in Geomechanics. India, 2008.

Shariatmadari, N., Salami, M. & Fard, M.K., 2011. Effect of inorganic salt solutions on some geotechnical properties of soil-bentonite mixtures as barriers. International Journal of Civil Engineering, 9(2), pp.103–110.

Sheela, Y. & Ann, R., 2010. Effect of Leachate on the Engineering Properties of Different Bentonites. Indian Geotechnical Conference – , pp.377-380.

Sujatha, E.R., Gurucharan R., Ramprasad C. Sornakumar V,2013. Impact of Municipal Solid Waste Dumping on the Geotechnical Properties of Soil and Ground Water in Ariyamangalam, Trichy, India.EJGE,vol.18 , pp.2119–2132.

Sitaram Nayak 1, B. M. S., ALlamaprabhu.K *3 2014. Assessment of Blended Lithomargic Clay as Landfill Liner Material. Current Advances in Civil Engineering, Vol 2, No 4. pp. 102 – 117.

Thomsen, N. I., Milosevic, N. & Bjerg, P. L. 2012. Application of a contaminant mass balance method at an old landfill to assess the impact on water resources. Waste Management, 32, 2406-2417.

Thiruvenkatachari ,R., vigneswaran,S.&Naidu, R.2008. permeable reactive barrier for groundwater remediation . Journal of Industrial and Engineering chemistry , 14(2), pp.145-56.

Vanda, Y., 2014. Effect of Pore Water Chemistry on Hydro- Mechanical Behavior of Compacted Expansive Clay. M.Sc.Thesis,College of Engineering, University of Eastern Mediterranean University.

Xuede, Q., Koemer, R., and Donald, H., G 2002. Geotechnical Aspects of Landfill Design and Construction. Prentice Hall. Upper Saddle River, New Jersey 07458.

Yilmaz, G., Yetimoglu, T. & Arasan, S., 2008. Hydraulic conductivity of compacted clay liners permeated with inorganic salt solutions. Waste management & research : the journal of the International Solid Wastes and Public Cleansing Association, ISWA, 26(5), pp.464–73. Available at: http://www.ncbi.nlm.nih.gov/pubmed/18927065