Consistency and Compressibility Characteristics of contaminated Compacted Clay liners

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Abstract

Processed and natural clays are widely used to construct 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 on consistency and compressibility characteristics of compacted clay was investigated at different concentrations. Two type of inorganic salt $MnSO_4$ and $FeCl_3$ are used at different concentration 2%, 5%, and 10%. The Clay used was the CL- clay (kaolinite).

The result shows that the consistency limits increased as the concentration of salts increased, while the compression index (C_c) decreases as the concentration increased from 2% to 5%, after that the C_c is nearly constant. The swelling index (C_e) tends to increase slightly as the concentration of $MnSO_4$ increased, while it decreases as the concentration of $FeCl_3$ increased.

Key Words: consistency limit, compressibility, inorganic salts, clay liners,

خصائص القوام و الانضغاطية لترب البطانات الطينية الملوثة

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الخلاصة

تستخدم الترب الطينية المصنعة والطبيعية لتنفيذ بطانات غير نفاذة على نطاق واسع في مطامر القمامة للنفايات الصلبة. ان الخواص الهندسية للبطانات يمكن أن تتأثر كثيرا بالراشح من كتلة النفايات. في هذا البحث تم دراسة تأثير المحاليل الملحية غير العضوية الموجودة في الراشح على خصائص الهندسية للطين وبتراكيز مختلفة. تم استخدام نوعين من الاملاح غير العضوية MnSO4 و FeCl3 بتراكيز مختلفة 2٪، 5٪ و10٪ لكل منها. الطين المستخدم (الكاؤلينايت) وبتصنيف (CL).وأظهرت النتائج أن حدود القوام تزداد عند زيادة تركيز الاملاح الغير عضوية بينما مؤشر الانضغاطية يقل عند زيادة تركيز كل من $MnSO_4$ و $FeCL_3$ من 2% الى 5% وبعدها يبقى تقريبا ثابت. اما مؤشر الانتفاخية فأنه يزداد تدريجيا عند استخدام $MnSO_4$ بينما يقل عند استخدام $Fecl_3$

1. Introduction

Landfills used as an engineering system for the disposal of solid wastes and prevent their 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. There are many types of soil can be used in constructed of (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, and SC) in order to be suitable for using as a (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 (CCL) must be not less than 0.6m and that the materials used in the

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construct of compacted clay liner have a permeability of less than or equal to $1x10^{-7}$ cm/s. These are essential requirements to prevent the percolation of leachate into the groundwater and surrounding environment.

When solid waste placed in a landfill, pollutants may be generated called as Leachate. Leachate may be due to bio action of solid waste material in a landfill, as well as by squeezing of waste material by self-weight of wastes (Saleh, 2005).

Xuedeetal.,(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

Mitchell (1993) showed that the mechanical 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, consistency limits, consolidation, shear strength with chemicals. Atterberg limits have been appeared to be valuable pointers to the behavior of clay, (Jefferson and Rogers, 1998).

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

Alhassan (2012) studied the contaminated soil by leachate from Municipal Solid Waste (MSW), he shows that the contaminated soil generally has relatively lower consistency limits than these for uncontaminated soil.

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

Ayininuola and Agbede (2013) studied the presence of inorganic salt such as NaCl, $CaSO_4$, and $KNO_3$with different concentration added with subsoil, it was shown 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 of CaSO4.

Also, In study conducted on laterite soil with leachate from municipal solid waste at concentration 0, 25, 50, 75, 100% by weight, these study showed decrease of liquid limit and plastic limit (George, 2011)

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

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 has been shown 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) study the effect of artificially fed lead nitrate on uncontaminated clayey soil, they show that the values of the coefficient of consolidation (C_v) increasing with increasing concentration of lead.

Vanda, (2014) studied the effect of inorganic salts ($NaCl_2$and $CaCl_2$) on consolidation parameter of clay when clay mixed with these salt at 0.5m and 1m concentration; it was concluded that there was a decrease in consolidation parameter when salt concentration increased.

Shariatmadari et. al. (2011) investigated the effect of three different inorganic salts (NaCl, CaCl2, and $MgCl_2$) solution on some geotechnical properties of soil Bentonite mixtures as barriers, they conclude that the compression index (c_c) decrease with the increase in salt concentrations.

Alawaji,(1999) shows that the swell potential, swell pressure and pressure and volume compressibility when evaluated by oedometer test using various concentration of $Ca(NO_3)_2$ and $NaNO_3$, these study indicated that the compressibility decreased with increased of salt concentration.

Shackelford et. al., (2000) and Jo et. al., (2001) observed that the swelling index of Bentonite was delicate to the valence of the cation and/ or concentration of electrolyte in a way that was consistent with the variation in the thickness of the adsorbed layer of the cation.

2. Materials

A commercial clay (kaolinite clay) CL-clay was used in this study. It brought from AL Anbar governorate (quarries in the western desert). The main specifications of this clay have been represented in Table 1

Table 1. Chemical Compositions of Kaolin

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

*L.O.I (Loss of Ignition)

Two types of inorganic salts $MnSO_4$ and $FeCl_3$ solutions had been used. The properties of these two salts are given in Table 2.Table 3 show the properties of clay used.

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

Table 3. The Properties of clay used (kaolinite)

Soil properties	Index	Standards
Specific gravity (Gs)	2.66	ASTM:D- 854
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
Maximum dry density(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 (1) shows The grain size distribution curve of the clay used. The soil was classified as CL according to the Unified Soil Classification System (USCS).

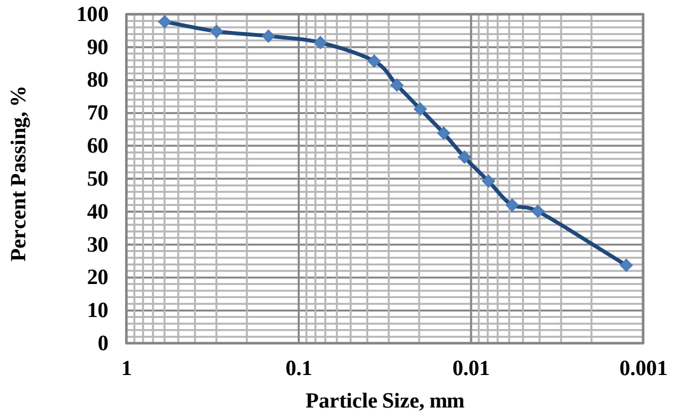

Figure 1. Grain size distribution of clay used (kaolinite)

The maximum density of the clay 1.665 g/cm^3 and the optimum moisture content is 18.74% as shown in the Fig. 2.

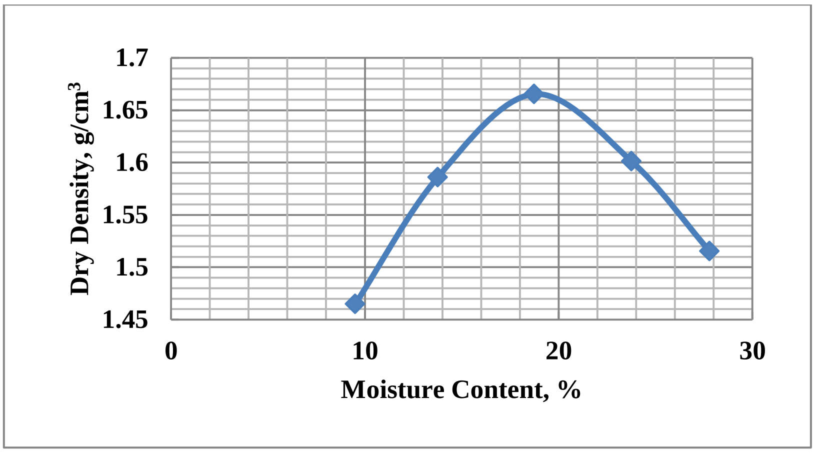

Figure 2. Moisture -Density Relationship of clay

3-Preparation of Specimens

Samples were prepared by blending soil 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 1.665 g/cm^3. The compaction 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 hours to reach moisture /chemicals equilibrium before conducted the tests.

4. Methods and techniques:

4.1 Consistency limit:

The tests were performed according to standard procedures outlined in ASTM D4318-00. Taking portions of specimens with different concentrations of salts ($MnSO_4$ and $FeCl_3$) to determine liquid and plastic limits and to estimate the plasticity index.

4.2 Consolidation test:

The test was performed according to the ASTM D2345-03 on specimens taken from the compacted soil with different concentration of salts ($MnSO_4$ and $FeCl_3$) after they were merged in for 72 hrs as mentioned in Art.3. The specimens were loaded up to 800 kPa and then unloaded to estimate the (compression index Cc and swelling index Ce).

3. Results and Discussions

Effect of inorganic salt on Consistency limits:

Figures 3 and 4 shows 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 consistency limits (liquid limit (L.L) and plastic limit (P.L)) were increased as the concentration of salts increased. The effect is more pronounced with a $MnSO_4$ solution than the $FeCl_3$ solution.

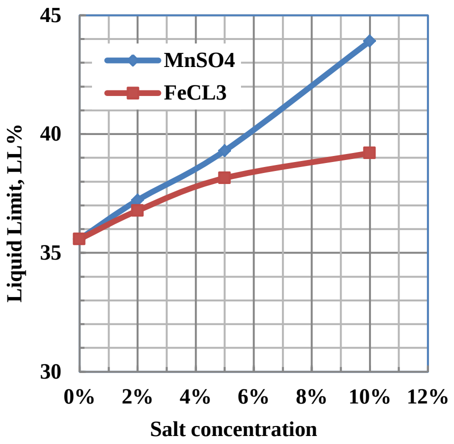

Figure 3. Variation of Liquid Limit vs. salt concentration

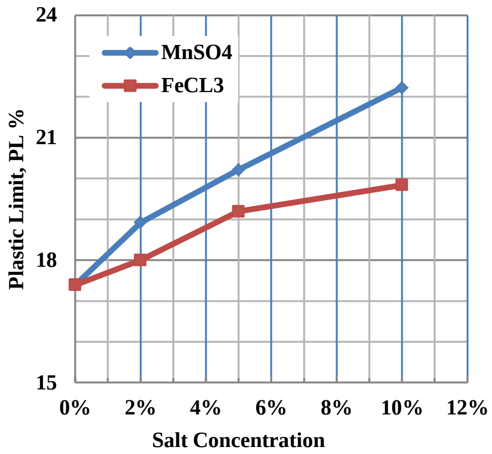

Figure 3. Variation of plastic limit vs. salt concentration

Consequently, the plasticity index increased as the salt concentration increased as shown in figure (5). The effect of $MnsO_4$ is more pronounced than the effect of $FeCl_3$.

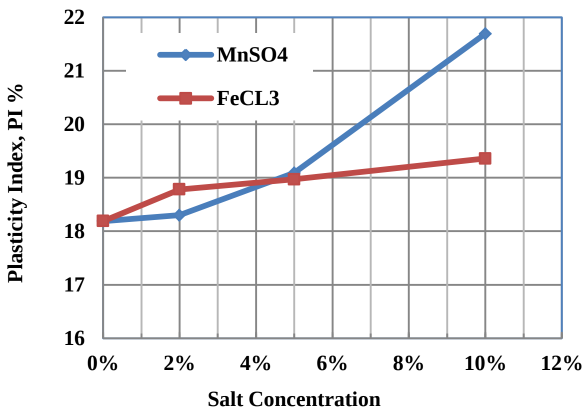

Figure 5. Effect of salt concentration on plasticity index

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 (non-swelling) clays and diffuses double layer (DDL).

Similarly, Bowder & Daniel,(1987) demonstrated that the using of chemicals tends the thickness of the diffuse double layer (DDL) to decrease, leading the soil skeleton to shrink and the repulsive forces decreased, thus encouraging clay particles to flocculate, and to dehydrate interlayer zone of expandable clays, thereafter the clay particles became a gritty or granular. Moreover, Sharma & Lewis (1994) stated that concentration valence of the cations affects the net electrical forces between clay mineral layers. They specified that there is a reduction in net repulsive forces as cation concentration or cation valence increased, hence causing clay particles to flocculate.

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

Effect of inorganic salt on compressibility characteristics.

From figure (6) & (7) show, the e-log pressure relationship of the clay obtained from odometer test with a different inorganic salt concentration of $MnSO_4$ & $FeCl_3$ respectively. It can be seen that as the salt concentration increased the compressibility of the soil decreased. This may due to the decrease of the electrical double layer surrounding the clay particles, the results were confirmed with Arsan, (2010).

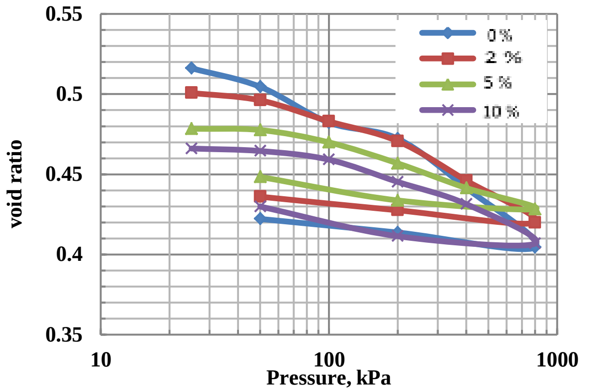

Figure 6. Effect of MnSO₄ concentration on void ratio-log pressure relationship

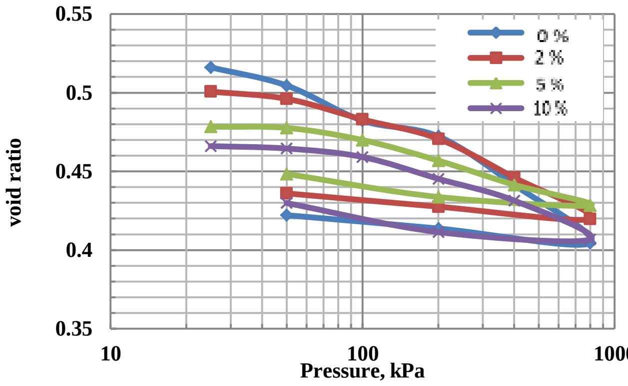

Figure 7. Effect of FeCl₃ concentration on void ratio-log pressure relationship

Figure (8) and (9) present the effect of salt concentration on the void ratio of clay contaminated 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 margined to initial value with $MnSO_4$ salt, and increased slightly with $FeCl_3$.

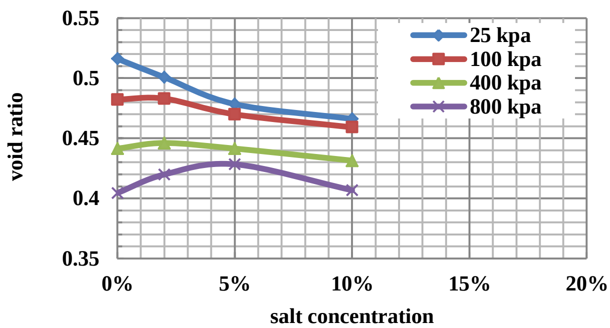

Figure 8. Void ratio-salt concentration ($MnSO_4$) relationship

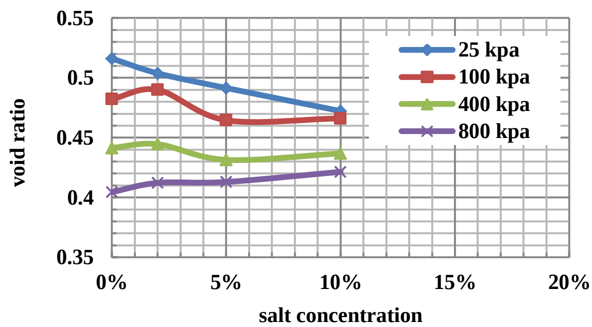

Figure 9. Void ratio-salt concentration ($FeCl_3$) relationship

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

Also, Bowders Jr and Daniel, (1987) 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 (10) and (11) show the effect of salt concentration on compression and swelling indices respectively:

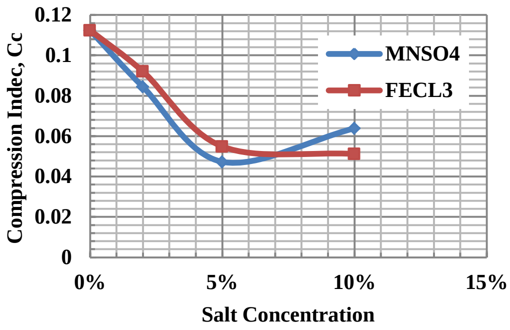

Figure 10. Effect of salt concentration on compression index

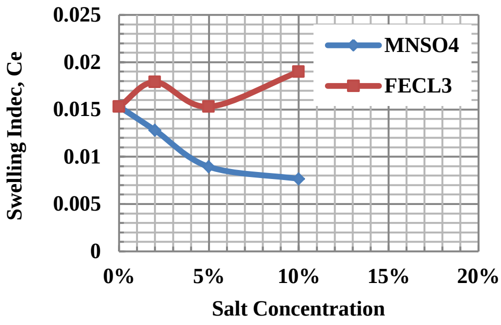

Figure 11. Effect of salt concentration on swelling index

From figure 10 & 11, it is obvious that the compression index for clay contaminated with $MnSO_4$ and $FeCl_3$ solutions decrease as salt concentration increase. The swelling index tends to have the same behavior, it decreases as salt concentration increase for clay contaminated with $MnSO_4$ while the swelling index for clay contaminated with a $FeCl_3$ increase slightly.

4. Conclusion

Based on the results of the study, the following conclusions are made:

The consistency limits increased as the concentration of inorganic salt($MnSO_4$ and $FeCL_3$) increased. This is mainly due to the effect of inorganic salt on the diffuse double layer

As the concentration of $MnSO_4$ and $FeCl_3$ increased from 2% to 5%, the compression index decrease, after that the C_C is nearly constant.

Swelling index tends to increase slightly as the concentration of $MnSO_4$ increased, while it decreased as the concentration of $FeCl_3$ increased.

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