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EVALUATION OF FIELD CAPACITY OF MUNICIPAL REFUSE DUMPSITE (A CASE STUDY OF UNIVERSITY OF MAIDUGURI DUMPSITE)

ABSTRACT

This paper presents the results of an evaluation of Field Capacity of municipal solid waste at the University of Maiduguri dumpsite. The work describes the methodology and the devices designed for the determination of field capacity of municipal solid waste, in which a lysimeter was constructed to simulate the activities within the refuse dumpsite. The method consisted of applying dynamic compaction to a representative sample of rubbish collected from the university waste dumpsite, to simulate three different depths, at 0.0, 0.5 and 1.0m respectively. The experimental results showed that the higher the compaction of the sample, the smaller the amount of water required to satisfy the field capacity and thus to start the leaching process. In other words, field capacity was found to be inversely proportional to the dry field density, with an Optimum value of 0.38L/kg. This is the water holding capacity of the waste per kilogram before leaching commences. The study suggest that, the results can be extrapolated to other landfills with similar characteristics, thus making it possible to design the dimensions of the device required to control the production of leachate with greater accuracy.

Keywords Field Capacity, Solid waste, Leachate and Lysimeter.

INTRODUCTION

Municipal Solid Waste in developing countries is composed mainly of easily biodegradable organic matter with high moisture content especially in tropical climate (Akpokodie, 2003). Municipal solid waste (MSW), also called urban solid waste, is a waste type that includes predominantly household waste (domestic waste) with sometimes the addition of commercial wastes collected by a municipality within a given area (Kockel and Jessberger, 1995). They are in either solid or semisolid form and generally exclude industrial hazardous wastes. Conventionally, landfill is designed to contain or store the wastes so that the exposure to human and environment could be minimized. Under the containment landfill concept, water infiltration into the landfill is minimized to reduce the emission of leachate and gases into the environment. However, cases of methane and other pollutants are occasionally found in these landfills, arising from improper handling by operators, which culminate in contamination of groundwater. The composition of municipal solid waste provides different environmental conditions for pollutant by product to be generated at the landfill in developed countries. The control of such pollutants is of utmost importance since incorrect handling can adversely affect the underground water and endanger human health (Velasquez et al, 2003). Municipal Solid Waste disposal in landfills requires estimation of refuse degradation and settlement behavior in order to utilize the available volume to its maximum capacity (Kelly, 2002). Moreover it is important to look at the Field capacity of that particular site in order to avoid the problems from landfills that will render underground water becoming polluted. Velhmeyer and Hendrickson (1931) introduced the field capacity concept and defined it as the amount of water held in the soil after the excess gravitational water has drained away and after the rate of downward movement of water has materially decreased. Vaidya (2002) defined field capacity as the ability of refuse to retain water, which is an important parameter in the water balance of active landfills. It finds application in groundwater monitoring to ensure that the landfill does not contaminate the aquifer and water table, as this could posed a threat to public health. It explores the development of a laboratory methodology to compact refuse, with the objectives of determining the Field Capacity of Municipal Solid Waste and the volume of leachate that will be produced.

Leachate is any liquid, including any suspended component in the liquid, which has percolate through or drained from waste (Reinhart and Al-Yousfi, 1995). It encompasses all types of liquid that come in contact or has been released from waste. Most leachate resulted from rainfall and run-off that infiltrate the refuse cells and comes in contact with decomposing garbage. Highly contaminated leachate is also a by-product of decomposition in landfills and water leaching out from the bottom of a landfill is severely contaminated with organics, metals and solids. Disposal containing leachate with high nitrogenous constituents has damaging impacts due to a reduction in

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chlorine disinfection efficiency, an increase in the dissolved oxygen depletion in the receiving waters, adverse public health effects, and a reduction in suitability for reuse (De Renzo, 1978).

Landfill leachate from old sites are usually contaminated with ammonia resulting from the hydrolysis and fermentation of nitrogen containing fractions of biodegradable refuse (Knox, 1985) and may contain 400-800 mg/l of ammonia nitrogen (Welander et. al, 1998). The knowledge of moisture holding potential of refuse is important to estimate the amount of moisture to be added in a landfill before any leachate is produced and drained off through the bottom. This amount of moisture expressed on a weight or volumetric basis as percentage of total refuse volume respectively is denoted as the field capacity of municipal solid waste.

The factors affecting the ability of refuse to retain moisture indefinitely against gravity i.e. its field capacity, are site specific. These include hydro-geological conditions, waste composition, in situ compaction, and biodegradation. Refuse absorptive capacity has been estimated as 125 l/m^3 (Marriott, 1981) and 1.62 inch/ft (Dilaj and Lenard, 1975). Achieving field capacity in waste starting at 10% to 20% moisture requires between 40 and 80 gallons per cubic yard of waste (Vaidya, 2002). Rosqvist and Destouni, (2000) have shown that nearly 90% of the vertically flowing water in a landfill flows preferentially through 47% of the total water content. The observed difference between the preferential flow quantification of the landfill and that of the waste sample were also found to be more related to waste material properties than to the prevailing flow conditions i.e. the flow rate or degree of saturation. The objective of this study therefore, is to provide a laboratory methodology that will help in estimating the field capacity of refuse dumpsite.

THE STUDY AREA

The study area is the University of Maiduguri, in Jere Local Government area of Borno State, North-East Nigeria. Jere was created out of the present Maiduguri Metropolitan council. The University of Maiduguri have a student's population over 40,000 and a staff strength of about 3,500, with only about 15% of the staffs living in the University staff quarters. The per capita waste generation rate of the University is 0.85kg/h/d, Alfred and Sangodoyin (2011). Borno state is located on latitude 11.510 north, longitude 30.050 east and an altitude of 354 meters above sea level. It is located in the sahel region of West Africa. Nwaiwu and Lingmu, 2011 identified three distinct seasons with the area in their study: the cold dry (harmattan) season (October to March), hot dry season (April to June) and the rainy season (July to September). The short period of rainfall has an average of 645.9mm/annum. The temperatures are mostly on the extreme throughout the year with hot season temperatures ranging between 39^{o}C and 40^{o}C. The lowest temperature could be as low as 25^{o}C between December and January (harmattan). The relative humidity is 45% in August which usually lowers down to about 5% in drier season between December and January.

MATERIAL AND METHODS

Field capacity tests were carried out on the University of Maiduguri dumpsite.
To carry out the test, a Lysimeter was constructed to simulate the activities that normally occurs in a given landfill/refuse dump i.e. after rainfall which may later constitute leaching. This can adversely affect the groundwater as in Figure 1. The components of the lysimeter were carefully arranged as shown and filled accordingly with the solid waste: a steel frame (2) was placed inside the steel drum (1) at the bottom to create a void between the waste and the bottom of the Lysimeter. This was to hasten the drainage of the percolated fluid. The said void was filled with gravel (3) retained on a 2mm sieve to prevent the passage of fine matter that might obstruct the draining process. The circular perforated steel wire mesh (4) was positioned to act as a false bottom for the Lysimeter, and to allow the percolated fluids to flow through. The geotextile (5) was laid on the false bottom to act as a filter

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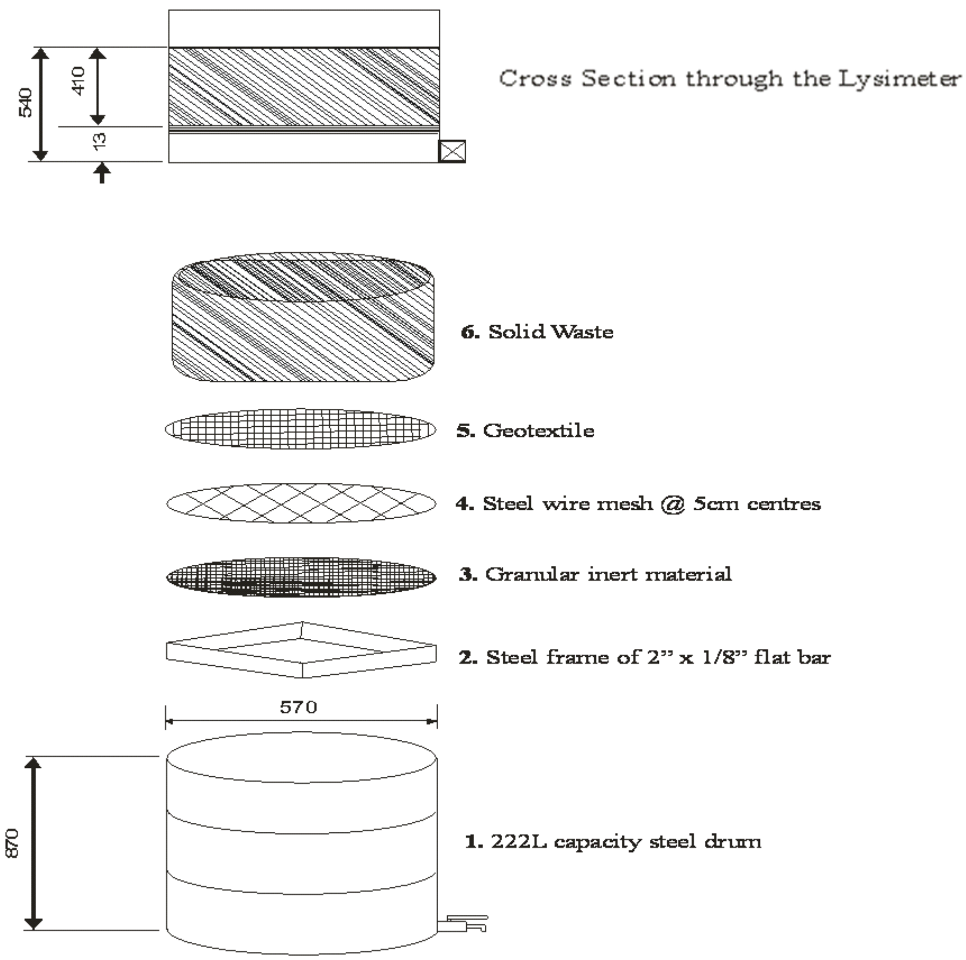

Figure 1: the Lysimeter and its components
Note: All dimensions in millimeters

In order to monitor the variation in field capacity, field capacity tests were carried out on samples collected at three different depths on the dumpsite, i.e. at the surface, at 0.5m and 1.0m depths respectively. The same compactive energy was used for the three samples to simulate the weight density of the waste at the various depths.

The following materials were used for the test, these are: Lysimeter, rubber gloves, nose mask, safety boots, digger, shovel, sacks (with polyethylene inside), weighing scale, 4.8kg rammer, moisture content tins, electronic balance (0.01g accuracy) and Electric drying oven.

A 100kg of solid waste sample was dug out at the University of Maiduguri dumpsite using a digger and shovel. The sample was properly tied in a two-layer sack with a nylon material at the interior. This was put in a second similar sack to prevent loss of moisture content due to evaporation and then taken to the laboratory immediately (within 20 minutes) for the commencement of the test.. A representative sample weighing 1000g was taken to determine relative moisture as registered by weight loss during drying. For this analysis, three

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empty moisture content tins were weighed. Some samples of the solid waste were weighed with the tins. The tins containing waste was put inside a drying oven for two days (due to unstable power supply) at 105^{o}C. After the 48hrs, the weight of the tins and its contents were measured. The moisture content is expressed as a percentage of weight loss during drying divided by the weight of oven dried waste sample. The next step involved packing the solid waste inside the Lysimeter, and then compacting it with a hand drop rammer to the desired compacting effort. The method used for the compaction of solid waste was by the application of impact loading. A compacting load of 4.8kg was dropped 75 times on 3 layers of waste from a height of 0.45m above the initial top waste in the Lysimeter. This results in the total compactive effort of 46.26kN/m^2 (46260 Joules). The same volume occupied by solid waste in the Lysimeter was used for the three depths simulated and the weight of solid waste compacted were all recorded.

After compaction, water was added until level with the top of compacted waste, in order to saturate the absorption capacity of the solid waste in the Lysimeter. The first drainage took place 15 minutes after level stabilization, to avoid excessive water accumulation and absorption by solid waste. An intermediate draining was carried out three hours after the first draining process, and a third draining after 24 hours. This completed the experiment.

In some cases where there were no liquid after the first 15 minutes, the next draining was carried out after the next 15 minutes, i.e. 30 minutes from the start of the experiment, then three hours after that draining and after 24 hours. The reason for executing three draining operations was to reduce water loss by evaporation, and thus to increase the accuracy of the measurements of the water drained. The dry density of the solid waste mass was then calculated and the Field Capacity also determined as follows:

The value of the Field Capacity was obtained using Equation (1).

$$Cc = \frac{\frac{H \times PV \times V}{100} + (Si - Di) \times d}{\{PV \times V \times (1 - H)\}}$$ *Equation 1*

Where

Cc - is the Field Capacity of the solid waste, expressed in kilograms of water per kilograms of dry basis waste;
PV – is the weight density in Kg/L
Si - is the volume of water in litres added to the lysimeter at the beginning of the experiment;
Di - is the total volume of water in litres extracted from the lysimeter during the three drainages;
d - Is the density of water in kg/L;
H - is the percentage of relative moisture in the solid waste;
ρ - is the dry field density of solid waste;
V - is the volume in litres occupied by the compacted waste.

The moisture content of the solid waste was calculated using Equation (2)

$$M_c = \frac{W1 - W3}{W3 - W1}$$ *Equation (2)*

Where:
Mc – is the moisture content of the waste sample (%)
W_1 - is the weight of empty tin;
W_2 - is the weight of tin + moist waste;
W_3 - is the weight of tin + oven dried waste

$$\rho = \frac{\rho_b}{1+H}$$ Equation 3

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$$\rho_b = \frac{Mass\ of\ compacted\ waste\ (M)\ in\ Kg}{Volume\ occupied\ by\ waste\ (V) M^3}$$ Equation 4

The dry field density was obtained using the Equation (5)
Substituting (4) in (3),

$$\rho = \frac{M}{V(1+H)}$$ Equation 5

RESULS AND DISCUSSION

The densities and relative moisture of solid waste at different depths obtained by applying the method described above are shown in Table 1 below.

Depth (m)	Dry Field Density (kg/m^3)	Relative Moisture (%)
0.0	438	9.9
0.5	948	11.5
1.0	1030	13.3

Table 1: Dry Field Density and Relative Moisture at various depths for determining Field Capacity.

The values for relative moisture are given in percentage, because the value corresponds to a ratio between the mass of water and the mass of dry solid waste.
Note that $V = \pi r^2 h$, r = 0.285m and h = 0.41m, hence V = 0.105m^3 (105L)

The same procedures were followed to determine the average water contents, dry density and the corresponding field capacity at 0.5m and 1m depths respectively. These are shown on the Table 2 below, which shows Field capacity parameters for solid waste samples without the use of surcharge i.e. by simulating those layers that underlie the final top layer of the University of Maiduguri dumpsite.

PARAMETERS	DEPTH (m)		
	0.0 (Surface)	0.5	1.0
Dry Field Density (kg/m^3)	438	948	1030
Relative Moisture (%)	9.9	11.5	13.3
Water for saturation (L)	76	26	36
Water extracted (L)	24.00	2.30	7.28
Volume occupied by solid waste (L)	105	105	105
Water Density (kg/m^3)	1	1	1
Field Capacity (L/kg)	1.36	0.40	0.46

Table 2: Summary of the result of Field Capacity determination

Figure 2 below is a graph showing the relationship between Field Capacity and Dry Field density at the three different depths of the dumpsite.

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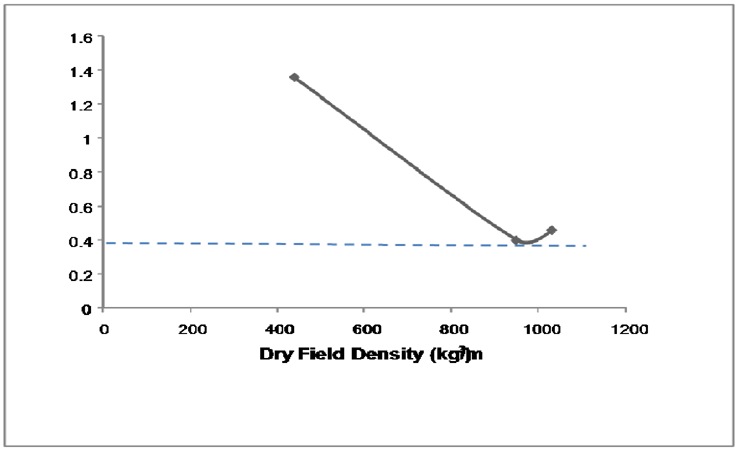

Figure 2: The relationship between Field Capacity and Dry Field density

The characteristic of municipal solid waste at the University of Maiduguri dumpsite constitute materials such as leaves, paper, metals, cans, textiles materials, food, fruit, vegetables, leather products, hair attachment, bottles, glass, polyethene bags, electronics components, wire and ropes. When characterizing solid waste, it is very difficult to obtained matching results because solid waste is heterogeneous medium with properties that varies from one region to the other and from one climate to the other. The results revealed that, Field Capacity is inversely proportional to the Dry Field Density, i.e. it decreases as the Dry Field Density is increased, and this corresponds with the findings by Velasquez et al. 2003. The result of the dry field density tests carried out on the solid waste at three different depths shows that, the dry field density of solid waste at the dumpsite increases with increasing depth as well. This could be attributed to the nature of the waste and its corresponding characteristics. At the surface, the wastes are still fresh with very little or no decomposition assumed to have taken place, while at 0.5m depth and 1.0m, the waste have slightly undergone some form of decomposition, which is evidently shown in the soil-like nature of the solid waste. Hence, higher dry density values were obtained at 0.5m and 1.0m after applying the same compactive effort with that sample taken from the surface of the dump side. The low values for relative moisture are due to the inherent nature of the waste and due to the extreme climate and high daytime temperature which induced moisture loss through evaporation while the tests were being carried out. The moisture content of the sample was observed to have increased as the depth increased. This is because the waste at the surface is exposed to the heat from the sun and thus, high rates of evaporation do occur at the surface than beneath. One other reason is that, because of the overlying layer, the waste sample at higher depth have undergone some sort of natural compaction/and settlement. Thus, the waste at such depths retains much of its moisture content. It was also revealed that, the higher the compaction effort applied to the waste volume, the smaller the amount of water needed to satisfy the field capacity and thus start the leaching process; and vice versa, this correspond to Similar studies done by Velasquez et al., 2003. The result from Figure 2 shows that, the Optimum Field Capacity is 0.38L/kg, and this is simply the water holding capacity of the waste beyond which if exceeded, the leaching process can start, which may adversely affect the groundwater. To make the results more relevant, some comparisons were made with other works done by some authors in different parts of the globe; (Sanchez et al, 1991; Zeiss et al, 1995; Uguccioni et al, 1997 and Velasquez et al, 2003).

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AUTHOR	WEIGHT DENSITY (kg/m^3)	FIELD CAPACITY (L/kg)
Velasquez et al, 2003	200 350 500 750	1.950 1.170 0.760 0.550
Uguccioni et al, 1997	600	0.200
Zeiss et al, 1995	140	0.710
Sanchez et al, 1991	538 580 684	0.430 0.380 0.230
Current work (University of Maiduguri dumpsite)	438 948 1030	1.060 0.460 0.400

Table 4: Comparison of current result with that of other authors

The observed differences between field capacity values obtained in this work and the values reported by other authors may be due to the characteristics of the waste, the methodology used and/or control exercised over the measurements recorded throughout the experiment and environmental factors.

CONCLUSION AND RECOMMENDATIONS

The field capacity parameter of solid waste is essential for calculating the amount of leachate that will be generated by a landfill. Therefore, its accurate determination requires the application of a relative methodology. The moisture content and the dry field density of the solid waste increased with increasing depth whereas the higher the dry field density, the lower the field capacity and vice versa. This is consistent with the result reported in the literature for municipal solid waste by Jorge et al. (1999), field capacity show decreasing trend with depth. The Optimum Field Capacity was found to be 0.38L/kg which indicate the water holding capacity of the waste. This project suggested that, the results can be extrapolated to other landfills with similar characteristics, thus making it possible to design the dimensions of the devices required to control the production of leachate with greater accuracy. The methodology should be able to simulate different depths of any given landfill, and monitor the variation of field capacity under such circumstances. It is essential to standardize a methodology for the determination of actual field capacity because that is the only way to compare results obtained in different parts of the globe. It is highly advisable to perform this type of test at different times of the year, and running several series tests in each season, in order to find representative average values. The experiment should also be repeated using a larger quantity of solid waste and using larger lysimeters. This is the only way to increase the accuracy of the results, because there would be more control over variables such as drained water and the characteristics of the solid waste.

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