

Suction, Water Retention Capacity and Permeability Assessment of Compacted and Unsaturated Cover Layer

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Abstract— This paper exposes characteristics from an evaluated cover layer (0.6 m height) from the experimental Muribeca landfill of Urban Solid Residues (SUR), located in Jaboatão of Guararapes, Brazil. Through laboratory experiments of suction, grain size distribution, and permeability, those parameters were analyzed based in the existing technical standard Brazilian for this procedure. The soil was studied by the division of a cover layer, after 5 years from its completion, of 0.6m, in depth the upper half (0.1 m to 0.3 m) and lower half (0.4 m to 0.6 m), looking for differences of leaching through the upper to lower part. Therefore, the consequences to be presented from the leaching of the materials, after 5 years of finalization of the landfill, making its permeability increase. Concerning its water retaining, it is the most retained in the upper part, which comprises the compost, with a difference in the order of 7 per cent the superior half to inferior half, retaining the least suction from the surface. Leaching was detected through permeability procedure of worthless difference between upper and lower part of the cover layer. Nevertheless, results revealed the efficiency of the cover layer in retaining the rainwater, offering this layer as an alternative solution for the appropriate waste disposal.
Keywords— Landfill, Water retaining, Permeability, Suction, Cover layer.

I. INTRODUCTION

The daily solid waste generation is inherent to the development of the human begin activities and if there is no proper disposal of this waste, pollution is generated.

Therefore, the disposal of solid waste generated should be a society priority, aimed at preserving the environment and the maintenance of healthy conditions of life.

The landfill has main function to protect the population around the Muribeca Landfill with habitations from distance of about 300 meters. Besides, the cover layer has a fundamental importance, prevent infiltration of rainwater (which into contact with the waste occurs an increase of gas production and leachate, toxic to the population) and the migration of the gases generated by the waste into the atmosphere; it is a way to improve pollution control and to protect neighborhood.

There is a search for alternative materials for the cover layer system with geotechnical and chemical aspects of coherent with layer's goal. In the occurrence of difficulty in finding materials available with the appropriate parameters, it is necessary to look for an alternative cover layer. Thus, there are layers of soil mixed with sludge from water and sewage treatment plants, shredded tires, rubber-sand, organic compost, among others. (e.g., Ahmed and Lovell 1993; Bernal *et al.* 1996; Bressette 1984; Reddy *et al.*, 2010; Jun He *et al.*, 2015)

Brazilian standards ABNT (1997) for the design, implementation and landfill operation does not present any technical specification regarding the geotechnical properties of the cover layers in general, only an upper limit to its permeability to the landfill.

Therefore, this article was accomplished to evaluate the cover mixed layer to improve its use and certify if the cover layer still work as it is intend to be after 5 years of its closure. The soil mixed with organic matter from

municipal solid waste (oxidative layers) were in depth studied by Maciel (2009), Maldaner (2011), Lopes (2011), Santos et. al. (2014). It was evaluated the geotechnical behavior of the experimental landfill covering layer, performed in 2010, of Muribeca, Jaboatão of Guararapes – PE, supported of the Group of Solid Residues (GSR), located at Pernambuco Federal University.

The maximum retention for this layer was evaluated by Lopes (2011) with 49%. Santos et.al. (2014) exposed for the same layer, 48%.

For this, the study of the interaction of the covering layer with the environment will be present in respect to their loss of tightness and increased permeability of two orders of magnitude due to leaching of particles larger layer to lower layers.

The objective of this work to expose characteristics from an evaluated cover layer from the experimental Muribeca landfill of Urban Solid Residues through of laboratory tests such as: suction, grain size distribution, and permeability, based on standard Brazilian procedures.

II. MATERIALS AND METHODS

Laboratory tests were developed in Group of Solid Residues (GSR) oxidative covering layer on its upper (top - 0.1 - 0.3 m) and lower (base - 0.4 - 0.6 m) part, assessing the Environmental Geotechnical features and the Soil Physics.

The oxidative covering layer studied was from the experimental cell of the landfill Muribeca, after 5 years of the landfill finalization. This layer had formed by 0.3 m of the compacted soil followed by 0.3 m of compacted layer soil in a ratio of 75 % soil (clay) and 25 % compost as Fig. 1.

The study can determine the influence of leaching within 5 years on soil behavior of the covering layer, so that the permeability is affected and the impermeability of the landfill could turn on inefficient cover layer.

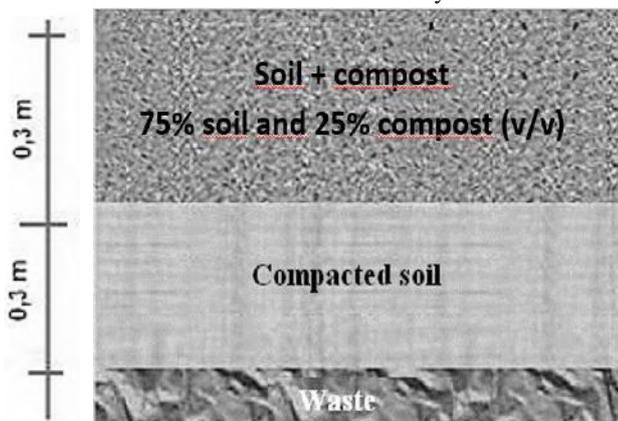


Fig.1: Sketch of assessed oxidative layer, where V/V means volume proportion.

2.1 Climate Data

Climatological data from Muribeca were obtained by the weather station located nearby to the landfill. Once the evaluation has performed based on the local microclimate the obtained parameters have a good accuracy for the necessary analyzes. There were collected rainfall data for the years 2009 to 2014, arranged with averages of each month for those years of analysis.

The region where Muribeca is located has two climatological characteristics of wet and dry conditions. Rainfall is abundant throughout the year and precipitation become of irregularly over time.

2.2 Soil Characterization

From the experimental cell of Muribeca where been taken undisturbed samples at two points (hole 1 and hole 2), illustrated in Fig. 2. Each sample had of approximately 0.2 m height. Disturbed samples for characterization with about 2000 g in desired depths were taken (on the cover layer). Three characterizations have performed as follows:

1. Characterization of the clay deposit;
2. Characterization of the layer in depth from 0.1 to 0.3 m into hole 1 and 2;
3. Characterization of the layer in depth from 0.4 to 0.6 m into hole 1 and 2.

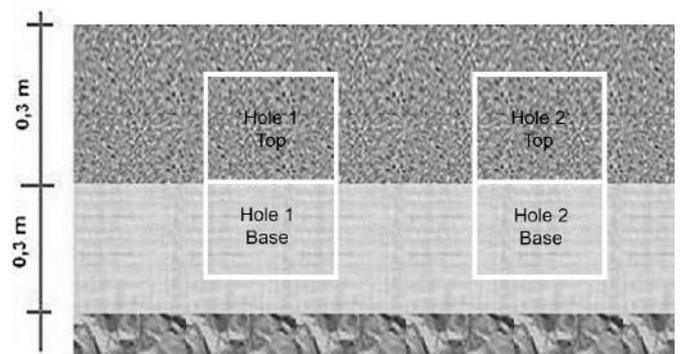


Fig. 2: Undisturbed samples from hole 1 and hole 2.

The laboratory tests, in turn, performed in accordance with the standards of the Brazilian Association of Technical Standards (ABNT) such as for particle size analysis (ABNT (1984b) Solo), determination of the liquid limit (ABNT (1984c) Solo), and determination of the plastic limit (ABNT (1984d) Solo).

To verify grain density two tests were conducted for the two soil depths studied in 2014, with the pycnometer 50 ml of capacity, placed approximately 10 g of each soil sample after had been sieved with a sieve # 200, according to DNER-ME 093/94.

It was possible to verify the porosity of the soil (n) according to the void ratio (e) calculated as given by:

$$e = H_v/H_s \quad H_s = W / (d * A) \quad (1)$$

Where:

e = Void ratio;

H_v = Specimen height (m);

H_s = Solids height (m);

W = Dry sample weight (kg);

d = Actual density of the grains (kg/m^3);

A = The sample area (m^2).

The porosity (n) was given by:

$$n = e / (1+e) \quad (2)$$

Santos et. al. (2014) showed that the same cover layer analyzed in this article had 42% of porosity behavior in 2014.

Analyzing voids ratio, was observed capacity of water raining retention, was given by:

$$L = n * H \quad (3)$$

Where:

L = Rainwater lamina;

H = Specimen height;

n = Sample porosity.

2.3 Soil water retention

To carry out the Retention Curve test were used the undisturbed samples collected from the oxidative layer from the depth of approximately 0.1 to 0.3 and 0.4 - 0.6m. From these undisturbed samples two steel rings of 20-mm in height and 60-mm in diameter were molded in the laboratory for suction tests.

To acquire the moisture equilibrium between soil and filter paper, the essay took seven (07) days for moisture homogenization.

The suction curve was obtained from the determination of the moisture from the filter paper on each side of each sample and the suction of the respective samples by using the equations proposed by Chandler et. al. (1992).

The tests were done 5 times for a successive loss of 6% water content started in around 45% water content until specimen present a residual water content, reaching 5 weeks of registered test.

2.4 Permeability (determination of hydraulic conductivity)

To perform this test were collected two soil samples on PVC cylinders with the characteristics of 0.15 m in diameter and 0.2 m in height depths from 0.1 to 0.3 m and 0.4 - 0.6 m each studied hole.

To perform the test have been taken in Tri - Flex 2 with imposition of a upflow hydraulic with 30kPa of pressure gradient and verify the time the water takes to percolate 5cm^3 through the sample.

The procedure was done 3 times to obtain an average of readings of time ranging +/-5%.

Water permeability coefficient (K_{sat}) was calculated by equation 4.

$$K_{\text{sat}} = V \times L / \Delta P \times t \times A_{\text{cp}} \quad (4)$$

Where:

K_{sat} = Saturated permeability to water flow (m/s);

V = Volume of percolated liquid (m^3);

L = Sample height (m);

ΔP = Pressure Variation (kPa);

t = Percolation time 5 cm^3 (s);

A_{cp} = Area of the sample (m^2).

Then the sample was taken out to dry in the air, after verified its moisture performed an air permeability test. The test procedures were similar to saturated permeability assay, but instead of water, the fluid inside the sample was air.

Then three flow readings were recorded in a flowmeter with a maximum capacity of 30 NL/h, because the 10 NL/h does not allow checking the permeability, since the sample had a high porosity material, adopting the average of the readings in the flowmeter.

According to Darcy's law (Eq. 5), the intrinsic permeability of the fluid, valid for incompressible fluids only, is:

$$K_{\text{int}} = v \times \mu \times L / \Delta P \quad (5)$$

Where:

K_{int} = Intrinsic fluid permeability (m^2);

v = Darcy's speedy parameter (m/s);

μ = Dynamic fluid viscosity (Pa.s);

L = Soil sample height length (m);

ΔP = Inlet and outlet pressure gradient (Pa).

For the air permeability analysis was sought another methods of assessing permeability of compressible fluids, in which Ignatius (1999) developed an equation (Eq. 6), made from Darcy's law, considering the effect of compressibility:

$$K_{\text{ar}} = 2 \times v \times \mu \times L \times P_s / (P_e^2 - P_s^2) \quad (6)$$

Where:

K_{ar} = Permeability of compressible fluids (m/s);

v = Percolation fluid velocity - Darcy (m/s);

μ = Dynamic viscosity of the air = $1,837 \times 10^{-5}$ Pa.s ;

L = Specimen length (m);

P_e = Inlet pressure (Pa);

P_s = Outlet pressure (Pa).

III. RESULTS AND DISCUSSION

The climate was analyzed through graphs of temperature and rainfall and drought chart to relate the rains with the soil water holding capacity of oxidative layer of 0.3m to 0.6m thick.

It is illustrated in Fig. 3 average precipitation and temperature data for the years 2009 to 2014; in Fig. 4 the average water deficit of the years 2009 to 2014. These data were collected from the weather station installed in Muribeca - PE.

It is clear, in that in the months from April to September, in which is located the wet condition, the rains are more intense, with positive water deficit reaching 108 mm in average. These data confirmed by the low temperature in these months, reaching a minimum average of 27,4°C on June, accordingly, the maximum average 296 mm of rain in the same month.

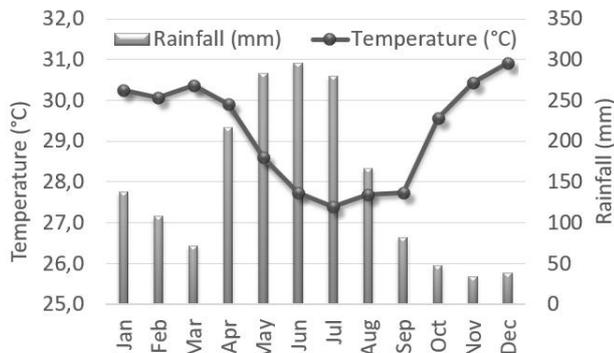


Fig.3: Climatological average data of temperature and rainfall in millimeters the years 2009-2014.

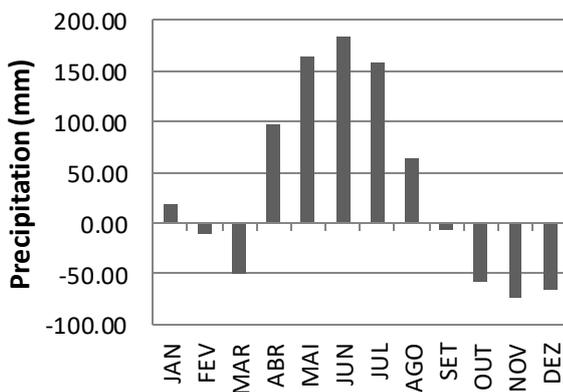


Fig.4: Water deficit for the years of 2009 to 2014

In the months of October to March settles the dry conditions, with negative water deficit reaching 41 mm in average. Through those months, the highest average temperature was found on December, with 31°C and the minimum average rainfall was in November, with 34.38 mm of rain.

From the samples collected were performed a characterization of the materials collected as shown in Fig. 5 and Table 1.

On the base, the landfill was compacted with sandy clay soil of the deposit, it was hoped, therefore, the behavior of hole 1 base and hole 2 base (LL, LP, gradation curve and classification by Unified System of Classification of Soils (USCS)) similar to the sandy clay soil deposit, but it has not happened.

Fig. 5 and Table 1 showed that the sandy clay soil of the deposit is a Clay with Low Plasticity (CL - USCS), but the soil from the hole 1 and hole 2, after 5 years of leaching and erosion has behaved like Silt (ML - USCS), similar with the topsoil.

The results from characterization showed that the topsoil and base were very similarly, however, different from the deposit of clay. It exposes that the clay of the base has leached, losing particles of soil. It was realized clearly in Table 2, where can be seen how the Ksat (permeability to water flow using the Eq. 4) and Kar (permeability to air flow using the Eq. 6) are close in average, but far from Lopes (2011) results.

Table 4 shows the porosity of a cover layer, with the porosity and voids of the evaluated holes between 0.3 and 0.6-m. These pores could be analyzed in terms of water accumulation capacity, in this case, regarding the porosity of the soil, the maximum capacity of water accumulation occupying all empty voids of the soil. Thus, the topsoil has, on average, 7% higher porosity/voids than the base, then afford the topsoil (soil + compost) absorbed about 7% more water than the base (clay).

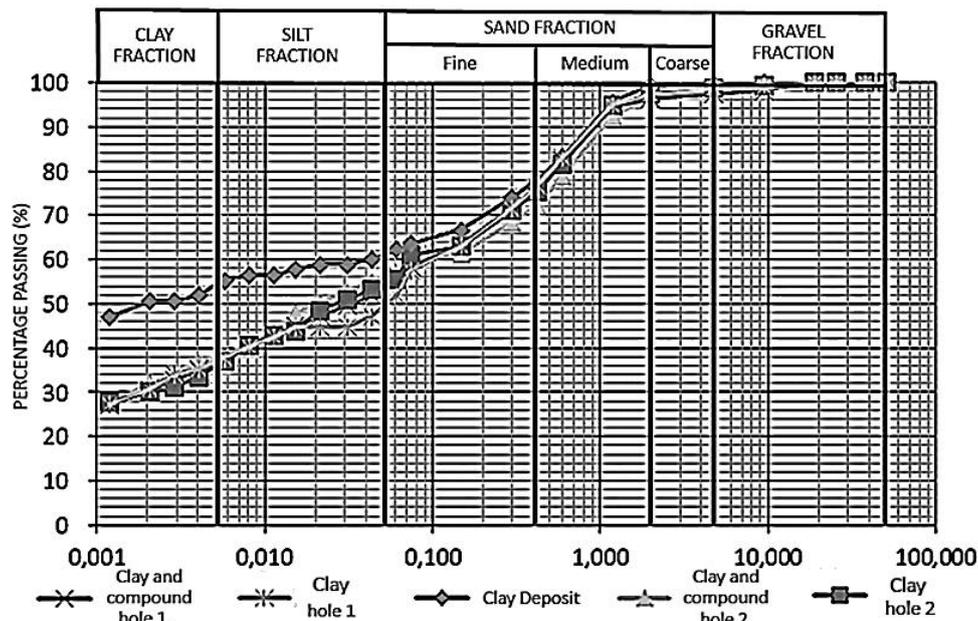


Fig.5: Particle size test hole 1 and 2 and the clay deposit.

Table.1: Parameters for Unified System of Classification of Soils (USCS)

Parameter	Clay Deposit	Clay and compost (hole1-top)	Clay (hole1-base)	Clay and compost (hole2-top)	Clay (hole2-base)
LL (%)	46%	52%	47%	47%	42%
LP (%)	32%	33%	33%	29%	23%
IP (%)	14%	19%	14%	18%	19%
USCS	CL	ML	ML	ML	ML

Table.2: The top Permeability (0,1-0,3m) and base (0,4-0,6m).

Permeability	Clay and compost (hole1-top)	Clay (hole1-base)	Clay and compost (hole2-top)	Clay (hole2-base)
Ksat (m/s)	2,8E10 ⁻⁰⁷	1,7E10 ⁻⁰⁸	3,4E10 ⁻⁰⁷	5,6E10 ⁻⁰⁷
Kar (m/s)	7,6E10 ⁻⁰⁷	5,6E10 ⁻⁰⁷	4,1E10 ⁻⁰⁷	4,0E10 ⁻⁰⁷

Lopes (2011) showed that in 2010 for the topsoil K_{sat} and K_{ar} as presented in table 3:

Table.3: The top (0,1-0,3m) and base (0,4-0,6m) Permeability.

Permeability	Clay and compost (topsoil)	Clay (base)
Ksat (m/s)	1,5 x 10 ⁻⁰⁹	9,2 x 10 ⁻⁰⁸
Kar (m/s)	4,4 x 10 ⁻⁰⁸	3,7 x 10 ⁻⁰⁷

Autor: Lopes (2011)

Table 4 showed higher porosity results than Lopes (2011), as the same way in current work (Eq. (8)), with 10% more porous.

Analyzing the Table 4, comparing with the sample porosity (n), and the Table 5, supposed specimen height (H), Eq. 9, in terms of water accumulation on voids in the soil, a layer of clay of and thickness of 0.3-m could retain excess 140-mm of water approximately. While a layer of the same thickness of soil mixed with compost a ratio of 3:1, could retain 160-mm. As for a layer 0.6-m thick, the clay could retain water 290-mm surplus, while the soil mixed with compost could retain around 315-mm, on average.

The maximum retention for the soil concerning porosity was evaluated from 48% to 40 % on the top and the base respectively, as shown in Table 4 and Fig. 6.

Table.4: Porosity

Sample	Porosity(n)
Hole 1 top	49%
Hole 1 base	48%
Hole 2 top	56%
Hole 2 base	49%

Table.5: Supposing Hight of 0,3 m and 0,6 m for a layer with soil from each hole.

Soil	Supposing Voids in H = 0.3 m (m ³ /m ²)	Supposing Voids in H = 0.6 m (m ³ /m ²)
Hole 1 top	0,15	0,29
Hole 1 base	0,14	0,29
Hole 2 top	0,17	0,34
Hole 2 base	0,15	0,29

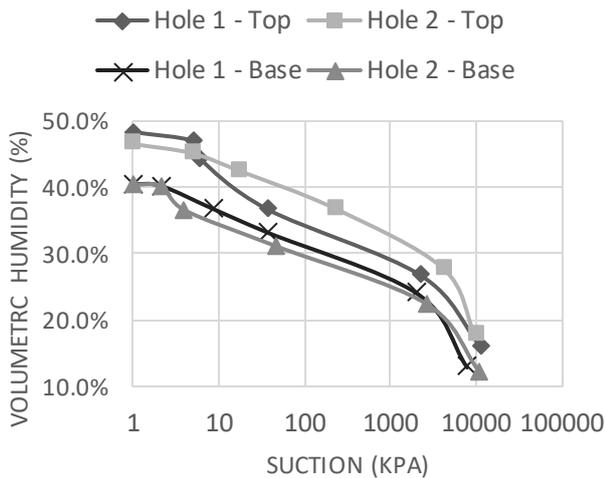


Fig.6: Suction curve holes 1 and 2 x Volumetric Water content.

Suction on inlet point (GAE) is an important parameter of air inlet through the landfill, which oxygen atmosphere causes methane oxidation. Therefore, the GAE has to be to prevent this air inlet.

In Fig. 7 it could be seen the suction on inlet point (GAE) 3200kPa evaluated for the clay (base) with degree of saturation of 49% and 5,500kPa to soil mixed with compost (topsoil) with degree of saturation of 63 %. This decrease of the degree of saturation is closely linked to leaching and the increased porosity of the topsoil.

Analyzing the behavior of each soil sample from the moisture variation (Δw) and suction ($\log \Delta S$), was been obtained the expected soil retention for the first stage (before the GAE point) using the physical indexes ($C = \Delta w / \log \Delta S$; Table 4). It was observed on average that the topsoil (soil mixed with compost 1:3) possesses higher water holding capacity (5.8 %) than the base (5.1%).

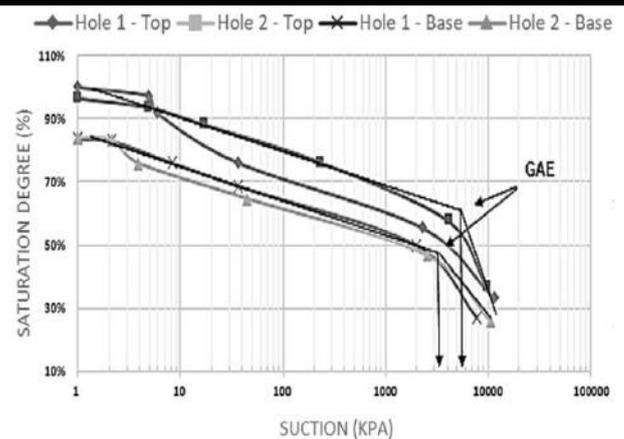


Fig.7: Suction Curve x Saturation Degree.

Table.4: Retention (C)

Samples	C
Hole 1 – Top	6,4%
Hole 1 - Base	5,0%
Hole 2 – Top	5,2%
Hole 2 – Base	5,2%

Analyzing void ratio, calculated by Eq. 7, in the samples studied, was observed that the samples had small changes and that the topsoil had obtained a greater variation of voids compared to the base, Fig. 8.

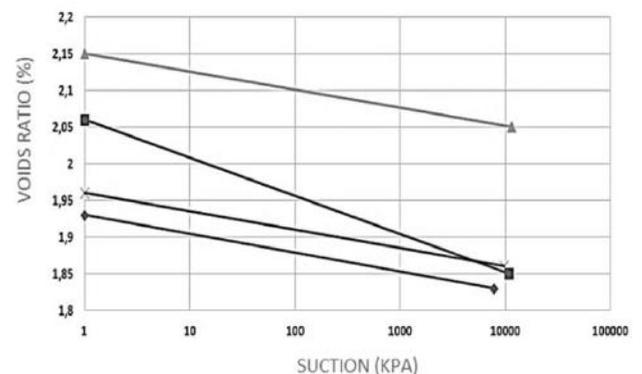


Fig.8 : Suction curve x Voids ratio

Analyzing Fig. 8 on average for both samples, the base scores a variation of 0.10% of voids ratio, while the topsoil 0.16%. This behavior of the variation of voids in the soil and the moisture reduction, which was set in particle size test from the soil, is common for a low compressibility soil, characteristics that a soil from a landfill should have to maintain the sealing of the cover layer (Ignatius, 1990).

IV. CONCLUSIONS

In granulometry test, was observed that there is no sensitivity in the test for detecting the occurrence of leaching from the upper layer to the lower layer after a

period of 5 years of landfill closing, in a final cover layer of 0.6 m height.

The porosity and void ratio of the cover layer increased after 5 years. Against Lopes (2011), it was found from the porosity that the topsoil (ML) was obtained in around 7 % more voids than the base (ML). Similarly, was observed to void ratios topsoil 7 % higher than the sandy clay soil. Comparing to Lopes (2011) results, it was observed on topsoil an increase on K_{sat} of two orders of magnitude and on K_{ar} an increase of one order of magnitude, within 5 years, causing an inefficient sealing in the cover layer. Comparing the permeability of base (clay) and topsoil (clay and compost), it was observed that the soil mixed with the compost is more porous, with higher permeability to air and water than the base.

The suction test is closely related to the porosity and voids ratio of the soil, it was observed that the soil mixed with compost (1:3 - topsoil), showed greater water retention capacity, on average, of 5.8 %, and the soil of the base, on average, of 5.1%.

The air inlet point (GAE) of the soil had a reduction related with saturation, after 5 years, demonstrating a correlation with increased porosity.

Analyze the weather and the water surplus are required to perform a cover layer of a landfill. Therefore, for anywhere that exists a water deficit of around 200-mm of rain, a layer of 0.6 m of clay soil of low compressibility mixed with compost in the ratio of 1:3, similar to the one analyzed from this paper, would have an efficient water proofing. For a region with precipitation around 100mm, a layer of 0.3m with the same 200-mm materials would be sufficient. In Recife city center with water deficit of 184 mm, it is suggested a layer of the same composition with 0.4m thick, which should bear a retaining around 213-mm of rain.

According to the features expected in a landfill, the soil presented compatible granulometry (clay - ML) and K_{sat} and K_{ar} (10^{-7} m/s in average for both), after 5 years of the Muribeca landfill finalization. Its efficiency is has been maintained.

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