Addition of Bentonite to Residual Soil

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ABSTRACT: Disposal in landfills is one of the main waste management practices in developing countries. The coverage system is a relevant factor during the construction and closure of landfills, considering leachate and gas production. The permeability control of the cover is important to improve the quality of the landfill. Sodium bentonite has proved to be one of the most effective sealants. The fact that it expands considerably when moistened leads to good sealing, in addition to being environmentally friendly. In Brazil, its mixture with soil has been used in coverage systems aiming to reduce permeability and the formation of cracks. Due to the high price, bentonite is used only in small proportions. The objective of this study was to determine the ideal percentage of bentonite in landfill cover systems with residual soil collected in a landfill near the city of Rio de Janeiro. A testing device was developed and installed that monitors the weight and moisture of the sample in real time, as well as suction through a tensiometer attached to the base. Results of the desiccation and permeability tests with different percentages of bentonite mixed with the soil are presented.

1 INTRODUCTION

The bacteria that degrade garbage need to breathe to do their job, a process that produces gases and leachate in landfills. Gases can be used to generate energy and carbon credits. In turn, leachate must be treated, which has a high ongoing cost in the management of landfills. The main problem is how to control water intake in a way that is not excessive, jeopardizing the landfill's stability, or too low, impairing the waste degradation processes. The main consequences of inadequate water input are increased administrative costs, reduced gas production, excessive leachate buildup and fewer possibilities for good energy use of the landfill.

Consideration should also be given to the presence of appropriate loan material in the vicinity of the landfill for its coverage. It is important for the landfill cover to have low permeability and ability to react to moisture loss without excessive cracking, which causes a significant increase in permeability as well as erosion. The formation of cracks is caused in particular by evaporation, starting at the moment the soil is exposed to the atmosphere, and by evapotranspiration of the plants. The water contained in the pores evaporates, causing an increase in negative pore pressure, which raises the effective pressure and causes volume reduction (Kleppe & Olson, 1985). The phenomenon of drying tends to cause irreversible changes in clays and at high temperatures can cause removal of adsorbed water, destroying the colloid properties and the expansive capacity of clays (Unal & Trogol, 2001). Expansive clays deform much more when expanding than contracting.

If soil water loss occurs in a gradual way, the soil volume decreases gradually, and ends when it reaches the limit of drying. This depends on the soil type, its mineralogy, structure and initial and final moisture. In the case of compacted soils, the increase in cracks is related to the increase in compaction moisture. If compacted with low moisture, the degree of saturation is low and the negative pore pressure has little impact on the effective pressure. If soil is compacted with high moisture, it has a high degree of saturation and substantial change in effective pressure (Kleppe and Olson, 1985). The amount of added bentonite is extremely important. Because it is an expansive material, it is indicated in cases where the desire is to reduce the formation of cracks and to have active behavior, with easy recovery. Mokhtari and Dehghani (2012) described the swell-shrink behavior of expansive soils. Most of the conclusions were related with swelling.

Tay et al. (2001) conducted a study with addition of 10 and 20% bentonite and compaction moisture ranging from 8 to 32%. The specimens were exposed to air and the formation of cracks was observed. Specimens compressed with 15% moisture and 10% bentonite addition (by dry weight) showed no visible cracks and those with 20% moisture only small cracks in the case of 20% bentonite addition.

The type of bentonite also influences the cracking process. Most commercial bentonites are of the sodium type. In the study of Egloffstein (2001), during the first four air-drying cycles the properties of sodium bentonite with large expansion capacity were maintained.

In a study carried out by Montañez (2002) using sandy soil with addition of bentonite, several test specimens were compacted with different initial moisture levels, but all with values close to the specific dry weight. The result of all drying tests tended to follow a common relationship, and during wetting, the same relationship was observed, confirming the hysteresis of the drying and wetting curve. Still in the study by Montañez (2002), regarding the volumetric variation of several test specimens, they observed that during the first drying there was no volumetric variation. During the first wetting cycle there was a significant increase in volume. For suction values less than 1000 kPa, the increase in volume was more noticeable, and the greatest volumetric increase occurred at suction values below 100 kPa. In the second drying cycle, there was volumetric variation until the residual saturation value was reached, and from this point on, there was no volu- metric variation. They also observed the influence of the size of the drying-humidification cycle on the volume variation. The amount of bentonite added to the soil caused a slight displacement of the soil's characteristic curve compared to the soil without addition of bentonite, and the degree of residual saturation increased with rising bentonite content.

The characteristics of the soil water retention curve are determined by the combination of the retention curves of its components. In the initial drying stage, the presence of sand changes the bentonite retention curve, resulting in higher suction values than those corresponding to bentonite for the same moisture values.

The drying curve of the mixture tends to approximate the bentonite curve, and both can coincide. The experimental results suggest that when the suction reaches values between 1000 and 3000 kPa, all the water present in the mixture is associated with bentonite. For suction values lower than these values, the water present is associated with the two components of the mixture, bentonite and sand (Montañez, 2002).

Often the loan material, even if well compacted and close to ideal moisture, does not have sufficiently low permeability to control the inflow of water into the landfill and the production of gases and leachates. An important alternative is to add sodium bentonite. To study the effect of its addition to landfill cover soil, a device was developed that allows monitoring the desiccation process and possible formation of cracks by visual observation. Figure 1 shows cracks in the cover of a waste landfill near the city of Rio de Janeiro.

Figure 1.Landfill cover soil with cracks.

One of the major problems of using soil as a cover layer in landfills is the infiltration of rainwater. This infiltration can increase due to erosion, soil drying (leading to cracking) and the presence of animals andvegetation.

In this study, soil was mixed with bentonite in eight different concentrations for permeability testing. The minimum permeability coefficient considered adequate by the environmental agency of the state of Rio de Janeiro for cover material is on the order of 10^{-9} m s^{-1}. Constant load permeability tests were performed for different percentages of soil/bentonite mixture. In addition to suction, the moisture, sample weight and temperature were measured during the drying test and the final condition of the sample was visually observed.

2 MATERIALS ANDMETHODS

2.1 Soil analyzed

The soil was characterized as being composed of sand, silt and clay (Figure 2)

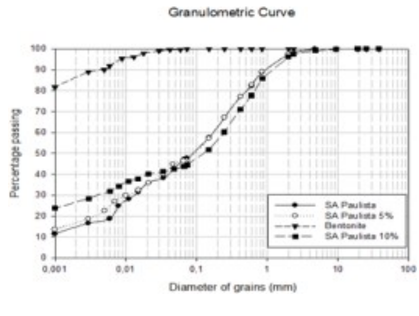

Figure 2.Granulometric distribution (Huse and Mahler, 2007).

Table 1 shows various geotechnical parameters of the soil studied and the bentonite used:

Table 1. Geotechnical parameters

	Real Grain Density	*Liquidity Limit (%)*	*Plasticity Limit (%)*	*Permeability Coefficient (m/s)*
Sand-Silt-Clay (SSC)	2.67	44.5	21.12	10^{-8}
BENTONITE	2.78	505.6	46.3	10^{-14}
SSC + BENT (5%)	2.71	75.5	28.3	10^{-9}
SSC + BENT (10%)	2.68	71.0	30.3	10^{-9}

In relation to dry apparent specific weight (g/cm3), sand-silt clay (SSC), SSC+ BENT (5%) and SSC + BENT (10%) present the respective values: 1.52, 1.45 and1.58.

The field capacity of the studied soil was determined by the characteristic curve, the moisture content for the matrix potential being 0.033 MPa, according to the method of Cassel and Nielsen (1986). The obtained field capacity results were AM1 33.1, AM2 31.4, AM3 30.4, AM4 29.8 and AM5 30.2 (Figure 3), with a mean moisture content value (X) of 30.98%, standard deviation of 2.65% and a coefficient of variation (s/X) of 0.09 (Ferreira & Mahler, 2006).

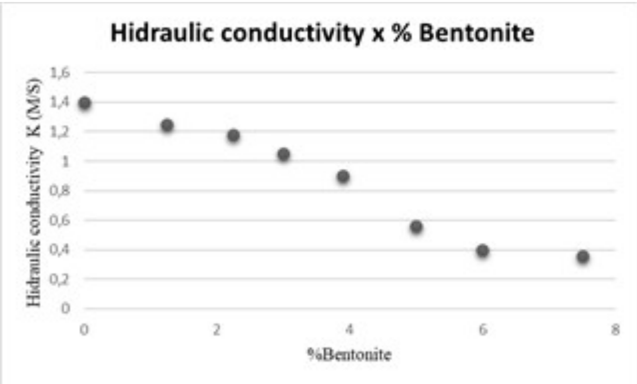

Figure 3. Characteristic curves of the soil (Ferreira and Mahler, 2007).

2.2 Active wetlands of soil and bentonite waterproofing

Waterproofing layers prevent percolation of fluids, thanks to the unique healing characteristic of preferred paths, faults and or holes in liners. When composed of a mixture of soils with bentonite, they guarantee the permanently expandable characteristic, when there is a need for healing.

2.3 Types of bentonite

There are two types of bentonite: Sodium bentonite has a natural swelling ability and will maintain its swelling ability throughout use. Calcium bentonite is a non-swelling bentonite, which does not swell without additives such as chemicals. Calcium bentonite enhanced with additives will quickly lose its swell ability.

It is the swelling ability of sodium bentonite that enables this clay to bond with the soil to create an impenetrable liner.

The quality of sodium bentonite deposits varies. As an additive to reduce the soil permeability, a sodium bentonite was used whose grain size distribution curve is also presented in Figure 2. It has a permeability coefficient of $1x10^{-14}$ m/s (Boscov et al., 2007), true grain density (Gs) of 2.78, LL of 505.6% and LP of 46.3%.

2.4 Soil type and index properties

The cover layer is built to prevent seepage of rainwater and thereby significantly reduce the production of leachates and gases. Soil erosion and desiccation can affect the behavior of the cover and lead to the formation of cracks.

One of the properties of bentonite is expansibility, particularly sodium bentonite. By adding bentonite to the natural soil, the capacity of the soil to crack by drying can be substantially reduced. Also, the mixture with sodium bentonite produces a cover with permeability coefficient within the official environmental limits.

The ideal amount of sodium bentonite to add to the cover soil of a landfill is found by determining the permeability coefficient of the soil without bentonite and with different levels of it. In this case, the option was to add different amounts of bentonite mixed with soil. The maximum permeability coefficient considered appropriate for the cover material is 10^{-9} m/s. Permeability tests were carried out with samples from 0% to 10% sodium bentonite mixed with the soil. The results are shown in Figure 4.

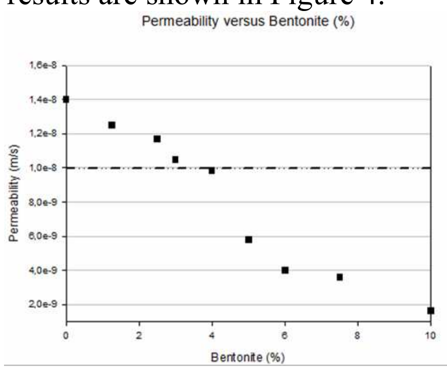

Figure 4.Hydraulic conductivity vs. % of added bentonite.

2.5 Tensiometer

The tensiometer was installed at the base of the device, in contact with the sample where the suction is measured.

A tensiometer consists basically of a porous stone, a transducer, and a metallic or acrylic body to support the porous stone, transducer and water (Figure 5).

Figure 5. Acrylic body, porous stone already installed and pressure transducer used.

The problem of cavitation, occurring usually around 80 kPa in traditional devices, is very common in tensiometers. This problem was solved by using a porous disk with high air entry value in a new tensiometer (Mahler et al., 2002; Mahler et al., 2005; Diene and Mahler, 2007), which comprises the following considerations:

- Use of good quality porous disk with high air entry built with an appropriate bubbling pressure for the maximum suction rates to be measured;
- Use of water during porous disk saturation and tensiometer assembly;
- Use of acrylic or extremely smooth steel in the tensiometer assembly to prevent the possibility of air captured between the water and equipment walls during the system saturation;
- Assembly, saturation, and calibration carried out with extreme care;
- Special care in the choice of technical specifications and characteristics of the transducer, which must also be appropriate for the suction rates.

This tensiometer measured suctions of up to 1450 kPa (Mahler and Diene, 2007), as shown in Figure 6, which presents the results obtained with the tensiometer described here, and with an equitensiometer (Diene and Mahler, 2007), and a TDR.

Figure 6. Tensiometer results (Diene & Mahler, 2007)

2.6 Desiccation test equipment

The equipment (Figure 7) built comprises a cylindrical body to which a tensiometer is adapted at the base (Figure 7). The soil was compacted in the size of Proctor and CBR samples. A geothermometer was also installed at the base and at the top of the equipment. The external temperature was measured as well. At the top of the equipment there is an opening through which the sample can be vented to accelerate drying. The device was supported on a load cell so that the weight could be measured continuously. Sample moisture is determined at the beginning of the test and the loss of moisture is controlled by measuring the weight of the system. The drying process was observed by loss of water and visually by the formation of cracks. Thus, the test checked the volumetric variation, suction, temperature, and water content. All the devices and parts were weighed separately at the beginning of the test.

Figure 7. Free desiccation equipment (Huse, 2007).

2.7. *Sample preparation*

The soil, already dewelled and passed through a #10 sieve, must be homogenized with water and placed in the humid chamber for a minimum period of 24 hours. Subsequently, it should be compacted in the tripart mold, which should be wrapped in plastic film. Still inside the mold, drilling is done to place the thermometer at the top and bottom. An effective increase in absolute suction was observed with addition of bentonite, caused by the higher percentage of fine particles present in the soil/bentonite mixture. The samples were prepared above the optimum compaction moisture with initial moisture being different, which may have caused some discrepancies in the sample behavior.

3 RESULTS

Only with the addition of 4% bentonite by dry weight to the soil was permeability on the order of 10-7 cm/s achieved. Characterization tests were car- ried out for the soil with addition of 5% bentonite by dry weight. The LL for this soil was 75.5% and LP was 28.26%.

Only a small change occurred in the grain size curve of the soil mixed with 5% bentonite, with a slight increase in clay and silt fraction in relation to the pure soil (Figure 2). The main gain was in relation to the geotechnical characteristics, with an increase in plasticity indices.

The optimum moisture content for the soil with 5% bentonite as determined by the compaction test was approximately 23.4%, corresponding to specific dry weight of 1.55 g/cm3 , and the permeability coefficient of this soil was on the order of 10-9 m /s.

Figure 8 presents results of the characteristic curves relating suction and moisture. In all of them, the suction decreases in absolute value with higher moisture, with smaller values for the samples with greater bentonite content.

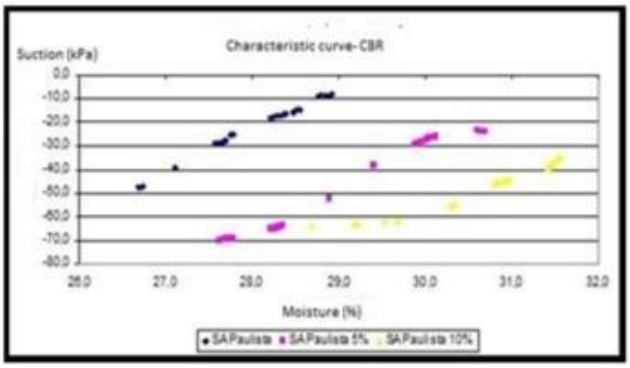

Figure 8. Characteristic curves relating suction and moisture

Figure 9 presents two photos of samples having CBR size after the test. The color is associated with water presence. The fissures were very small and only observed in the cases without addition of sodium bentonite.

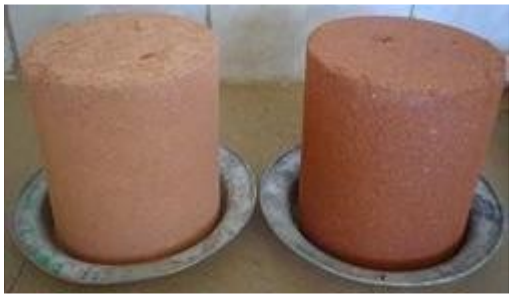

Figure 9. Samples with CBR size at the end of the tests without addition of sodium bentonite

4 CONCLUSIONS

The addition of bentonite improved the plastic characteristics of the original soil, as well as the permeability. Ii also improved swelling of the mixed soil, which still showed contraction, but lower. The tensiometer developed worked satisfactorily, even operating in a range of low suction values.

For the same water, the results showed lower suction with less bentonite, indicating lower stress resistance to contraction and production of fissures.

The creation of active barriers is certainly a good solution to decrease the permeability of landfill cover layers and to assure that it can adapt to the great deformations of the landfill satisfactorily, especially the shrinkage process during hot and dry weather periods.

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