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Emissions of gases through various types of materials used as cover layers of an experimental chamber filled with municipal solid wastes

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The biogas generated in urban sanitary landfills can be harmful to the atmosphere when lost through the cover layer, contributing to the greenhouse effect. The present study aimed to evaluate the performance of different materials in the reduction of gas emissions to the atmosphere when used as cover layers in a sanitary landfill. The cover with the Emerald grass obtained the best result among the covers tested, showing the lowest average rate of methane emission at 0.7% compared to 0.8% emitted through the conventional layer. The Emerald grass, however, had an average emission of 1.0% of carbon dioxide gas, which was 150.0% higher than the 0.4% from the conventional layer. The civil construction waste and coconut fiber had an average escape of methane at 0.8% each, yet both were above the average value of the carbon dioxide gas liberated by the conventional layer. The worst result was for the grained pruning residues with an average value of 2.8% methane and 10.5% carbon dioxide. In conclusion, the cover layers vegetated with the Emerald grass contributes to the reduction of greenhouse gas emissions, optimize the use of biogas in the production of energy, and promote environmental rehabilitation of the sanitary landfill.

Key words: Landfill, cover layers, gas emissions.

INTRODUCTION

Among the management strategies of municipal solid waste (MSW), the sanitary landfill is the most used strategy globally, mainly in third world countries (Xu et al., 2014). In Brazil, the majority of the waste is destined for sanitary landfills, which should be designed based on engineering studies to ensure the secure containment of the wastes, to control environmental pollution, to reduce environmental impacts caused in waste disposal, and avoid damage to public health. When dumped in sanitary landfills, wastes generate by-products through biodegradation, in their anaerobic, non-anaerobic methanogenic and methanogenic phases, in the form of liquids and gases (Silva et al., 2013), which need to be treated and utilized.

The main components of the gas produced in sanitary landfills are methane (CH_4), carbon dioxide (CO_2), ammonia (NH_3), nitrous oxide (N_2O) and sulfur dioxide (SO_2), harmful to health, with methane being the greatest contribution to the greenhouse effect, representing 50 - 55% of the biogas produced in sanitary landfills (Jin, 2015; Ahmed et al., 2015; Johari et al., 2012). The CH_4 and CO_2 gases are freely emitted to the atmosphere or simply burned in the majority of landfills of Brazil, losing an important source of energy in one way or another (Audibert and Fernandes 2012). According to Candiani (2011), methane gas presents a global warming potential 21 times greater than carbon dioxide (CO_2). Lopes et al. (2013) affirmed that methane has 23 times more potential than CO_2 in contributing to the greenhouse effect.

Considering these alarming figures, the sanitary landfills are responsible for 10 to 20% of the methane emissions generated by anthropogenic activity.

A fraction of the gas generated in sanitary landfills can cross the residue conventional cover layers (soil layer), escaping into the atmosphere, even when the chambers use biogas capture systems.

These systems are often incapable of capturing 100% of the gases generated and significant portions end up escaping to the atmosphere. The cover system must then avoid or minimize the losses of these gases through the surface by forcing the direction of the gases to the drains, ultimately optimizing the treatment and use of the gases (Silva et al., 2013).

The wastes in conventional cover systems of sanitary landfills are covered by a layer of compacted soil to form a physical barrier between the decomposing waste and the atmosphere. The soil is usually virgin soil from the area in which the landfill has been located. Over time and with the typical weather conditions of northeastern Brazil (high temperatures and long periods of drought) the efficiency of the layer becomes reduced and permits the gases to escape to the atmosphere. The emissions also vary with the type of soil used in the final cover layer, the thickness and the degree of compaction of this soil, the type and age of the existing waste, and in addition to the geotechnical characteristics of the terrain (Silva et al., 2013; Maciel and Joey, 2011; Mariano and Juca, 2010).

The rate of surface methane emissions measured by static flow plates ranges from 0 to 14,749 g/m².day (Silva et al., 2013; Capaccioni et al., 2005; Park and Shin, 2001; Tanaka et al., 1997). Silva et al. (2013) studied fugitive emissions of methane through the cover layer of two sanitary landfills in Brazil. The test was carried out at two landfill locations using the flow plate and found methane leakage through the surface cover, representing 16% of the emissions at Bandeirantes landfill and 35% at the Caieiras landfill.

Biocovers have been used as a mitigation strategy of the gas emissions to the atmosphere through the final cover layer of sanitary landfills. Santos and Mota (2010) investigated the behavior of a turf and four species of grass planted over the final layer of the sanitary landfill, and demonstrated that the Mombasa grass (*Panicum maximum cv Mombaça*) had a greater retention capacity relative to the conventional cover of the landfill.

In this context, it is important to determine the emissions of the gases through the cover layer of the sanitary landfill, to monitor the efficiency of the systems, and to propose alternative materials. The alternative materials must be resistant to the climate, of low cost, represent an environmental problem when disposed incorrectly, and capable of reducing the escape of gases to the atmosphere, optimizing the use of both the gas as well as the material in question to contribute to the reduction of greenhouse gases.

This study aimed to evaluate six different materials as alternatives cover layers for sanitary landfills, and to analyze their capacity to reduce biogas emissions into the atmosphere.

MATERIALS AND METHODS

The present study was carried out at the Aterro Sanitário Metropolitano Oeste of Caucaia (ASMOC), located in the municipality of Caucaia, Ceará, Brazil, bounded by the parallels 3º 45’ and 3º 47’ longitude south and by the meridians 38º 43’ and 38º 45’ longitude west, lying about 30 km from the center of Fortaleza, Ceará.

The operating procedure of this landfill consists of the weight of the wastes, daily compaction and cover for a soil layer 30 to 50 cm in thickness until it reaches a height of approximately 8m where the slopes of the chamber are compressed and the collection drains are installed until reaching a total height of about 3m where the cover layer or the final layer of 0.8 to 1.0m in thickness is compacted. An experimental chamber with the following internal dimensions was constructed in 2011 to execute the study: length of 50 m, height of 10 m and width of 50 m (total volume: 25,000 m^3). The experimental chamber was filled with solid wastes, destined to ASMOC, spread and compacted with a final inclination of 2H (horizontal): 1V (vertical), with an intermediate cover layer at 5 meters height and a final conventional top layer of soil with about 80 cm.

In qualitative terms, there are several factors that can alter the composition of the biogas. Despite so many variables to characterize the behavior of a chamber in the production and emission of gases, without a doubt the most influential is the composition of the waste in decomposition. It is understood that when there is a higher content of organic matter, there is a greater and faster decomposition of the domestic waste.

The composition of the disposed waste is considered to depend directly on the behavior of the population as guided by the customs of the population, technological advances, local development, education, population growth, economic situation and consequently consumerism. Thus, no chamber is equal to another. Therefore, an analysis was performed in the gravimetric composition of the wastes used at the time of filling the experimental chamber.

The quartering method was used for the wastes generated in Fortaleza-CE-Brazil and destined for ASMOC. With the aid of a platform balance with a capacity of up to 150kg, a 100L recipient container lined with a plastic liner of 15m^2 was used to weigh the waste. A portion of 1,600kg of waste was collected randomly from the trucks that arrived at the landfill and was weighed five times (five repetitions). This volume was divided into four parts of 400kg each, of which two parts were discarded randomly and the other two parts were homogenized (800kg). The remaining volume was divided again into four parts of 200kg each, of which one part was randomly selected and analyzed according to its gravimetric composition.

In January 2014, six modules with different covers were installed above the experimental chamber, each with areas of $9m^2$ (3m x 3m), organized randomly according to the scheme shown in Figure 1. The modules consisted of the following materials:

- Civil construction residues (CCR) – such wastes are constantly generated and reused in the civil construction industry, but the possibilities of reuse and the units for its treatment are still quite small when compared to the large volume generated. Thus, this waste of low value not fully consumed, making its final disposal and deposition an environmental problem.
- Residues from the weeding of streets (dry weeds) – is the product of cleaning public roads from weeding, where there are small plant species or shrubs that do not generate substantial volumes of stalk or wood, but has a constant supply and large total volumes since it is mixed with the products of the street sweeping (land and inorganic waste).
- Emerald grass (*Zoysia japonica*) – among the materials chosen, the emerald grass (Zoysia japonica) is the material with the highest value when considering the high cost to finalize the cell in the recovery of degraded areas of the landfill. However, Alberte *et al*. (2005) showed that revegetation is an alternative in the recovery of the area, including the natural landscape, and provides security to maintain the sustaining and sanitary conditions of the landfill. The vegetation aims to minimize erosion with the rapid establishment of the roots. Once the pioneer vegetation became established, the secondary, successive and climax vegetation should require less maintenance over time, decreasing the long term costs.
- Mombaça grass (*Panicum maximum cv Mombaça*) – with the intent to compare two plant species, a second option of vegetation undergrowth was chosen of low cost seeds, of easy proliferation and plantation, and with commercial value, as it is used to feed grazing cattle.
- Coconut fiber – many studies have sought to make use of the coconut residue and have achieved success in its processes, but the uses are still modest in comparison with the volumes of the wastes generated. The production chain of this fruit is well established in Ceará, which is a major producer in the Northeast, but it is a massive fruit in which only its liquid content is used when the fruit is green, and then its fleshy material when the fruit is dry. Thus, the coconut fiber and its rigid shell become a problem for disposal since it is highly degradable organic matter and is generated in large volumes.
- Grained pruning residues (pruning) – cleaning of the public roads is also consisted of the pruning residues and taken from the vegetation from the areas where their existence could threaten the safety and wellbeing of the population. This waste is destined for the sanitary landfill where it is crushed, generating tons of organic matter from the pruning residues. Some of this material is reused in the fabrication of agglomerate (such as a brick) and used as fuel for burning. The majority, however, is discarded in the same landfill generating tons of organic material disposed in the cells.

These materials were placed to substitute the cover layer consisted of compacted soil, with the exception of the vegetated layers that were planted over the conventional layer. In addition to these materials, the conventional cover used in the landfill operations was evaluated as a comparative control to the other modules tested and the composition its gases from the drain were analyzed as well.

Samples of residues were collected under the areas of each module to characterize the materials in decomposition in the experimental chamber, to thus accompany the stage of decomposition of the wastes disposed in the cell for more than three years.

A static flow plate was used to determine the flows of CH_4 and CO_2 through the cover layer of the experimental chamber according to the methods described by Mariano and Juca (2010), in six different periods, that encompassed six distinct months of which three comprised the rainy season (February, March and April) and three comprised the dry season (May, June and July) in the State of Ceará.

The static flow plate was designed in the form of a "step" (10 cm height and width) and was conceived to prevent the entrance of atmospheric air into the interior of the container. The "step" remains in direct contact with the soil, thus ensuring the passing of the flow only in the area of 40 x 40 cm^2, which retain the gas in its internal environment while being monitored, as shown in Figure 2a. The plate also has two quick release valves that are easy to seal at the top, for the proper fitting of the measuring equipment (Figure 2b). For the installation of the flow plate, a trench was excavated in the shape of the larger step and the excavated soil was reserved in a way to fit the shape of the space to permit the positioning of the plate. Then, the spaces were filled with the excavated soil and then compacted manually to be installed as shown in Figure 2c.

The compositions of the gases were determined using the equipment LANDTEC GEM 5000, for three hours and five minutes. The first 5 minutes of the data collection was done at 1 minute intervals, at 5 minute intervals for the first hour, at 10 minute intervals for the second hour, and at 15 minute intervals for the third hour, where each measurement was taken over a 30 second span. This procedure was carried out in the morning and the evening for the six experimental modules and for the conventional cover layer of the cell. For each data collection 30 values were taken, which, in six periods totaled 180 values for each module analyzed.

The quantification of the methane gas and the carbon dioxide emitted through the cover layer was done using the statistical mean of the values obtained in the tests

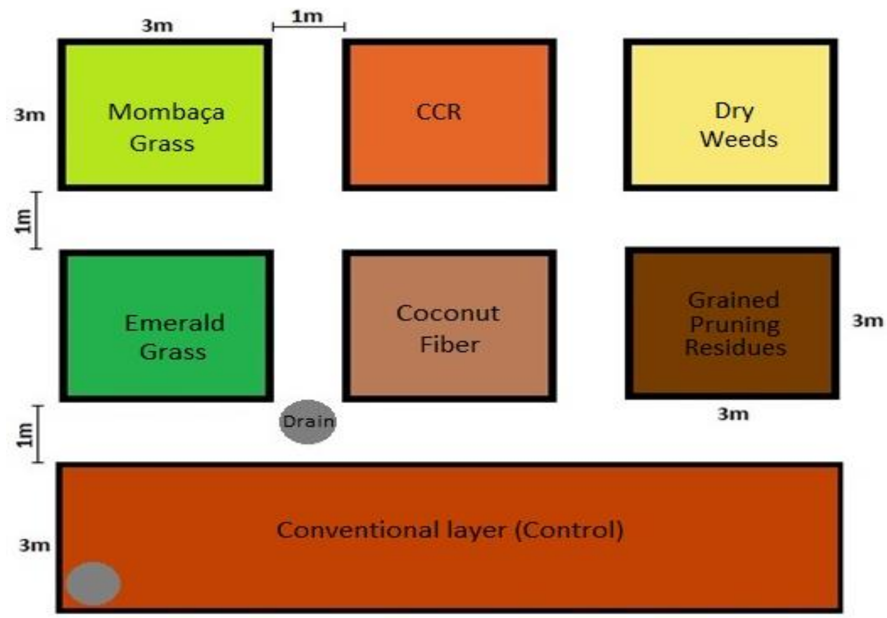

Figure 1. Distribution of the modules, with different cover materials in the area of study.

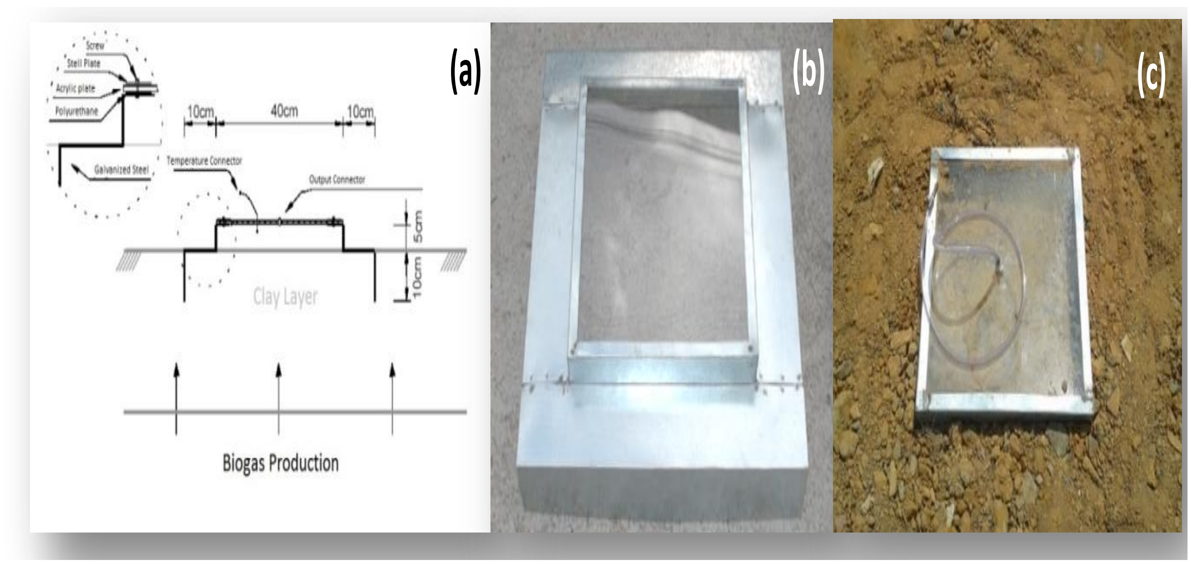

Figure 2a. Static flow plate design and settling scheme of the plate; (b) Static flow plate ready; (c) Static flow plate installed. Source: Adapted from Maciel and Juca, 2011.

with the flow plate in each module.

RESULTS AND DISCUSSION

Gravimetric analysis

The solid wastes destined for the experimental cell had the following physical composition: food wastes (35.8%), flexible plastic (12.4%), diaper (8.4%), rags (7.7%), paper (4.8%), hard plastics (3.2%), compost (3.0%), cardboard (1.9%) newspaper (1.8%), PET (1.5%), dark glass (1.4%), carton packaging (1.4%), iron (0.8%), clear glass (1.2%), rubber (1.1%) and aluminum (0.8%), others (12.6%).

These data should not be compared and are included in this work as a reference, since they vary according to the origin of the wastes, the different types, economic situation and consumption habits of the population, and the different methodologies adopted to quantify these percentages. It is worth noting that at least 35.8% of the waste is composed of organic material, which is fundamental in the production of biogas.

Characterization of the waste mass

Table 1 shows the values found for the various parameters of the mass of waste disposed in the experimental chamber, corresponding to the various cover modules: M1 – Dry Grass, M2 – Pruning, M3 – Civil Construction Residue, M4 - Coconut Fiber, M5 – Mombasa Grass and M6 – Emerald Grass.

The optimum range of pH for the majority of the anaerobic bacteria is 6.7 to 7.5, or, close to neutral. The production of methane is favored when within the optimum range of pH, whereas the production is limited when outside of this range. The pH values found in the samples generally remained within the optimal pH range for decomposition reactions, although the pH values in the M2 (grained pruning residues) and M6 (emerald grass) modules were a little below the minimum limit.

The moisture supports microorganisms that decompose the organic matter existing in the solid wastes. The moisture content influenced the calorific value and the moist specific weight of the residues. According to Caterpillar (2001) and Monteiro and Zveibil (2001) the moist content of the municipal solid wastes could varied from 40 to 60%, depending on the season of the year, on the sampling procedures, and on the composition of the residues. The values of the moist content found in the present study were observed to be within the normal range of moisture found for municipal solid wastes in decomposition and, thus do not constitute a limiting factor in the production of biogas.

The solids are important indicators of the degradability of solid wastes, especially the volatile solids (Silva *et al*., 2011). The high concentrations of solids indicated high concentrations of organic material, while lower values represented wastes that underwent a sharp degradation process. In examining the values determined for the solids (Table 1), the analyzed materials can be considered as being in an advanced stage of decomposition, because they possess low concentrations of total solids thus are treated as older wastes with the reduced production of biogas. It is necessary to remember that the experimental chamber was filled with wastes in 2011 and the characterization of the levels of solids in the present study occurred in 2014.

When examining Table 1, the mass of the waste exhibited low concentrations of nitrogenous compounds. Microorganisms that act during hydrolysis and fermentation experience reduced growth rates when there is a deficiency of nutrients. This decrease of nutrients represents a stable degradation process, characterizing the methanogenic phase, which corroborates with the other results analyzed.

Characteristics of the biogas

The conventional cover system of the ASMOC is comprised of the soil native to the site where the landfill is located. The soil is composed of 26.4% coarse sand, 19.2% fine sand, 33.4% silt and 21.0% clay, and with a density of 1.22g/cm³.

The conventional cover allowed the escape of on average 0.7% of methane and 0.4% carbon dioxide while the drain, in turn, contributed to an average of 33.0% methane and 24.4% of carbon dioxide to the atmosphere. This means that the conventional layer is able to retain 97.6% of the methane and 98.4% of the carbon dioxide emitted by the experimental cell, appearing as a good option of sealing material to use as a cover layer.

Table 2 shows the mean values of CH_4 and CO_2 emissions present in the biogas, for the different cover materials. In this table it is possible to notice that the vegetated layer with the emerald grass had the best results among the materials analyzed, retaining 13% more than the average methane in the conventional cover, but allowed carbon dioxide to escape 2.5 times more than the control. Still, the Emerald grass remains as a good option for the cover layer since the methane has the potential to contribute 21 to 23 times more than carbon dioxide to the greenhouse effect (Candiani, 2011; Lopez et al., 2013).

The coconut fiber and the civil construction residue had the same performance as the control with respect to the retention of methane, but both wastes allowed carbon dioxide to escape on average 3 and 10.75 times more than the control.

With respect to the control, the dry weeding demonstrated a moderate effect on the escape of the gases, averaging 13% more methane and 1.12 times more carbon dioxide than the conventional layer.

The Mombasa grass did not produce the expected results. Despite being a plant species with a niche similar to the Emerald grass, the Mombasa grass retained on average 200% less methane and 500% less carbon dioxide than the conventional layer.

The corresponding module to the pruning residues showed the worst results among the materials analyzed. This material allowed methane to escape on average 7.0 times more than the conventional layer and 26.25 times more than the conventional layer. Considering the gravity of the gases that contribute to the greenhouse effect, the pruning residues should not be considered for use as the final layer in sanitary landfill cells.

Figure 3 shows the means of the concentrations of CH_4 in the biogas for the different cover layers, in the 6 (six) measuring months. In observing Table 2 and Figure 3, the module containing the emerald grass was noted to

Table 1. Characteristics of the mass of waste disposed in the experimental chamber.

Module	pH	Moist Content (%)	Nitrogenous Compounds (mg/l)			Total Solids (mg/l)
			Ammonia	Nitrite	Nitrate	
M1	7.0	30.4	2.96	0.882	0.219	68.64
M2	6.5	49.8	7.4	0.271	0.317	48.59
M3	7.0	52.4	2.8	0.182	0.326	45.43
M4	7.3	25.1	2.62	0.228	0.457	74.37
M5	6.8	10.3	3.63	0.198	0.155	88.46
M6	6.6	36.3	4.73	0.116	0.174	62.89

M1 – Dry Grass, M2 – Pruning, M3 – Civil Construction Residues, M4 – Coconut Fiber, M5 – Mombasa Grass, M6 – Emerald Grass.

Table 2. Concentration average, minimum and maximum CH_4 and CO_2 in the control layer and in the 6 different cover layers, and retention capacity of these gases in the layers tested in relation to the control layer.

Cover Layer	Mean (%)		Minimum (%)		Maximum (%)		CH_4 retention in relation to control	CO_2 retention in relation to control
	CH_4	CO_2	CH_4	CO_2	CH_4	CO_2		
Control	0.8	0.4	0	0.1	1.7	1.6	-	-
Emerald Grass	0.7	1.0	0	0	7.9	0	-13%	150%
Coconut Fiber	0.8	1.2	0.2	0.4	1.5	2.0	0%	200%
CCR	0.8	4.3	0.1	0	1.5	16.1	0%	975%
Dried Grass	0.9	2.8	0.2	0	1.8	7.0	13%	600%
Mombaça Grass	2.4	2.4	0.9	0.1	12.8	8.1	200%	500%
Pruning	2.8	10.5	0.7	1.1	6.2	23.3	250%	2525%

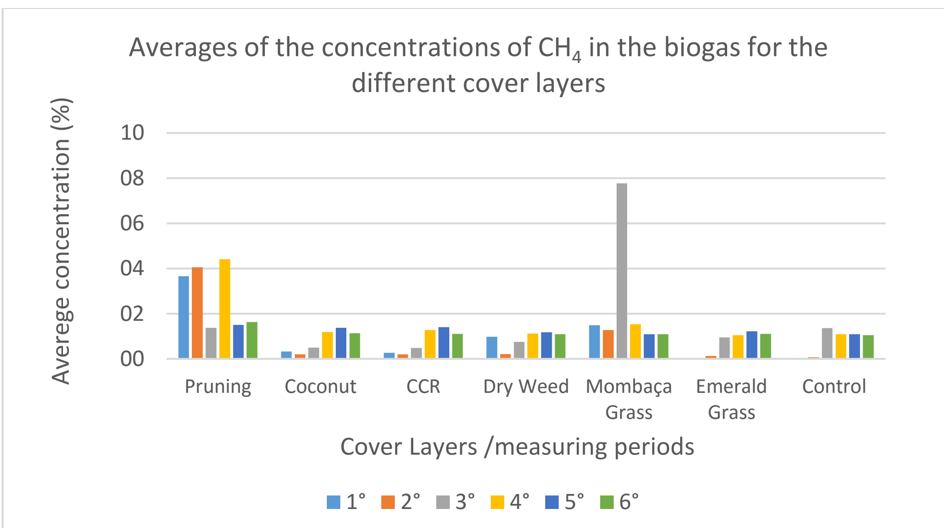

Figure 3. Averages of the concentrations of CH_4 in the biogas for the different cover layers, in the six measuring periods in 2014.

emit the lowest amount of CH_4, with values below those found for the cover layer of the experimental chamber (control). The other cover materials presented average levels of CH_4 higher than those emitted in the conventional cover layer of the experimental chamber with the soil (control). The module with the Civil Construction Residues – CCR demonstrated satisfactory values of CH_4 emission throughout the 6 measurements, which leads to the conclusion that the accommodation of the material over the residue is conditioned to optimize the capacity to retain gases.

In most of analyzed modules increases in the concentrations of CH_4 in the final periods of the analysis were found, which is explained by the high incidence of rain in the initial months and the consequent infiltration of liquids into the cell, but also the increases occurred with mild temperatures. The filling of empty spaces and the percolation of liquids impede the habitual liberation of gas, while, after the rainy period the soaked ground becomes dry, but maintains sufficient moisture to maintain the bacterial reactions and consequently increase the production of biogas.

The Mombasa grass, although not present, in general, poor results, had its performance hampered by the data taken in the third month of measurement, when recorded an average peak of 7.8% of methane. This peak was probably caused due to the occurrence of rain the night before data collection. According Boltze and Freitas (1997) at a time when there is excess moisture in the soil may lead to higher carbon dioxide dissolution in the ground water, through water-filled pores, increasing the methane concentration in the released gases. These authors also argue that changes in wind speed, temperature, atmospheric pressure and precipitation (especially rain or irrigation), can alter gas emission. These factors do not necessarily operate in isolation. Some may be combined and generate diurnal and seasonal influences on gas flux.

The cover composed of the grained pruning residues demonstrated the worst biogas emission among the layers studied. This waste is consisted primarily of organic material. When this waste becomes in contact with rainwater, its decomposition reactions become accelerated after the assimilation of water through the system, releasing additional gases to the atmosphere, which will be added to the gases released by the waste that lies beneath this covering layer.

Conclusions

In general, the cover with the emerald grass was shown to be the most effective barrier among the materials studied for the emission of methane to the atmosphere in sanitary landfills, demonstrating better results than the conventional layer using compacted soil.

The Civil Construction Residues also demonstrated promising results for the retention of CH_4, indicating a potential for its use as a cover layer or an intermediate layer for sanitary landfills.

Although the other materials studied demonstrated a lower retention efficiency of CH_4, they may still be used over the final layer of soil over the sanitary landfills, which could result in a smaller quantity of gases escaping to atmosphere.

In addition to reducing the emission of gases that cause climate change, the use of turf and grasses over the final cover layer provide the revegetation of the surface of sanitary landfills. Besides the positive visual and protector effect, the remediation of these areas with the use of plant species is generally a legal requirement and a social commitment that needs to be executed (Londe and Bitar, 2011).

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