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EFFECTS OF INORGANIC SALT SOLUTION ON SOME PROPERTIES OF COMPACTED CLAY LINERS

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Abstract

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 inorganic salt solutions will be investigated. These solutions 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 results show that the consistency limits and unconfined compressive strength increased as the concentration of salts increased. While the permeability tends to decrease as salt concentration increased. Also, the compression index decreases as the concentration increased from 2% to 5%. The swelling index tends to increase slightly as the concentration of $MnSO_4$ increased, while its decrease as the concentration of $FeCl_{3.}$ In this paper, it is aimed to investigate the performance of compacted clay liner exposed to the certain chemicals generated by the leachate and their effects on the geotechnical properties of compacted clay liner such consistency limits, permeability coefficient, compressibility characteristics and unconfined compressive strength.

Keywords: Inorganic salts, compacted Clay, liners, Engineering properties.

1. Introduction

Landfills used as an engineering system for the disposal of waste and prevent 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 groundwater, as well as prevent the emission of gas into the atmosphere. Mitchell [1] showed that the mechanicals and hydraulic behavior of clay soil can be strongly affected by the clay-fluid system interaction. For this reason

Nomenclatures

C_c	Compression Index
C_e	Swelling Index
G_s	Specific Gravity
k	Permeability Coefficient, cm/s
L.L	Liquid Limit, %
P.L	Plastic Limit, %
P.I	Plasticity Index, %
q_u	Unconfined Compressive Strength, kPa

Greek Symbols

ρ_{dmax}	Maximum dry density gm/cm^3
w	Water content, %

Abbreviations

CCL	Compacted Clay Liner
CH	High plasticity clay
CL	Low plasticity clay
GCL	Geosynthetics Clay Liner
L.L	Liquid Limit
MSW	Municipal Solid Waste
O.M.C	Optimum Moisture Content
P.I	Plasticity Index
P.L	Plastic Limit
UCS	Unconfined Compressive Strength
USCS	Unified Soil Classification System

to properly use the compacted raw clay as impermeable liners, more theoretical and experimental study is needed to investigate the variation of hydraulic conductivity, consistency limits, consolidation, shear strength with chemicals.

Most of the researchers had shown that the consistency limit increased when the concentration of salt solution increased for CL-clay [2 - 4] other researchers [5 - 12] stated that the liquid limit decreases when salt concentration was increased for CH-clay.

Al-Hassan [13] studied the contaminated soil by leachate from Municipal Solid Waste (MSW), he shows that the contaminated soil generally has relatively lower consistency limits than the uncontaminated soil.

Sheela and Ann [14] studied the effect of Acetic acid and calcium chloride solution as components of leachate on differents type of Bentonites. They show that the liquid and plasticity indices decreased with an increase of the concentration of Acetic Acid and calcium chloride for all type of Bentonites.

Ayininuola and Agbede [15] studied the presence of inorganic salts such as NaCl, $CaSO_4$ and KNO_3 with different concentration added to the subsoil, he shows that after the soil was contaminated with these salts, both plastic limit and liquid limit decreased due to the presence of NaCl and KNO_3, on the other hand, they increased due to presence $CaSO_4$.

Sunil et al. [16] studied the effect of leachate on lateritic soil at different concentration 5%, 10% and 20% by weight of soil. They show that there is a slight increase in cohesion and a decrease in friction angle as the concentration increased and also there is an increase in the liquid limit and plasticity indices as the concentration increased.

Ayininoula et al. [17] had shown that there is an increase in friction angle and cohesion when subsoil saturated with $CaSO_4$ at different concentration.

Naeini and Jahanfar [18] studied the effect of inorganic salt on the shear resistance of clay. They used different solution concentrations of NaCl (0-10%). As the concentration of NaCl increased up to 2%, the undrained shear strength increased then it decreased as the concentration of NaCl continues to increase up to 10%.

Also, AL Fares [19] studied the effect of landfill leachate on the natural soil in Kuwait. He found that the cohesion increased from 10 kPa to 17 kPa for uncontaminated soil, due to an increase of leachate concentration up to 5% by weight of dry soil with no significant change in the angle of friction. 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 [20] showed that the unconfined compressive strength increased as the NaCl and $CaCl_2$ salt concentration increased. The failure strain increase in NaCl added specimens, thus becoming more ductile, on the other hand in $CaCl_2$ the specimens become more brittle.

Ayininoula et al. [17] studied the behavior of subsoil saturated with $CaSO_4$ at different concentrations. They showed that the increase in salt concentration may lead to increase in friction angle and cohesion parameters. Ojuri and Akinwumi [21] studied the effect of high concentrations of heavy metals in the landfill leachate on the behavior of clayey soil in Nigeria. They show that the compression index and swelling index (*Cc* and *Ce*) decreased with an increase in the degree of nitrate concentration.

Similarly, Resmi et al. [22] studied the effect of artificially fed lead nitrate on uncontaminated clayey soil, they show that the values of the coefficient of consolidation (C_v) increase with increasing the concentration of lead. Vanda [20] studied the effect of inorganic salts (NaCl and $CaCl_2$) on consolidation parameter of clay when clay mixed with these salts; they concluded that there is a decrease in consolidation parameters when salt concentration increased.

Shariatmadri et al. [23] 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 concluded that the compression index (*Cc*) decrease with the increase in salt concentrations.

Alawaji [24] evaluated the swell potential, swell time, swell pressure and volume compressibility by oedometer test using various concentration of $Ca(NO_3)_2$ and $NaNO_3$, he observed that these parameters decreased with increasing salt concentration.

Shackelford et al. [25], Jo et al. [26] noticed that the swelling index of Bentonite was sensitive to the cation valence and/ or electrolyte concentration in a manner that was consistent with the change in the thickness of the adsorbed layer of the cation.

Sivapullaiah and Manju [4] studied the effect of five different inorganic salt solution (NaCl, NH4Cl, 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 while for CL-Clay, the hydraulic conductivity decreased when the concentration of the salt solution was increased, this was observed for all salt solution.

Many of researchers studied the hydraulic conductivity of higher activity clays such as Bentonite or geosynthetic clay liner (GCL) affected by salt solution, they reported that the hydraulic conductivity increases when the concentration of salt solution was increased [9, 25, 27, 28]

Also, it was noticed that the hydraulic conductivity of leachate-contaminated soil increased when the leachate concentration increased [16, 21, 29]. ALhassan [13] showed that the contaminated soil by leachate from MSW has higher values of coefficient of permeability than the uncontaminated soil.

Sujatha et al. [30] studied the effect of dumping municipal solid waste (MSW) on hydraulic conductivity of soil sampled from a differents location below the landfill, the result showed that there is a decrease in hydraulic conductivity as the dry density of the dumped MSW increased.

Yilmaz et al. [31] studied the effect of inorganic salt on hydraulic conductivity of CL - clay, they found that the hydraulic conductivity decreases with an increase in salt concentration.

2. Material and Sample Preparation

A commercial clay (kaolinite clay) CL - clay was used in this study. It brought from AL Anbar governorate - Iraq (quarries in the western desert). The main specifications of this clay have been represented in Table 1. Distilled water as well as two salt solutions, $MnSO_4$ and $FeCl_3$ had been used. The properties of these two salts are given in Table 2. The main reasons for choosing these two types of salts is to create solutions with Anions of (CL and SO_4) with (Fe and MN) heavy metals as these constituents were registered as a high concentration in Leachate generated in Baghdad city landfills.

Table 1. Chemical compositions of Kaolin.

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

*L.O.I (Loss of Ignition)

Table 2. The properties of salt used.

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

2.1. Particles size distribution:

The clay used has the grain size distribution curve shown in Fig. 1 and is classified as CL according to the Unified Soil Classification System (USCS). It is obvious that the maximum dry density is 1.665 g/cm^3 and the optimum moisture content (O.M.C) is 18.74%.

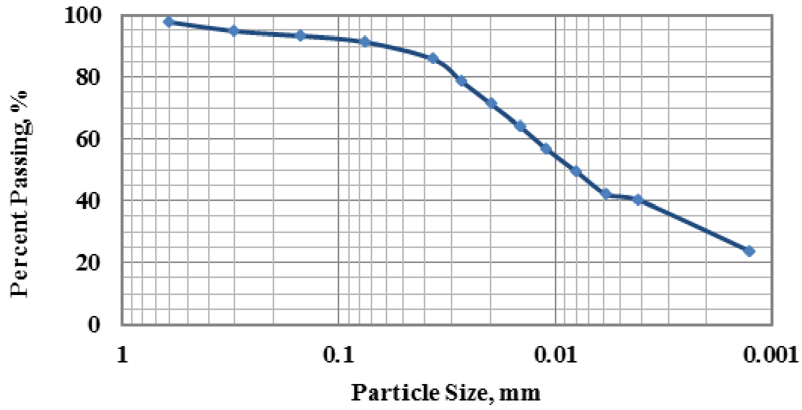

Fig. 1. Grain size distribution of clay used.

2.2. Preparation of specimens

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

Table 3. The engineering tests.

Soil properties	values	Standards
Liquid limit (L.L%)	35.58	ASTM:D- 4318
Plastic limit (P.L%)	17.39	ASTM:D- 4318
Plasticity index (P.I%)	18.19	ASTM: D- 4318
Falling head permeability test	2.1x10^{-7} cm/s	ASTM: D- 5084
Consolidation test	C_c = 0.1124 C_e = 0.0153	ASTM: D- 2435
Unconfined compressive strength	200 kN/m^3	ASTM:D- 2166

3. Result and Discussion

In this section, the effect of using different concentration of $MnSO_4$ and $FeCl_3$ on different properties of compacted clay used such consistency limits, shear strength, compressibility and permeability characteristics are presented.

3.1. Consistency limits:

Figures 2 and 3 show the variation of liquid and plastic limits as the concentration of inorganic salts $MnSO_4$ and $FeCl_3$ increased respectively. It is clear from the figures that both liquid limit (L.L) and plastic limit (P.L) increased as the salts concentration increased. The effect is more pronounced with a $MnSO_4$ solution than the $FeCl_3$ solution.

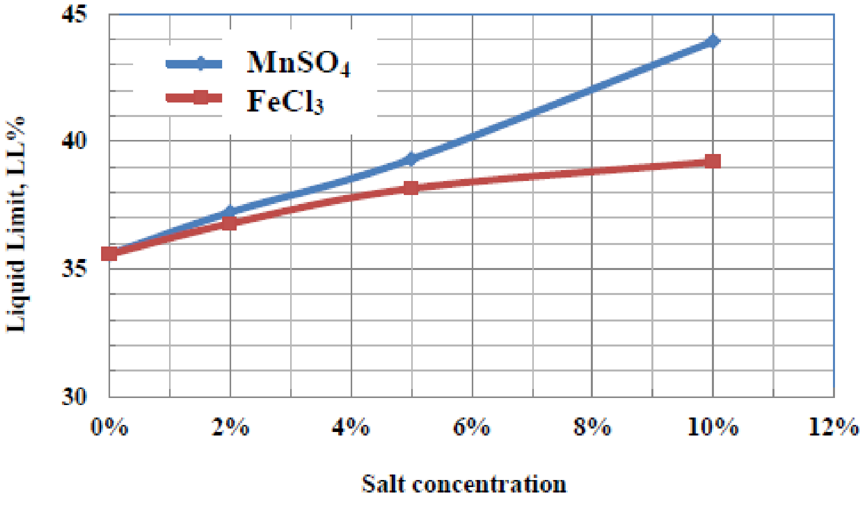

Fig. 2. Variation of Liquid Limit vs. salt concentration.

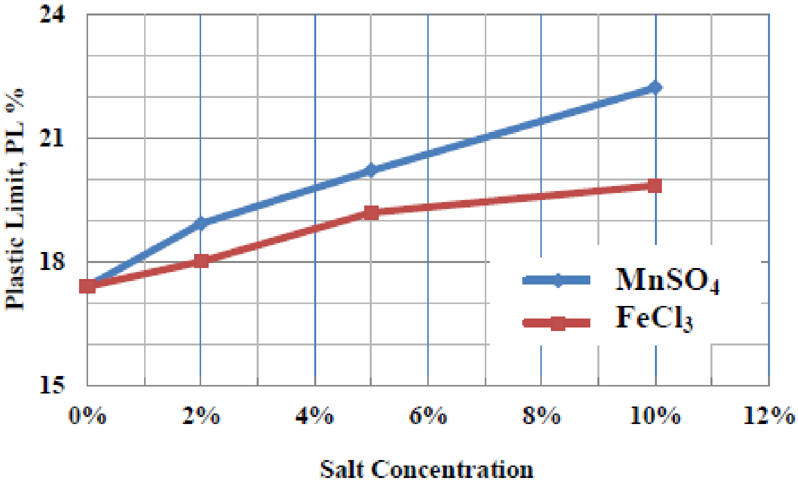

Fig. 3. Variation of plastic limit vs. salt concentration.

Consequently, the plasticity index increased as the salt concentration increased as shown in Fig. 4. The effect of $MnSO_4$ is more pronounced than the effect of $FeCl_3$.

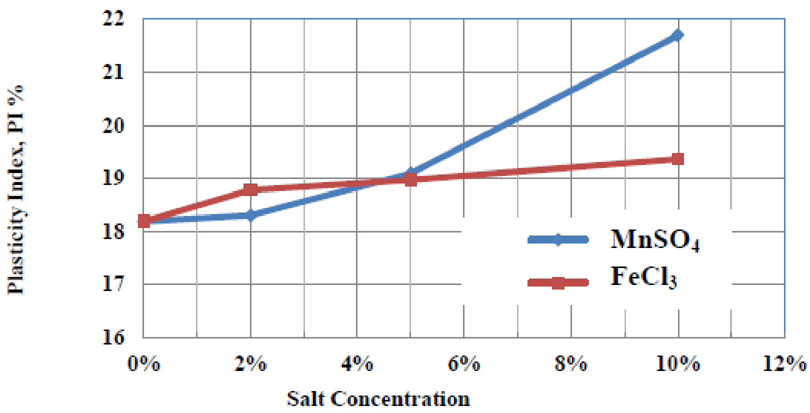

Fig. 4. Effect of salt concentration on plasticity index.

These results are in line with the requirements specified by [32] 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. These changes in consistency limits may interpret the changes in diffuse double layer (DDL) and fabric changes.

Similarly, Bowder and Daniel [6] showed 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 [33] stated that the net electrical forces between clay mineral layers were affected by the concentration valence of the 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 [4] stated that the salt solution may cause the formation of new swelling compounds and this new compound increased the liquid limit of clay.

3.2. Strength characteristics of the clay:

For both salts solution, as the salt concentration increased the unconfined compressive strength increased as shown in Fig. 5. This increase is a result of the interaction of clay with salt, the increase in the salt concentration causes an increase in the ion concentration of pore water followed by a reduction in the diffuse double layer. Furthermore, this causes a decrease in the antiparticles repulsion and an increase in the attraction.

Figures 6 and 7 show the stress-strain relationship of the clay as the salt concentration ($MnSO_4$ and $FeCl_3$) increased.

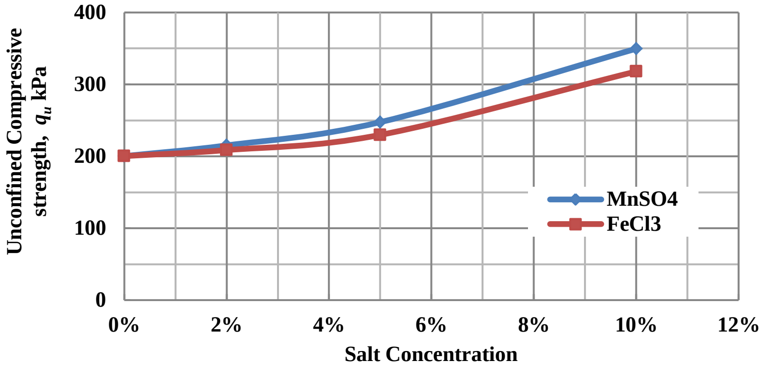

Fig. 5. Variation of Unconfined compressive strength vs. salt concentration

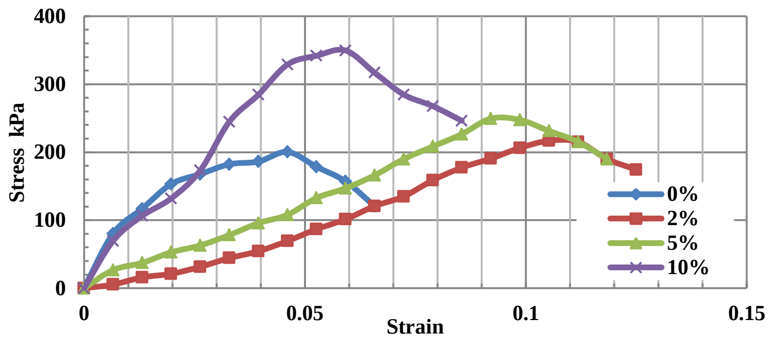

Fig. 6. Stress-strain relationships with different concentration of $MnSO_4$.

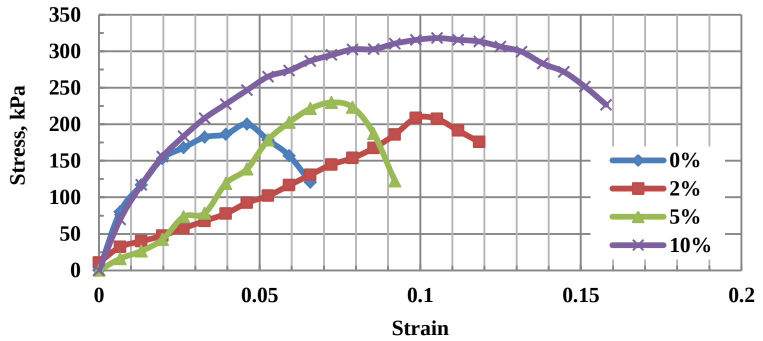

Fig. 7. Stress-strain relationships with different concentration of $FeCl_3$.

The strength characteristics of clay depend on cohesion which is the ability of particles to stick together as such porosity is being decreased and density increased. From the results, it is concluded that the clay contaminated with both salt solutions meets the strength requirement of not less than 200 kPa [34] recommended for use as the clay liner when tested with water and inorganic salt.

3.3. Compressibility characteristics:

Figures 8 and 9 show the e-log pressure of the clay obtained by odometer test with a different inorganic salt concentration of $MnSO_4$ and $FeCl_3$ respectively. It can be seen that as the salt concentration increased the compressibility of the soil decreased. This is as a result of the decrease of the electrical double layer surrounding the clay particles [35].

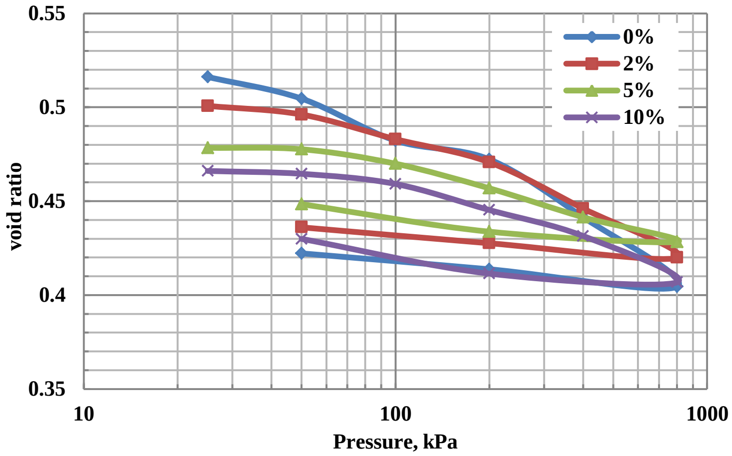

Fig. 8. Effect of $MnSO_4$ concentration on void ratio-log pressure relationship.

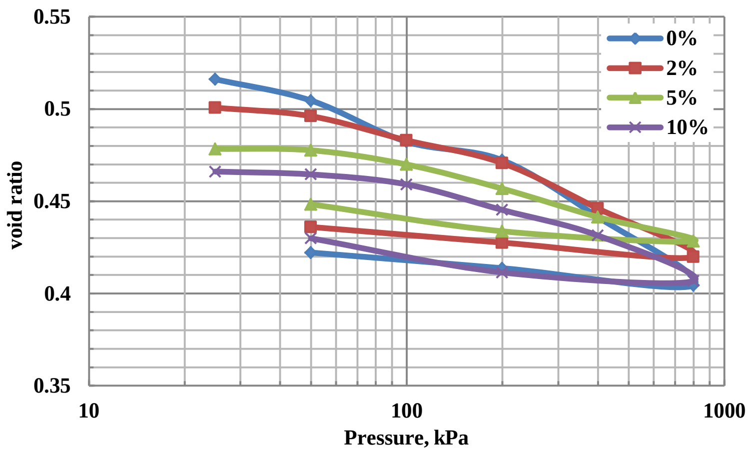

Fig. 9. Effect of $FeCl_3$ concentration on void ratio-log pressure relationship.

Figures 10 and 11 present the variation of the void ratio of clay contaminated with a different salt concentration of $MnSO_4$ 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 margined to initial value with $MnSO_4$ salt, and increased slightly with $FeCl_3$.

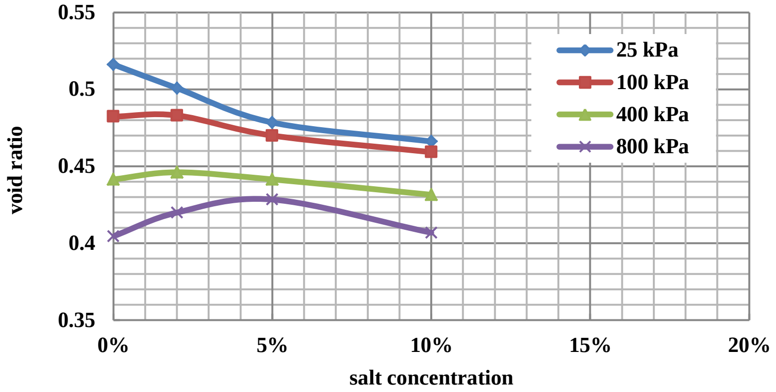

Fig. 10. Variation of void ratio for clay contaminated with different salt concentration of $MnSO_4$.

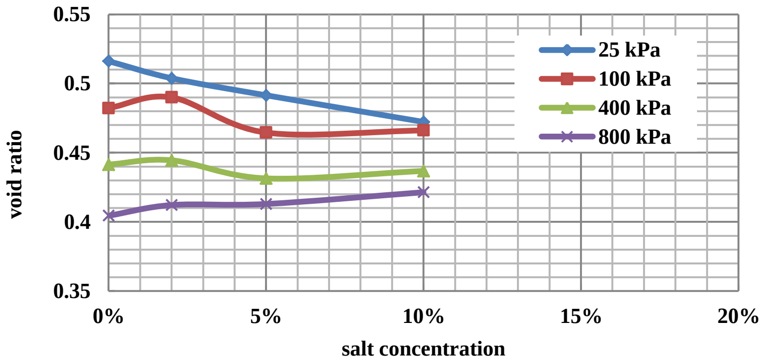

Fig. 11. Variation of void ratio for clay contaminated with different salt concentration of $FeCl_3$.

There are many reasons that lead to a decrease in compressibility characteristics. Lee et al. [28] stated that increases the chemical concentration shrink the diffuse double layer, causing flocculation of the clay particles and a reduction of compressibility characteristics.

Also, Bowders and Jr Daniel [6] stated that the chemical concentration tends 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 12 and 13 show the effect of salt concentration on the compression and swelling indices respectively.

From these figures, it is obvious that the compression index (C_c) for clay contaminated with $MnSO_4$ and $FeCl_3$ decreases as a salt concentration increases, besides the swelling index (C_e) decreases as a salt concentration increases for clay contaminated with $MnSO_4$ while it is increased slightly for a clay contaminated with $FeCl_3$.

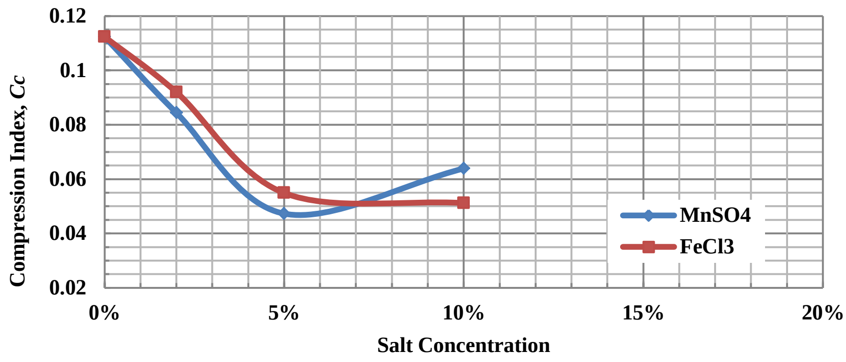

Fig. 12. Effect of salt concentration on compression index.

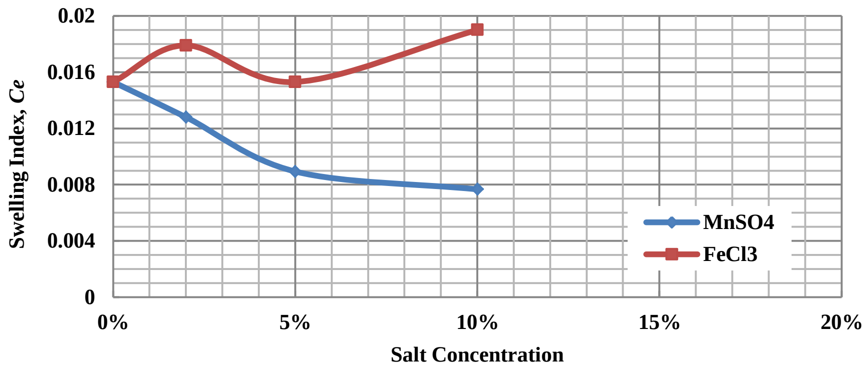

Fig. 13. Effect of salt concentration on swelling index.

3.4. Permeability characteristics:

The variation of permeability coefficient of clay contaminated with different concentration of $MnSO_4$ and $FeCl_3$ is presented in Fig. 14.

It is obvious that the permeability coefficient of clay contaminated with $MnSO_4$ and $FeCl_3$ decreases as salt concentration increased. This result agrees with results reported by [4, 13, 31, 36].

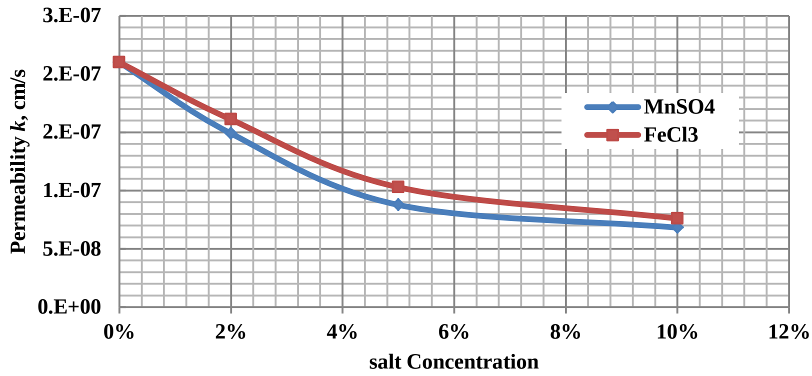

Fig. 14. Effect of salt concentration on permeability.

4. Conclusion:

Compacted Clay Liners (CCL) is very important facilities to design landfills. That has 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. In this study, the effect of the inorganic salt solution on Geotechnical properties of a soil system at the laboratory scale was investigated. The performance of the clay used is fine as a clay liner. The following conclusion could be derived from this study as follows:

- The consistency limits increased as the concentration of inorganic salt increased. This is mainly due to the effect of inorganic salt on the diffuse double layer.
- The unconfined compressive strength increased as the concentration of $MnSO_4$ and $FeCl_3$ increased.
- As the concentration of $MnSO_4$ and $FeCl_3$ increased from 2% to 5%, the compression index decreased, after that the Compression index is nearly constant.
- Swelling index tends to increase slightly (0.015 to 0.019) as the concentration of $FeCl_3$ increased, while decreased as the concentration of increased $MnSO_4$
- Permeability coefficient tends to decrease as the concentration of $MnSO_4$ and $FeCl_3$ increased this is a good recipe for material that is used a CCL.

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