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CLIMATIC CHARACTERISTICS AND HOURLY VARIATIONS IN BIOGAS CONCENTRATION IN A SANITARY LANDFILL IN NORTHEAST BRAZIL

CARACTERÍSTICAS CLIMÁTICAS E VARIAÇÕES HORÁRIAS DA CONCENTRAÇÃO DO BIOGÁS EM UM ATERRO SANITÁRIO LOCALIZADO NO NORDESTE DO BRASIL

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ABSTRACT

This study determined the hourly variations in the concentration of methane (CH_4), carbon dioxide (CO_2), and oxygen (O_2) during 24-hour periods in a sanitary landfill located in Northeast Brazil, with a predominantly hot tropical mild semi-arid climate. Data were collected over 24 hours in four campaigns in November 2014 and January, March, and April 2015. The measurements were taken in a drain of the sanitary landfill using a portable gas analyzer. We found that, in general, the highest methane concentrations corresponded to the highest biogas temperatures. The maximum concentration of CH_4 (59.2%) occurred at a temperature of 36.8ºC, while the minimum concentration of CH_4 (43.2%) was identified at a temperature of 25.4ºC. No relationship was found between CH_4 emissions and rainfall, with temperature being the factor that most influenced the concentration of this gas.

Keywords: solid wastes; methane emissions; carbon dioxide emissions; nychthemeral analysis; temperature; biogas generation.

RESUMO

Neste trabalho foram determinadas as variações horárias das concentrações de metano (CH_4), dióxido de carbono (CO_2) e oxigênio (O_2), ao longo de 24 horas de medições em um aterro sanitário localizado na região nordeste do Brasil, onde predomina o clima tropical quente semiárido brando. Foram realizadas quatro coletas de dados durante 24 horas, cada, nos meses de novembro de 2014, e janeiro, março e abril de 2015. As medições foram feitas em um dreno do aterro sanitário, utilizando-se um analisador portátil de gás. Constatou-se que as maiores concentrações de metano foram encontradas para os maiores valores de temperatura do biogás. A máxima concentração de CH_4 (59,2%) ocorreu para a temperatura de 36,8ºC, enquanto a mínima concentração de CH_4 (43,2%) foi determinada para a temperatura de 25,4ºC. Não se observou relação entre a emissão de CH_4 e a ocorrência ou não de chuvas, sendo a temperatura o fator que mais influenciou a concentração desse gás.

Palavras-chave: resíduos sólidos; emissões de metano; emissões de dióxido de carbono; análise nictemeral; temperatura e geração de biogás.

INTRODUCTION

According to Nabavi-Pelesaraei *et al*. (2017), the exponential increase in both technological development and human population since the industrial revolution led to continuing growth in the amount of waste produced. In addition, environmental issues related to the indiscriminate production of various types of waste have become more important than ever.

Further, according to Karak, Bhagat and Bhattacharyya (2012), municipal solid waste (MSW) is expected to double over the next decade due to population growth, increasing urbanization, and the social and economic development of low- and middle-income countries.

Sanitary landfills have been used as a solution for MSW disposal. However, various environmental problems can result from their use, especially gas production, whose characteristics depend on the decomposition of the waste.

MSW decomposes in sanitary landfills due to various processes with several phases. Residue decomposition depends on numerous factors, mainly the presence or absence of oxygen, the availability of microorganisms, and the environmental conditions. Essentially, organic matter, which is usually at its greatest volume in the waste mass, is decomposed by bacteria and, to a lesser extent, fungi and protozoa (LUCERONI, 2017).

Escamilla-García, Tavera-Cortés and Pérez-Soto (2017) points out that biogas is generated in particularly high volumes in landfills (also known as landfill gas), and that organic matter is decomposed in the landfill in the absence of oxygen, resulting in biogas emission to the atmosphere.

The main components of the gas produced in landfills are methane (CH_4), carbon dioxide (CO_2), ammonia, nitrous oxide, and sulfur oxide. Methane is the gas that most contributes to the greenhouse effect (JIN, 2015).

It is produced by the anaerobic biodegradation of MSW and represents 50–55% of the biogas generated in landfills (JOHARI *et al*., 2012).

According to Riddick *et al*. (2018), the chemical breakdown of organic matter in landfills represents a significant source of CH_4. Current estimates suggest that landfills are responsible for 3–19% of global anthropogenic emissions. Net CH_4 emissions resulting from biogeochemical processes and their modulation by microbes in landfills are poorly understood due to imprecise knowledge of environmental constraints. This uncertainty regarding absolute CH_4 emissions from landfills is therefore considerable.

According to Oliveira (2000), landfill biogas has a molar composition of 40–55% methane, 35–50% carbon dioxide, and 0–20% nitrogen.

MSW landfills are the third-largest source of human-related methane emissions worldwide, accounting for approximately 15.4% of such emissions in 2015 (EPA, 2016; XI and XIONG, 2013).

Methane, the main gas produced from waste decomposition, is the second-largest contributor to anthropogenic emissions of greenhouse gases. This situation requires attention in Brazil, where approximately 4,000 open dumps are still being used, contributing to environmental contamination (MACIEL; JUCÁ, 2012).

As stated by Abushammala *et al*. (2014), the migration of CH_4 from landfills to the surrounding environment negatively affects both humankind and the environment. Therefore, developing management techniques to decrease CH_4 emissions from landfills is crucial to minimize global warming and reduce the human risks associated with CH_4 migration.

The environmental impact of gaseous emission from landfills, which are globally or regionally significant, can be mainly grouped into contribution to the greenhouse effect and damage to the ecosystem. Apart from that, the risk of explosion and the odor problem due to some trace gases can also be identified as significant impacts. Landfill gas can pose an environmental threat because methane is a greenhouse gas and many of the volatile organic compounds (VOCs) are odorous and toxic (DANTHUREBANDARA *et al*., 2012).

According to Trulli *et al*. (2013), organic carbon is the common element among the biodegradable materials that allow the development of energy and production of methane; many studies have investigated municipal waste on other sites.

Qasaimeh, Abdallah-Quasaimeh and Hani (2016) state that functional parameters, such as abiotic factors and landfill operating procedures, influence the rate of landfill gas production. The abiotic factors of concern can be summarized as pH, nutrients, inhibitors, temperature, and water content, while the landfill operating procedures of interest can be summarized as waste composition, addition of sewage sludge, shredding, compaction, soil cover, leachate recirculation, and pre-composting.

According to Moreira *et al*. (2017), factors such as rainfall affect the physical, chemical, and biological processes responsible for the consumption of organic matter and generation of biogas in landfills. A case of higher biogas production took place about two months after a peak of heavy rainfall, preceded and followed by periods of drought.

Silva and Campos (2008) evaluated gas production and quality at the Bandeirantes Landfill, São Paulo, Brazil. The results of this work indicated that the gas production of a landfill well depends not only on favorable factors to anaerobic degradation but on the conditions of the landfill drainage system and external environmental factors.

The landfill ecosystem is quite diverse due to the heterogeneous nature of waste and the variety of landfill operating characteristics. The diversity of the ecosystem promotes stability; however, the system is strongly influenced by environmental conditions such as temperature, pH, the presence of toxins, moisture content, and the oxidation-reduction potential (DANTHURE-BANDARA *et al*., 2012).

Rada *et al*. (2015) revealed that temperature affects the kinetics of anaerobic biodegradation. They further stated that the lack of information about the hydrological balance of a landfill and, consequently, the water content of waste leads to uncertainties and approximations in estimating the biogas potential.

Biogas generation increases significantly with temperature, as demonstrated by the results of several studies (ANDREOTTOLA; COSSU, 1998).

Amini, Reinhart and Niskanen (2013) highlight the challenges in measuring large-scale emissions, i.e., under actual landfill conditions, as well as the broad fluctuations of these emissions over space and time.

According to Zhang *et al*. (2019), for the foreseeable future, landfills will continue to be one of the main methods for solid waste disposal. Thus, systematic and in-depth research on greenhouse gas emissions from landfills is necessary.

Biogas is little explored in Brazil, and its potential remains controversial, mainly due to the different evaluation methodologies adopted. Considering the existing estimates, Brazil exploits only 7 to 20% of the biogas produced in landfills for energy purposes (NASCIMENTO *et al*., 2019).

According to Maciel and Jucá (2012), Brazil has few projects for energy recovery due to some factors: uncertainty in predicting the generation of biogas for local waste conditions and climates; lack of development of local technology (specific equipment for landfill biogas); low financial viability of the electrical energy produced from biogas in the current market scenario.

Pagliuso and Regattieri (2008) conducted research in the sanitary landfill of São Carlos, Brazil, a city with 200,000 inhabitants, to verify the feasibility of the thermal treatment of the leachate using landfill gas as the energy source. So far, the results show that there is enough energy to make the leachate incineration possible, but more research is underway, since the gas flow rate may have a large variation from well to well, and not all of them have been assessed. The chemical balance showed that the air pollution potential for the thermal process is small and, even with no gas treatment, most of the emissions would be lower than the one established by the environmental legislation.

The landfill gas generated in MSW landfills can be emitted to the atmosphere through the gas collection system or by its escape through the final cover layer (LOPES; MACIEL; JUCÁ, 2012).

In Brazil, few studies have addressed gas emission through drains and cover layers.

Lopes, Maciel and Jucá (2012) investigated superficial CH_4 emissions at three different cover layers in an experimental cell, located in the Muribeca Landfill, Recife, Pernambuco. According to them, the study of alternative cover layers and their physical-chemical and constructive properties to reduce CH_4 emissions and prevent pollution of the atmosphere is extremely important for most small- and medium-sized landfills in Brazil, where the recovery of landfill gas is incipient and impractical.

Many authors have employed the biochemical methane potential (BMP) assay to determine the methane generation potential from a certain amount of refuse on a small scale.

Schirmer *et al*. (2014) monitored the generation of biogas with BMP assays, commonly used to assess the anaerobic biodegradability of solid and liquid wastes under controlled conditions. The experiment used 5 g of substrate of both refuses (fresh and one-year-old wastes), digested with 250 mL of inoculum in 1 L flasks as bioreactors (all of them in triplicate, operating under batch conditions at ± 35ºC). Despite the distinct ages of the refuses evaluated, they showed no significant differences in volume (near 1,800 mL) and composition (55% methane) of the biogas generated in 80 days of incubation under mesophilic conditions. The important parameters of both refuses (such as moisture content, volatile solids, and chemical oxygen demand) also presented very similar initial values.

Despite the number of studies available in the literature, the comparison of biodegradability data between them is hard due to the diversity in experimental conditions, such as substrate and inoculum amounts, inoculum nature, the flask headspace volume, environmental parameters, etc., besides the different units in which results are presented (ANGELIDAKI *et al*., 2009).

Biogas generation capacity from sanitary landfills has usually been investigated in Brazil with international models.

According to Crovador *et al*. (2018), international data may not be suitable for landfills in Brazil. Thus, field studies need to be carried out to determine biogas production from landfills.

Zhang *et al*. (2019) highlight that researchers from different countries have recently proved that landfills are an important source of greenhouse gas (GHG) emissions. Nonetheless, few reviews have been conducted within the associated fields, resulting in a lack of comprehensive understanding related to relevant study achievements.

Few studies have investigated hourly variations in biogas production in landfills. In Brazil, we found no data on hourly variations in gas emission through drains.

Rada *et al*. (2015) used a modified model of biogas generation in a sanitary landfill in Italy. The changes considered the role of the temperature field normally established within each layer of waste. The study revealed that temperature affects the anaerobic biodegradation kinetics. Therefore, nine sets of kinetic constants, derived from literature, were employed for the simulations. Results showed significant variability in the maximal hourly biogas flow on a yearly basis, with consequences for the collectible amount during the operating period of a hypothetical engine. The approach is a useful tool to assess the lowest and highest biogas productivity in order to analyze the viability of biogas exploitation for energy purposes.

Studies on variations of landfill biogas emission throughout the day are important, especially when using this gas for energy production.

This study carried out a nychthemeral analysis (continuous analysis) of gas emissions in a sanitary landfill to determine variations in the concentrations of CH_4, CO_2, and oxygen (O_2) over 24 hours of measurements.

Investigations like this (field studies) are essential, mainly because they consider the specific climatic characteristics of Northeast Brazil.

MATERIALS AND METHODS

The research was developed in the Western Metropolitan Sanitary Landfill of Caucaia (*Aterro Sanitário Municipal Oeste de Caucaia* — ASMOC), located in the municipality of Caucaia, in the state of Ceará, Northeast Brazil. The area of the landfill is within the coordinates 3º45’ and 3º47’ S, and 38º43’ and 38º45’W (GOVERNO DO ESTADO DO CEARÁ, 2015). The area for waste disposal is 78.47 hectares.

This sanitary landfill receives MSW from the cities of Fortaleza and Caucaia. On average, the solid waste destined for the landfill has the following physical composition: food waste (35.8%), flexible plastic (12.4%), diapers (8.4%), rags (7.7%), paper (4.8%), rigid plastic (3.2%), garden residue (3.0%), cardboard (1.9%), newspaper (1.8%), PET (1.5%), dark glass (1.4%), cartons (1.6%), iron (0.8%), light glass (1.2%), rubber (1.1%), aluminum (0.8%), and others (12.6%). The gravimetric composition was performed in 2016. The method used for waste characterization was sampling and weighing refuse by category.

The cover layer is about 60 cm thick and consists of 26.4% coarse sand, 19.2% fine sand, 33.4% silt, and 21.0% clay, with a density of 1.22 g/cm^3.

A clay layer ensures waterproofing of the landfill base. Gas capture in drains has been done passively.

A nychthemeral analysis of gas emissions was carried out in a drain of one cell of the sanitary landfill, with readings taken at intervals of 30 minutes. Data were collected over 24 hours in four campaigns in November 2014 and January, March, and April 2015.

The overall average mass flow of CH_4 and CO_2 emitted through the cover layer near the drain was determined as follows: 0.77x10^{-2} g/m^2.s. and 1.54x10^{-2} g/m^2.s, respectively.

The drain where the measurements were taken was adapted for the installation of the gas meter, as shown in Figure 1.

The drain (approximate height — 12 m) was located in a landfill cell in full gas production (methanogenic phase) (MONTEIRO, 2016).

Figure 1 – Gas measurement in a drain of the Sanitary Landfill in Caucaia, Ceará, Brazil.

The gas measurements were taken using a LANDTEC model GEM™ 5000 portable gas analyzer. GEM™ detection principle for methane and carbon dioxide is based on the ability of these gases to absorb electromagnetic radiation in the infrared range.

Table 1 shows the mean monthly rainfall in the research area in the months in which the gas concentrations were measured.

The heaviest rainfall occurred during April and May, which is common in the region where the survey was conducted. In November, the rainfall was negligible, which is also usual during this period.

In the semi-arid region of Northeastern Brazil, the highest rainfall occurs during the first six months of the year, while in the last six months, rainfall is very low.

RESULTS AND DISCUSSION

Table 2 shows the concentrations of CH_4, CO_2, and O_2 in the biogas collected in a drain of the landfill on different days. The table also contains data on gas temperature.

The highest temperatures occurred in November 2014 (36.8ºC) and January 2015 (36.1ºC), while the lowest temperatures were identified in March and April 2015 (23.1 and 25.4°C, respectively).

Thus, the greatest concentrations of CH_4 happened at the highest biogas temperatures. The maximum concentration of CH_4 (59.2%) occurred at a temperature of 36.8ºC, while at a temperature of 25.4ºC, the methane concentration was 43.2%.

These results corroborate the findings of Aghdam, Scheutz and Kjeldsen (2017), who declared that an

Table 1 – Monthly precipitation in the research area. Caucaia, Ceará, Brazil.

Measurement	Period	Monthly precipitation					
		Normal (mm)	Max. (mm)	Deviation (%)	Normal (mm)	Mean (mm)	Deviation (%)
1	Nov/14	3.4	8.2	141.7	3.4	3.2	-6.7
2	Jan/15	106.5	106	-0.5	102.8	50.4	-51
3	Apr/15	277.9	685.2	146.6	282.7	325.4	15.1
4	May/15	287.9	712	147.3	287.4	313	8.9

Table 2 – Concentrations of CH_4, CO_2, and O_2 and temperature of the biogas from the Caucaia Sanitary Landfill, Ceará, Brazil, in hourly measurements over 24 hours.

Days	8 & 9 Nov, 2014				9 & 10 Jan, 2015				23 & 24, Mar 2015				23 & 24 Apr, 2015			
Parameter	CH_4 (%)	CO_2 (%)	O_2 (%)	Gas temp. (°C)	CH_4 (%)	CO_2 (%)	O_2 (%)	Gas temp. (°C)	CH_4 (%)	CO_2 (%)	O_2 (%)	Gas temp. (°C)	CH_4 (%)	CO_2 (%)	O_2 (%)	Gas temp (ºC)
Mean	58.5	40.2	0.0	34.7	55.8	44.2	0.0	34.9	56.9	42.9	0.2	25.2	57.1	41.0	0.1	27.4
Minimum	57.0	40.0	0.0	31.9	55.4	43.8	0.0	31.9	53.8	41.8	0.0	23.1	43.2	33.5	0.0	25.4
Maximum	59.2	41.7	1.3	36.8	56.2	44.6	0.1	36.1	57.9	44.7	4.4	26.7	58.6	41.7	4.0	29.3
Mode	58.8	40.2	0.0	35.4	55.6	44.4	0.0	35.4	57.3	42.8	0.0	26.1	57.4	41.5	0.0	29.2
Standard deviation	0.6	0.2	0.2	1.2	0.2	0.2	0.0	1.2	0.8	0.6	0.7	1.1	2.4	1.3	0.6	1.2

RBCIAMB | n.54 | dez 2019 | 1-12 - ISSN 2176-9478

increase in temperature leads to a higher production of CH_4.

Aghdam, Scheutz and Kjeldsen (2017) determined and compared the BMP from different types of shredder waste (SW) — fresh, old, and sieved. The biotic experiments showed that when the moisture content was 35% w/w, and the temperature was 20–25ºC, CH_4 production was extremely low. Raising the temperature from 20–25 to 37ºC resulted in significantly higher CH_4 production, while further increasing the temperature from 37 to 55ºC led to higher CH_4 production, but to a lesser extent.

A study carried out by Gollapalli and Kota (2018) estimated CH_4 and CO_2 emissions from a landfill in Northeast India using a flux chamber, from September 2015 to August 2016. The average emission rates of CH_4 and CO_2 were 68 and 92 mg/min/m^2, respectively. Emissions were higher in the Summer and lower during the Winter. The diurnal variation indicated that emissions follow a trend similar to that of temperature in all seasons. CH_4 presented an excellent correlation with temperature. The correlation coefficients for CH_4 and temperature during the Summer, monsoon, and Winter were 0.99, 0.87, and 0.97, respectively.

The research area showed no significant seasonal variation, only periods with more or less rainfall. There are few changes in the climate of the semi-arid region of Northeastern Brazil during the year.

We found no significant differences in CH_4 emissions due to rainfall. In the research area, the period of very low precipitation coincides with the highest ambient temperatures; thus, as pointed out above, the temperature of the biogas contributed most to the changes in CH_4 concentration.

In studies developed in regions with seasonal variations, the concentration of landfill gas changed throughout the year.

Rada *et al*. (2015) developed a model of biogas generation and used it in a sanitary landfill in Italy. Results showed significant variability in maximum hourly biogas flows on a yearly basis. Based on the considered scenarios, the annual average for the calculated maximum hourly biogas flow presented large variability, ranging from 114 Nm^3 h^{-1} to 180 Nm^3 h^{-1}.

Some studies have shown that higher CH_4 and CO_2 emissions are more common during the wet season than the dry season.

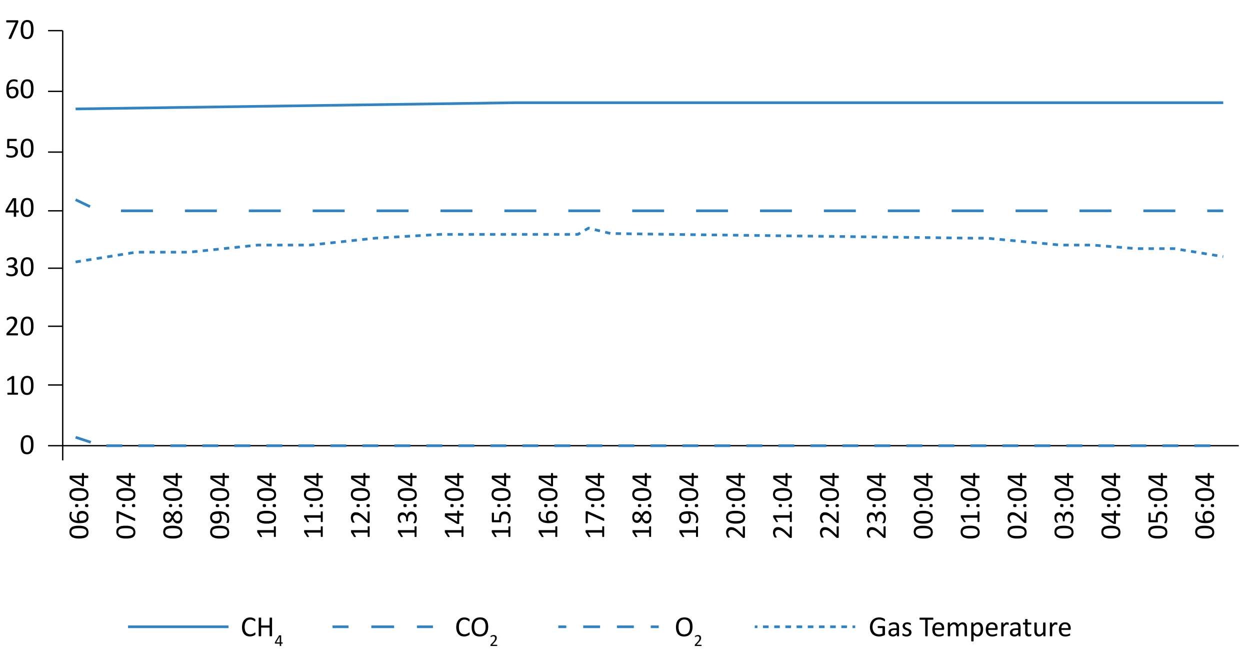

Figure 2 – Hourly concentrations (%) of CH_4, CO_2, and O_2 and biogas temperature (ºC) on November 8 and 9, 2014.

According to Abushammala, Basri and Younes (2016), landfill gas emissions were measured in a landfill under tropical conditions in Malaysia to investigate seasonal variations in CH_4 and CO_2 emissions. The study results revealed that CH_4 and CO_2 emissions varied from 0 to 1,602 g m^{-2} d^{-1} and from 5 to 2,753 g m^{-2} d^{-1} during the wet and dry seasons, respectively, corroborating that higher CH_4 and CO_2 emissions are more frequent during the wet season than the dry season.

Figures 2 to 5 show the hourly variations in CH_4, CO_2, and O_2 concentrations and biogas temperature over 24 hours for the four collection periods.

There were no significant hourly variations in biogas emission, with small differences between the minimum and maximum values for the concentrations of CH_4 and CO_2.

November (Figure 2) had the maximum temperature (36.8ºC) and the highest methane concentration (59.2%) for all measurements. The minimum temperature in this period was 31.9ºC, at which the methane concentration was 57%.

Gas temperatures determined in January (Figure 3) ranged from 31.9 to 36.1ºC, at which the CH_4 concentrations were 55.4 and 56.2%, respectively.

March 2015 (Figure 4) presented the lowest gas temperature (23.1ºC), at which the CH_4 concentration was 53.8%. During this period, a concentration of 57.9% methane was determined at the highest temperature (26.7ºC).

The lowest gas temperature during April (Figure 5) was 25.4ºC, with a CH_4 concentration of 43.2%. The highest temperature was 29.3ºC, with a methane concentration of 58.6%.

As discussed above, the maximum concentrations of CH_4 were generally found at the highest biogas temperatures, with the minimum concentrations occurring at the lowest temperatures.

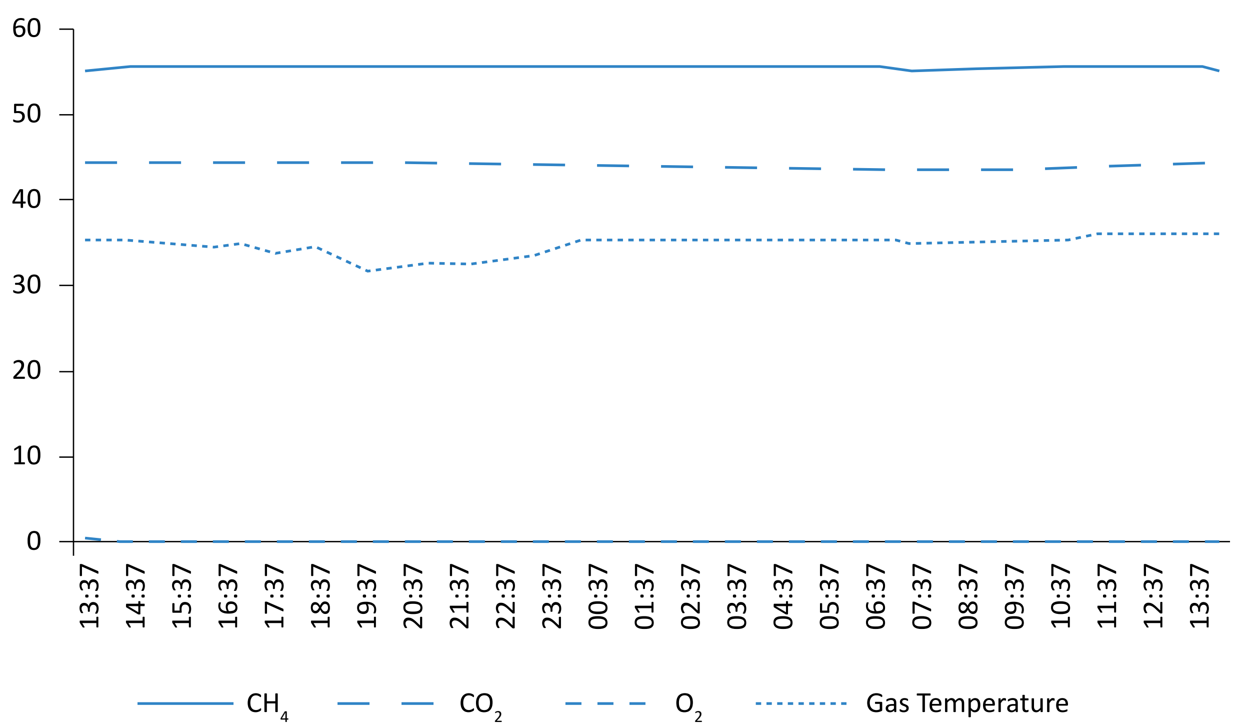

Figure 3 – Hourly concentrations (%) of CH_4, CO_2, and O_2 and biogas temperature (ºC) on January 9 and 10, 2015.

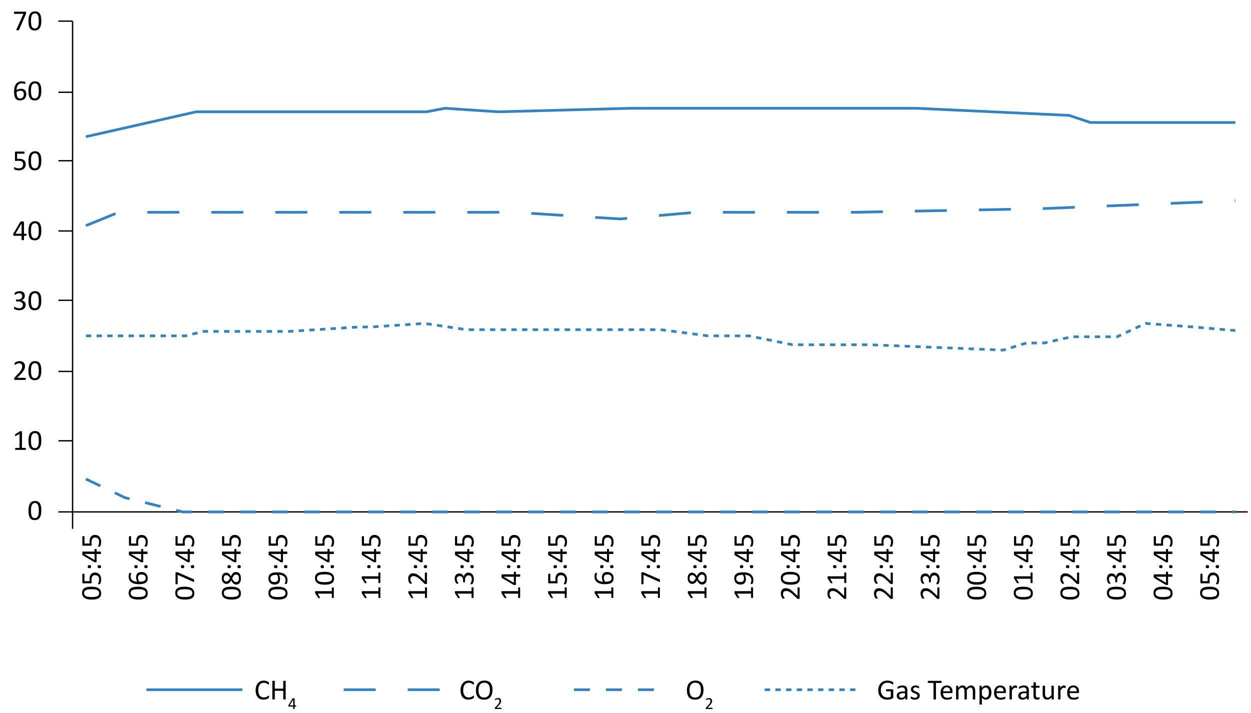

Figure 4 – Hourly concentrations (%) of CH_4, CO_2, and O_2 and biogas temperature (ºC) on March 23 and 24, 2015.

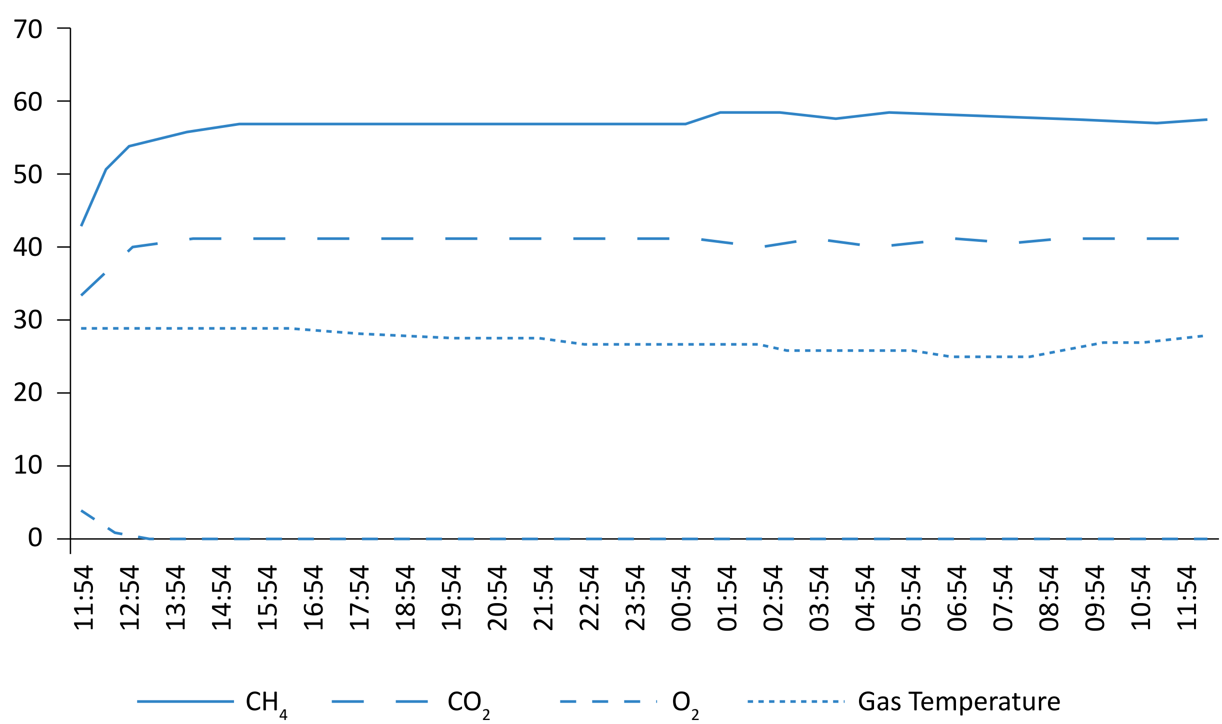

Figure 5 – Hourly concentrations (%) of CH_4, CO_2, and O_2 and biogas temperature (ºC) on April 22 and 23, 2015.

CONCLUSIONS

The semi-arid region of Northeastern Brazil, where the research was carried out, showed no significant seasonal variation. Consequently, no major changes are expected in the gas concentrations of sanitary landfills in the area over time.

The variations in hourly gas emissions determined in this research indicated that, in general, the maximum methane concentrations occurred at the highest biogas temperatures.

Biogas temperature, therefore, contributed most to the changes in CH_4 concentration. The maximum concentration of CH_4 (59.2%) occurred at a temperature of 36.8ºC, and the minimum (43.2%) at a temperature of 25.4ºC.

As demonstrated by the results of several studies, biogas generation increases with temperature.

This finding is important for the semi-arid region of Northeastern Brazil, where biogas temperatures reach values above 35ºC for much of the year.

Biogas emissions had no significant hourly variations. Small differences were identified between the minimum and maximum values for the concentrations of CH_4 and CO_2.

We found no relationship between CH_4 emissions and rainfall. In the research area, the period with very low rainfall coincides with the highest ambient temperatures. Thus, temperature was the factor that most influenced the concentration of this gas. The highest temperature occurred during a period of almost no precipitation (November 2014), when the highest concentration of methane (59.2%) was detected.

Studies on hourly variations in landfill gas emissions in Brazil are virtually non-existent. We recommend the development of further research.

Estimating the potential biogas is particularly important to assess the feasibility of its exploitation for energy purposes.

Investigations like this (field studies) are essential, mainly because they consider the specific climatic characteristics of Northeast Brazil.

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