Potential of lateritic soils as a liner in landfill: A case Study of a dumpsite in Ado-Ekiti, Southwestern Nigeria

Abstract

The permeability characteristics of the lateritic soil from Ilokun dumpsite were studied with a view of investigating its suitability or otherwise as liners in sanitary landfills. The soil samples were collected from trial pits at different depths within the lateritic soil zone. The samples were subjected to specific gravity test, grain size distribution analysis, consistency limits, compaction tests and permeability test.

All the soil samples are well graded. The study also showed that the plasticity of the soils ranges from medium to low plasticity and hence low compressibility. The maximum dry density (MDD) values for all the studied soil samples range from1.72t/m^3 to 2.02t/m^3 for Standard Proctol and the maximum dry density (MDD) values of the studied soil range from1.78t/m^3 to 2.08t/m^3 for Modified Proctol while the optimum moisture content (OMC) values of the studied soil range from 9.0% to 14.0% for Standard Proctol and the optimum moisture content (OMC) values of the soil range from 7.0% to 13.0% for Modified Proctol. It was revealed that the higher dry density values were obtained when the soil samples were compacted with higher energy of compaction. The coefficient of permeability obtained for the samples range from 1.5 x 10^{-3}mm/s to 2.5 x 10^{-2}mm/s and this is considerably higher than the maximum value of 10^{-6} mm/s recommended for the soil that should be useful as a liner in landfills.

It is therefore recommended that in-situ compaction and lining be done if the soils at the location will be used as liners in landfill. This will hinder the migration of liquid phase of the wastes.

KEYWORDS: Compaction, Grain size, Landfill, Lateritic soil, Permeability

INTRODUCTION

The world population is on the increase daily, so is the quantity of solid wastes being generated. Rapid technological changes, increased population growth and high concentration of people in urban centres are compounding the problems of maintaining the environment at a healthy level due to enormous wastes generated. The issue of solid waste management has recently dominated the environmental scene in the developing countries. Sittig (1979) attributed this to the increased awareness of the consequences of environmental change to future generations by indiscriminate dumping of refuse.

“Waste management has been discovered as one of the most challenging environmental problems facing towns and villages in most developing countries. Waste disposal is a problem for many communities in different countries because of the associated risks to human health and the general environment. It is very important for wastes to be properly and safely disposed to minimize environment pollution. The situation has worsened in Nigeria as a result of increased industrial developments and human population growth in the most urban areas. Hence there is need for effective waste management strategies relevant for this part of the world. However, sanitary landfill has been recommended as the most suitable facility for handling waste in developing and developed countries” (Ziess and Atwater, 1987), (Mepaiyeda, 2019), (Luczak-Wilamoswska, 2022), (Yoon *et al.* 2022), (Jakimiuk, 2022).

The city of Ado-Ekiti which is the capital of Ekiti State falls into southwestern region of Nigeria. Ado-Ekiti according to the National Population Commission (2006) census figures has a population of 409,060 people with an enormous amount of waste at an estimate of 0.5kg/person generated on daily basis as a result of domestic, agricultural and industrial activities. The bulk of the wastes generated include leaves, paper, nylon, food waste, tins, glass, plastics, rags, metals etc. Efforts at curtailing environmental pollution arising from indiscriminate dumping of wastes in different places, a major final waste disposal site has been strategically located at Ilokun. Ilokun open dumpsite along Ado-Iworoko road has been thoroughly investigated in this study.

This study is therefore aimed at evaluating the permeability characteristics of the lateritic soil from Ilokun dumpsite with a view of investigating its suitability or otherwise as liners in sanitary landfills.

STUDY AREA

Ilokun dumpsite is an active dumpsite which runs throughout the year. The dumpsite is situated in Ado-Ekiti along Ado-Iworoko road within Longitude 5.28 and 5.31 and Latitude 7.66 and 7.67 in decimal degrees (Figure 1).

The size of the dumpsite is about 7,700 square meters. There is a good accessibility to the dumpsite. There is a small community of Ebira people within the study area occupying close to fifty houses which is about 400 metres to the dumpsite. The composition of wastes at Ilokun dumpsite are organic materials, polythene and plastic materials, meta scraps, animal wastes etc. (Lateef *et al.).* There are farmlands around the study area where the people staying in the area practice farm work. The dumpsite was commissioned on the 17th June, 2012 by Mrs. Hadiza Ibrahim Maiafia who was the then minister of environment. The site has been approved by the authority of National Environment Standard and Regulation Agency.

GEOLOGY

The study area, Ado-Ekiti, is underlain by the Precambrian Basement Complex rocks of southwestern Nigeria Rahaman (1988) and it comprises of rock units such as gneisses, migmatites, including older graniteridges and pegmatites.

The area is underlain dominantly by migmatite-gneiss (Figure 1). This rock unit occurs as surface outcrops around the study area. The area falls within the tropical rainforest vegetation and also characterised by short dry and long wet seasons. The relief of Ado-Ekiti is moderately low with disengaged slopes (isolated hills) and inselbergs that are dome shaped (Lateef *et al.*). The major waterway depleting the zone is Ireje River which streams (flows) south–East. Ado–Ekiti has a planimetric region of about 84km.

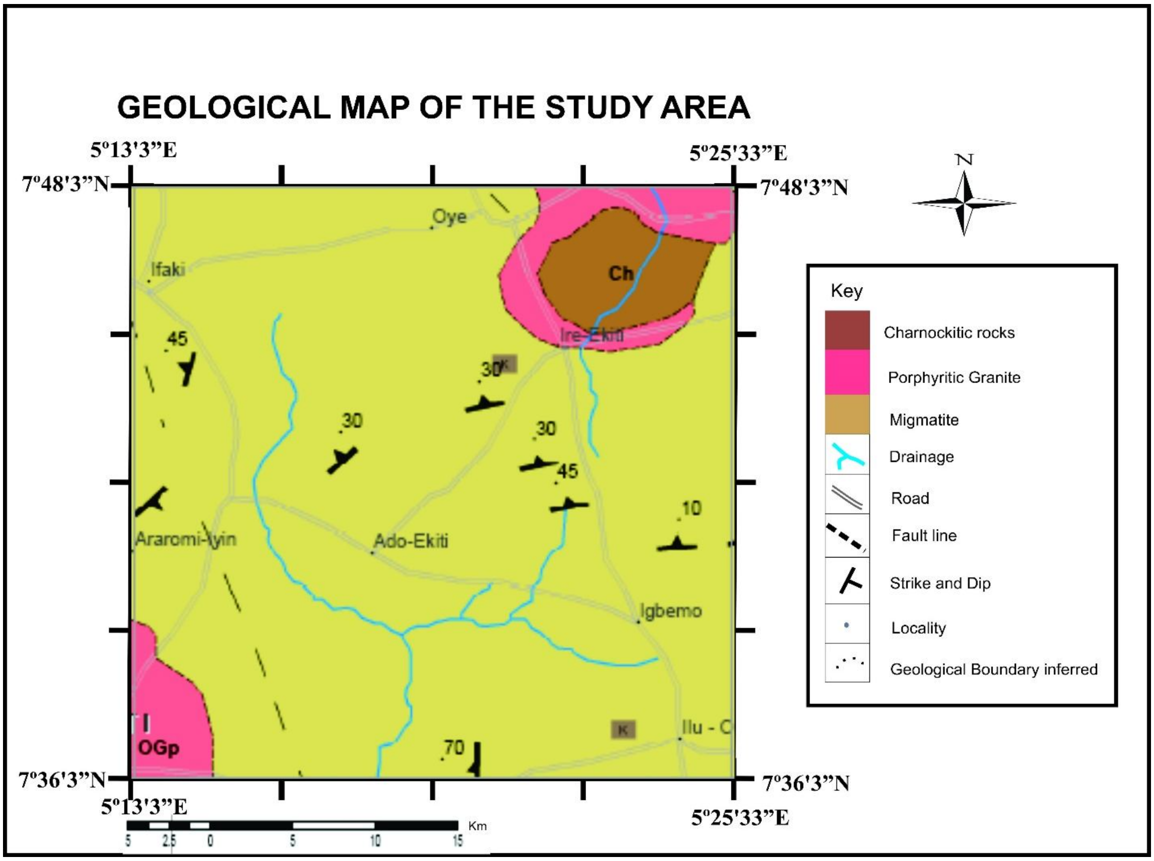


Figure 1: Geological Map of the study Area (Modified after NGSA, 2017)

MATERIALS AND METHODS

Ten bulk soil samples were obtained from the site at different depths in trial pits which is the cheapest method of exploration to shallow depth. For the purpose of this work geotechnical sampling involved the establishment of four trial pits. Both disturbed and undisturbed samples were obtained at different depth within the lateritic zone. The variation in the depth of soil sample was necessary to know the geotechnical properties of the laterite zone which may be useful as mineral seals in the construction of sanitary landfill. The disturbed samples collected in polythene bags were obtained using digger and shovel. The undisturbed samples were obtained using cutters (100mm x150mm) with marshal rammer ramming it into place.

The samples were air-dried for few weeks prior to the tests. The tests carried out included determination of the specific gravity of grains, grain size distribution, plasticity, compaction tests and permeability test.

RESULTS AND DISCUSSION

The general laboratory assessments required for lateritic soils to be used as mineral seals are specific gravity, the grain size distribution, the Atterberg limits, the moisture content-density relationships and the coefficient of permeability (ÖNORM S2074, 1990; Oeltzschner, 1992; Jessberger, 1994; Seymour and Peacock, 1994; Taha and Kabir, 2006; USEPA, 2005; Ash and Jeggar, 2008).

Specific gravity of grains

Table 1 shows that there is a very close range in the values of the specific gravity of the grains of the studied soils since the soils are of the same genetic origin and in the similar weathering environment. The specific gravity ranges from 2.62 between 2.76.

Table 1: Result of Specific Gravity of the migmatite-gneiss-derived soil samples at depth 2m

Sample	**ADE-1**	**ADE-2**	**ADE-3**	**ADE-4**	**ADE-5**	**ADE-6**	**ADE-7**	**ADE-8**	**ADE-9**	**ADE-10**
Specific Gravity	2.71	2.73	2.76	2.74	2.66	2.62	2.73	2.75	2.75	2.75

Comparing the results obtained with that of Bowels (1979) specification as shown in the table 2 below, sample ADE-1 is classified as Clay (Inorganic), ADE-5 and ADE-6 are classified as clay (Organic), ADE-2, ADE-3, ADE-4, ADE-7, ADE-8, ADE-9 and ADE-10 are classified as Silt.

Grain size distribution characteristics

The grain size distribution curves of the ten studied soil samples are presented in Figure 2. The summary of the grain size distribution characteristics of the studied soils are shown in the Table 2 below. The graphical representation of the results of the grain size analysis of soil sample ADE-1 gave an indication that it is clayey-silt, ADE-2 is clayey-sand, ADE-3 is sandy-silt, ADE-4 is clayey-gravel, ADE-5 is sandy-gravel, ADE-6 is clayey-sand, ADE-7 is gravelly-sand, ADE-8 is sandy-gravel, ADE-9 is sandy-gravel, ADE-10 is sandy-gravel.

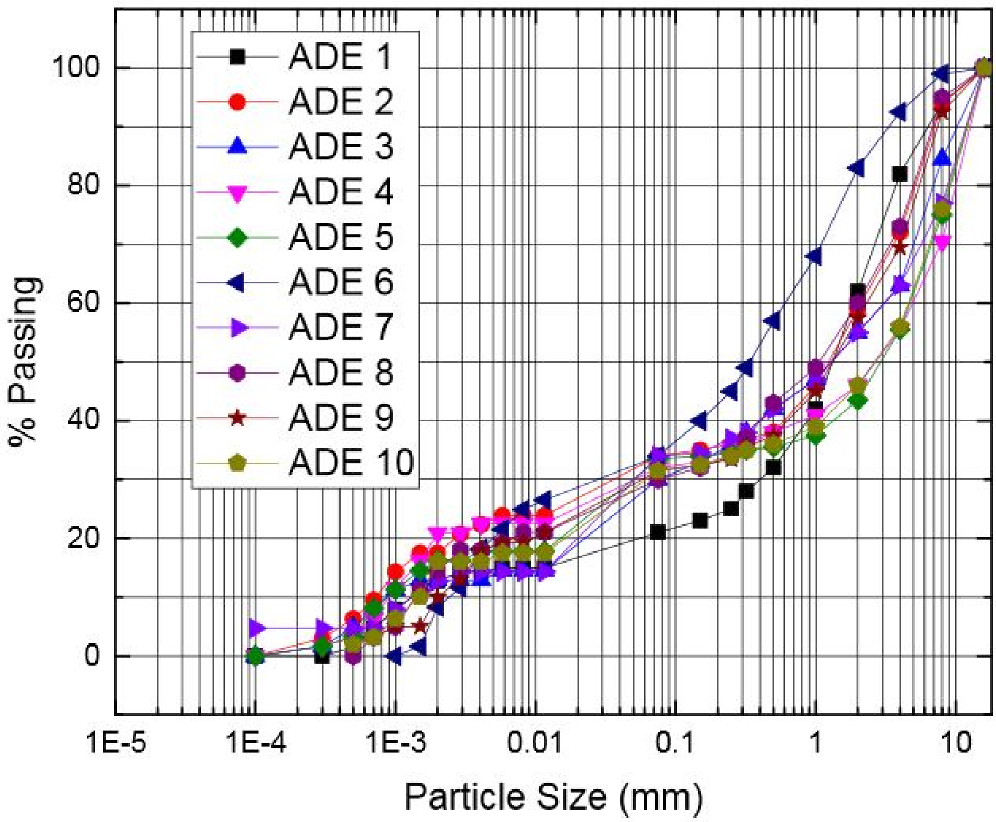
The ten samples of Ilokun dumpsite have gravel percentage ranging from 2% to 55%, percentage of sand ranging from 25% to 69%, silt percentage ranging from 6% to 40%, clay percentage ranging from 2% to 31%. This shows that the total amount of fines ranges from 18% to 66%.

All the samples are well graded. It can be seen that the soils have a much lower percentage of fines (clay and silt-sized particles) indicating better geotechnical characteristics. The lower the amount of fines in a soil sample, the better the engineering properties of the soil.

Daniel (1993b) recommended amount of fines of at least 20% for landfill seals i.e. for soil that can be good for base of landfill. Therefore the studied soils meet this standard specification and can be used for base of landfill except sample ADE-10 that has less than 20% of fines.

Table 2: Grain size distribution characteristics of the studied soils

SAMPLES	% GRAVEL	% SAND	% SILT	% CLAY	AMOUNT OF FINES (%)	UNIFORMITY COEFFICIENT (D_{60}/D_{10})	D_{50}(mm)	COEFFICIEENT OF PERMEABILITY $K=CD^2_{50}$, C=0.00357
ADE-1	13	25	36	26	62	150	0.008	6.4×10^{-5}
ADE-2	15	43	11	31	42	380	0.12	1.4×10^{-2}
ADE-3	2	32	40	26	66	17.27	0.0065	4.2×10^{-5}
ADE-4	45	20	12	23	35	3846.15	0.05	2.5×10^{-3}
ADE-5	42	25	14	19	33	5000	3.5	1.2 x 10
ADE-6	5	69	6	20	26	3846.15	3.0	0.9 x 10
ADE-7	30	38	16	16	32	150	0.35	1.2×10^{-1}
ADE-8	42	36	20	2	22	369.23	1.2	1.44
ADE-9	45	34	18	3	21	270	1.5	2.25
ADE-10	55	27	15	3	18	657.14	3.0	0.9 x 10



Clay	Silt	Sand	Gravel

Figure 2: Grading curves of residual lateritic soil samples

ATTERBERG (CONSISTENCY) LIMITS OF SOILS

A consistency limit characteristic is an important parameter for selecting lateritic soils as lining materials.

Table 3 summarizes the consistency limits of the studied soils at Ilokun, Ado-Ekiti. It shows that the liquid limit of the soil samples ranges from 21.6% to 32.0%. The plastic limit of the soil samples range from 17.5% to 21.3%. All the samples plot in the low plasticity regime except ADE-6 and ADE-9. According to Bagchi (1994), a lateritic clayey soil with liquid limit (LL)

≥30% and plasticity index (PI) ≥ 15% is recommended as mineral seal. Ilokun soils meet this standard specification and therefore can be used as liner. Ilokun site has lateritic soil that is geologically suitable with low plasticity and hence low compressibility.

The Casagrande chart classification (Figure 3) shows that all the soil samples are placed in the low plasticity/compressibility region and hence the soils would be expected to exhibit low swelling potential (Ola, 1982). All the lateritic soil samples from Ilokun fall within the field of inorganic clays of low plasticity (Casagrande, 1948).

According to Terzaghi, (1958), lateritic soils which plot below A-line have proved problematic when the soils are used for construction purposes.

Seven out of ten soil samples fall within the field of inorganic clays of low plasticity while three samples fall within the field of inorganic clays of medium plasticity (Casagrande, 1948).

Table 3: Summary of Atterberg (Consistency) limits for soil samples

SAMPLE	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	FLOW INDEX (%)	TOUGHNESS INDEX (%)	SHRINKAGE LIMIT (%)
ADE-1	28.0	18.6	9.4	25.0	0.38	5.3
ADE-2	26.0	20.4	5.6	29.0	0.19	4.9
ADE-3	28.0	19.9	8.1	31.0	0.26	5.7
ADE-4	28.0	18.25	9.75	18.5	0.52	5.3
ADE-5	25.6	15.45	10.15	21.1	0.48	5.2
ADE-6	32.0	21.0	11.0	26.32	0.42	8.2
ADE-7	21.6	18.25	14.8	23.95	0.62	4.1
ADE-8	26.0	17.5	8.5	15.0	0.56	4.7
ADE-9	30.5	21.3	9.2	33.0	0.30	4.6
ADE-10	29.2	20.0	9.2	29.1	0.32	4.7

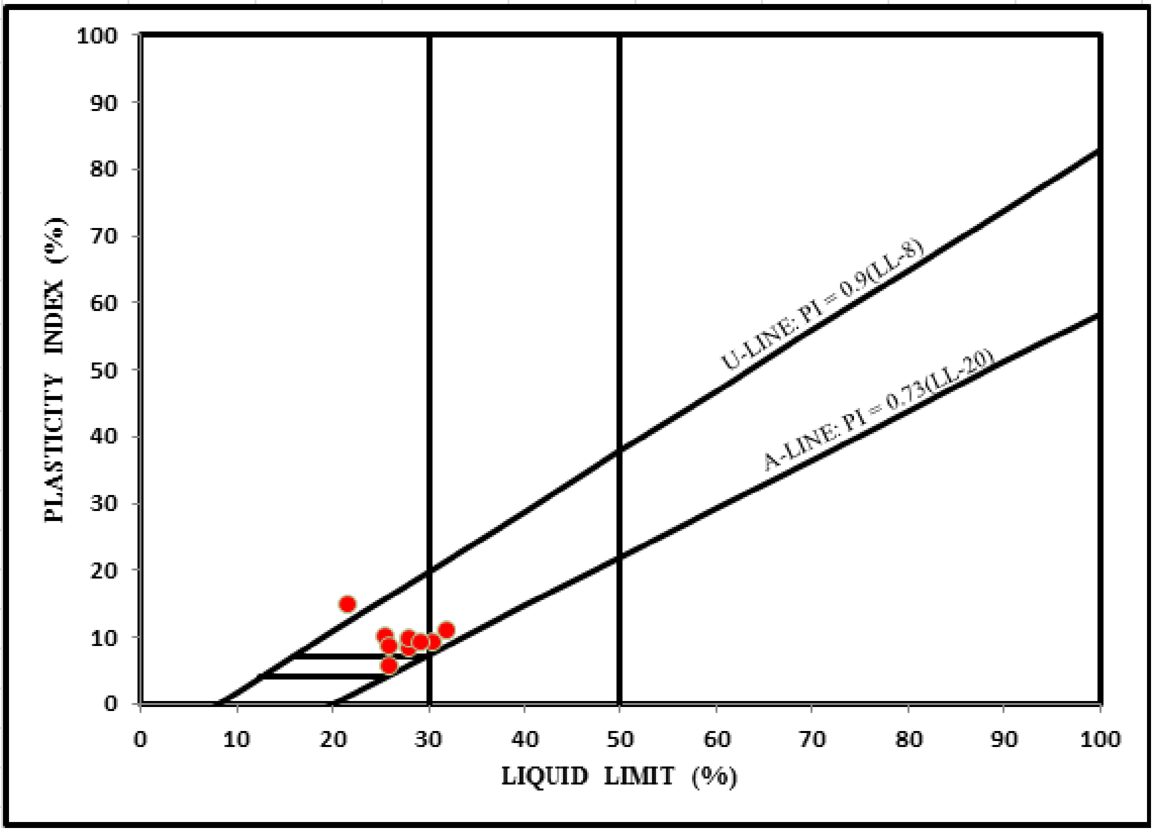


Figure 3: Casagrande Chart Classification of Ilokun Soil Samples

COMPACTION CHARACTERISTICS (MOISTURE CONTENT-DENSITY RELATIONSHIPS)

According to Daniel (1990), permeability decreases with increasing compactive effort. This is because increasing compactive effort decreases the frequency of large pores (Acar and Oliveri, 1990). ÖNORM S 2074(1990) and Taha and Kabir (2006) recommended a maximum dry density of ≥1.70t/m^3 for soils to offer desire permeability to be useful as mineral seals.
For this study, the soils were compacted at different levels i.e. standard and modified proctors. These were done with a view to determining the best level of compaction for the soil samples derived and also to determine the optimum moisture content (OMC) and maximum dry density (MDD).

Summary of compaction test results for both standard and modified Proctor energies are presented in Table 4. The maximum dry density (MDD) values range from1.72t/m^3 to 2.02t/m^3 for Standard Proctol while the optimum moisture content (OMC) values range from 9.0% to 14.0% for Standard Proctol compaction condition. The soils have MDD values range from1.78t/m^3 to 2.08t/m^3 and OMC values range from 7.0% to 13.0% for modified Proctor compaction condition.
As shown in Table 4, the sample ADE 1, ADE 3, ADE 7 and ADE 9 had better compaction parameters than the rest of the soils samples when compacted at Standard Proctol level. The soil sample ADE 3, had the highest MDD and the lowest OMC. The soil samples ADE 7, ADE 3, ADE 1, and ADE 9 had better compaction parameters than other samples compacted at Modified Proctool. The higher the MDD, the better the soil for engineering purpose and also the lower the OMC, the better the soil for engineering purpose.

Maximum Dry Density

From the compaction results summarized in Table 4, the maximum dry density (MDD) values of the studied soil range from1.72t/m^3 to 2.02t/m^3 for Standard Proctol and the maximum dry density (MDD) values of the studied soil range from1.78t/m^3 to 2.08t/m^3 for Modified Proctol. From Table 4, higher dry density values were obtained when the soil samples were compacted with higher energy of compaction. These results conform to the speculation of Taha and Kabir (2006).

The data show that the highest MDD of 2.02t/m^3 and the lowest OMC of 7.0% are exhibited by soil sample ADE 7 compacted at Modified Proctol of the compaction rammer. The basic assumption underlying the compaction test is that the strength of soil increases with increasing dry unit weight.

Taha and Kabir (2006) recommended a maximum dry density of ≥1.70t/m^3 for soils to offer desire permeability to be useful as mineral seals.

Optimum Moisture Content

The optimum moisture content (OMC) values of the studied soil range from 9.0% to 14.0% for Standard Proctol and the optimum moisture content (OMC) values of the studied soil range from 7.0% to 13.0% for Modified Proctol. The increase in energy of compaction drastically reduces optimum moisture content of the studied soils. The lowest OMC produced the highest MDD at Modified Proctol. Modified Protocol has been adjudged to be the best for some southwestern Nigerian lateritic soils (Owolabi, 1991 and Adeyemi, 1992).

The results obtained in this study also show that the compaction at Modified Protocol is the most suitable for all the samples because it produced the best moisture content and dry density parameters.

Table 4: Summary of compaction test results

SAMPLE NO	**STANDARD PROCTOR**		**MODIFIED PROCTOR**	
	Optimum Moisture Content (OMC) %	**Maximum Dry Density (MDD) g/cm^3**	**Optimum Moisture Content (OMC) %**	**Maximum Dry Density (MDD) g/cm3**
ADE-1	9.0	1.98	8.0	2.07
ADE-2	9.0	1.92	7.0	1.99
ADE-3	9.0	2.02	8.0	2.07
ADE-4	9.0	1.95	8.5	1.98
ADE-5	10.0	1.90	9.0	1.97
ADE-6	14.0	1.72	13.0	1.78
ADE-7	9.0	1.97	7.0	2.08
ADE-8	11.0	1.88	10.0	1.94
ADE-9	9.0	1.95	8.5	2.08

ADE-10	10.0	1.93	9.0	1.98

COEFFICIENT OF PERMEABILITY

Table 4 shows the compaction parameters of soil samples compacted at standard proctor and modified proctor. The coefficient of permeability obtained for the samples range from 1.5 x 10^{-3}mm/s to 2.5 x 10^{-2}mm/s. All the studied soil samples can be classified as pervious soil because they have permeability coefficients higher than the recommended borderline. According to Clayton and Huie (1973), the permeability coefficient for the base of a landfill should not exceed 10^{-6}mm/s. Considering the standard set by Clayton and Huie (1973), all the samples do not meet the standard.

On the suitability of compacted clay soil as mineral seals in sanitary landfill, several recommendations have been proposed (USEPA, 1982; Tavenas et al, 1983; ÖNORM S2074, 1990; Oeltzschner, 1992; Jessberger, 1994, Seymour and Peacock, 1994; USEPA, 2005; Taha and Kabir, 2006). USEPA (1982) recommended that such soils should possess a k-value of <1 x 10^{-9}m/s; ÖNORMS 2071(1990) preferred k-value of 1x 10^{-9}m/s; Oeltzschner (1992) suggested k-value <10^{-10}m/s. Jessberger (1994) recommended k value 1x 10^{-10}m/s; Seymour and Peacock (1994) suggested k-value of 1x10^{-9}m/s. Considering the standard set by USEPA, 1982; Tavenas et al, 1983; ÖNORM S2074, 1990; Oeltzschner, 1992; Jessberger, 1994, Seymour and Peacock, 1994; USEPA, 2005; Taha and Kabir, 2006 all the samples do not meet the standard.

The coefficient of permeability (k) decreases with the increasing compactive effort, because increasing effort decreases the frequency of large pores (Acar and Oliveri, 1990). This reduction in pore size yield lower permeability which also changes with change in compaction water content.

Table 5: Summary of permeability test results

Sample	Volume of drained water(Q)cm3	Height of core sample (l) cm	Radius of core sample (r) cm	Area of ore sampler (cm2)A	Hydraulic tread (cm) (h)	Time (t) (sec)	Ksat (cm/s)
ADE-1	51.5	5.5	2.25	15.91	5	300	0.0119
ADE-2	34	4.9	2.2	15.21	5	300	0.0073
ADE-3	30.5	6	2.25	15.91	5	300	0.0077
ADE-4	50	4.9	2.2	15.21	5	300	0.0107
ADE-5	91	5	2.2	15.21	5	300	0.0199
ADE-6	77.5	5.5	2.25	15.91	5	300	0.0179
ADE-7	23	4.9	2.25	15.91	5	300	0.0047
ADE-8	93	6.0	2.2	15.21	5	300	0.0245
ADE-9	46	4.3	2.2	15.21	5	300	0.0087
ADE-10	7	4.9	2.2	15.21	5	300	0.0015

CONCLUSION AND RECOMMENDATION

The studies carried out on the soil samples taken from trial pits at varying depth, have confirmed the following: All the soil samples are well graded. The plasticity of the soils ranges from medium to low plasticity and hence low compressibility. The study also showed that the higher dry density values were obtained when the soil samples were compacted with higher energy of compaction. The coefficient of permeability obtained for the samples is considerably higher than the maximum value recommended for the soil that should be useful as a liner in landfills. It is therefore recommended that in-situ compaction and lining be done if the soils at the location will be used as liners in landfill.

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