Acta Scientiarum. Technology
ISSN: 1806-2563
eduem@uem.br
Universidade Estadual de Maringá
Brasil

Audibert, Jorge Luiz; Fernandes, Fernando
Preliminary qualitative and quantitative assessment of gases from biodigestion of solid wastes in the landfill of Londrina,Paraná State, Brazil
Acta Scientiarum. Technology, vol. 35, núm. 1, enero-marzo, 2013, pp. 45-52
Universidade Estadual de Maringá
Maringá, Brasil

Acta Scientiarum

http://www.uem.br/acta
ISSN printed: 1806-2563
ISSN on-line: 1807-8664
Doi: 10.4025/actascitechnol.v35i1.11453

Preliminary qualitative and quantitative assessment of gases from biodigestion of solid wastes in the landfill of Londrina,Paraná State, Brazil

Jorge Luiz Audibert[1*] and Fernando Fernandes[2]

*[1]Universidade Estadual de Londrina, Rod. Celso Garcia Cid, PR-445, km 380, Londrina, Paraná, Brazil. [2]Departamento de Engenharia Civil, Universidade Estadual de Londrina, Londrina, Paraná, Brazil. *Author for correspondence. E-mail: jmaudibert@sercomtel.com.br*

ABSTRACT. Trials conducted in controlled landfillsor dumps are still incipient in Brazil. This paper aimed to qualify and quantify the emission of biogas in the landfill of Londrina, Paraná State. Measurements were performed by three types of tests: static closed chamber for the characterization and quantification of gas leakage by the surface layer, inspection tubes for pressure quantification and qualification of the biogas produced below the surface layer and, finally, measurements in vertical drains to quantify and qualify the biogas. Results for the flow rates of methane gas in the vertical drains ranged from 0 to 190.2 N m ^{3} h^{-1}, depending on the shape of the drain and to the age of solid waste deposition. The tests with static closed chamberhad results between 1.3 and 30.6 NL h^{-1} m^2, influenced by changes in the age of solid waste deposition, different thicknesses of the surface layer, and excessive rainfall during the tests. With the data of methane gas flow obtained by thestatic closed chambertests and by the biogas drains, it was preliminary quantified the total emission of methane in the landfill of Londrina, Paraná State.

Keywords: landfill, gases, measurements.

Avaliação preliminar qualitativa e quantitativa de gases originados da biodigestão de resíduos sólidos no aterro de Londrina, Estado do Paraná, Brasil

RESUMO. Ensaios realizados em aterros sanitários, controlados ou lixões são ainda incipientes no Brasil. O presente trabalho tem por objetivo qualificar e quantificar a emissão de biogás no aterro de Londrina/Pr. Foram realizadas medições por meio de três tipos de ensaios: placas de fluxo para caracterização e quantificação do gás em fuga pela camada de superfície, tubos de inspeção para quantificação de pressões e qualificação do biogás gerado abaixo da camada de superfície e, por último, medições em drenos verticais existentes para quantificar e qualificar o biogás que vaza através dos mesmos. Os resultados de vazões de gás metano nos drenos verticais variaram de 0 a 190,2 N m^3 h^{-1}, dependendo do formato do dreno e da idade de deposição dos resíduos sólidos. Os ensaios com placa de fluxo apresentaram resultados variando de 1,3 a 30,6 NL h^{-1} m^2, influenciados por alterações na idade de deposição de resíduos sólidos, diversidade de espessuras da camada de superfície e precipitações pluviais excessivas no período dos ensaios. Com os dados de vazão de gás metano obtidos nos ensaios de placa de fluxo e nos drenos de biogás, quantificou-se de forma preliminar a emissão total de gás metano no aterro controlado de Londrina, Estado do Paraná.

Palavras-chave: aterros, gases, medições.

Introduction

Controlled landfills and dumps are the most used alternatives in Brazil for the final disposal of domestic solid wastes. These alternatives have a good cost-benefit relationship for the municipalities, but result in environmental setback with two potentially polluting components: leachate and biogas.

Each municipality has singular characteristics in the composition of its domestic solid wastes. Gravimetric tests can detect these particularities with variable percentage of organic matter, recyclable materials and inert waste (FRÉSCA et al., 2008). Diverse factors influence these parameters, including the social class of the populations, regional economy, public policy for collecting recyclable, landfill management, etc. The physical characterization of the solid wastes directly influences the quantification and qualification of the biogas produced in the controlled landfill or dump, making the studies peculiar to each region.

The production of biogas from domestic solid wastes comes from their biodigestion, mainly the anaerobic digestion. From the disposal of solid

waste into controlled landfills or dumps, initially the aerobic digestion takes place by the direct contact of the waste with the atmosphere oxygen. The aerobic phase is prolonged until when these wastes are covered and the amount of dissolved oxygen is almost zero. Then the anaerobic phase begins and lasts for a few years (MACIEL; JUCA, 2000).

In Brazilian landfills, researches have presented results diverging from those obtained in Northern hemisphere countries. The factors that most influence the production of these gases in landfills are the composition of the waste, temperature, pH, internal and external humidity. In general, the literature brings humidity values around 50-60% for maximizing the anaerobic process; but high rates of waste decay with humidity ranging from 20 and 40% have already been registered in Brazil. Thus, the results of quantification and qualification of the biogas may change with the diversity of characteristics and climate in the regions of Brazil.

In general, on the upper layers of the garbage mass in the landfills, the waste decay occurs under alternate aerobic and anaerobic processes. This occurs mainly owing the infiltration of the rainfall that carries dissolved oxygen to the inner environment of the landfill and inhibits the anaerobic digestion. The anaerobic processes dominate at depths greater than 3 meters (MACIEL; JUCA, 2011).

The percolation of methane through the landfill surface is usually highly variable (BORJESSON et al., 1998; MARIANO; JUCA, 2010). In this study are presented results of an experiment of quantification and qualification of methane obtained inthe controlled landfill of Londrina, Paraná State, for three types of tests: static closed chamber, inspection tubes below the surface layer, and biogas measure in the vertical drains.

The US Environmental Protection Agency (USEPA, 1998) suggested a mathematical model to estimate the methane generation in landfills. This methodology is also adopted by other international organizations such as the World Bank. The model was applied to the landfill of Londrina, Paraná State, aiming to evaluate preliminarily the results gathered in the tests and those obtained by using the aforementioned methodology.

Material and methods

Controlled landfill of Londrina, Paraná State

The controlled landfill of Londrina is located at the Estrada do Limoeiro, km 3, Eastern area of the city. Its position conflicts with some environmental laws, including because it is located a few meters from the airport of Londrina.

The tests were performed on October 17th and 18th, 2009, by the Group of Solid Wastes of the Federal University of Pernambuco, with the aid of research engineers of the State University of Londrina.

With the results obtained in the tests, we developed a methodology to evaluate the emissions of gases in the landfill of Londrina, Paraná State, aiming to evaluate preliminarily the annual emissions of methane. The landfill was divided into three areas, considering the age of waste disposal in each area. The area 1 had the largest part filled by relatively recent waste with age equal to or lower than one year. The area 2 was operated before the area 1, with larger part of waste aged between 1 and 5 years. The area 3 was an ancient area of operation, with great part of disposed waste with age above 5 years.

On the occasion of the tests, the landfill was at the final stage of operation, with approximately 31 years. The sites selected for the tests aimed a general analysis of the emissions of gases in the landfill of Londrina, Paraná State. For this, it was chosen locations with different ages of disposed solid wastes, located at diverse levels.

Equipments used in the tests

The equipments used in the tests are listed below:

- squarechamber with 0.156 m^2 in area, and 8.3 liters in volume;
- gas detector (CH_4, CO_2, O_2 and H_2S) model X-am 7000 of Drager;
- digital thermometer with sensor (measuring ranges: -50 to 1300ºC and 199.9 to +199.9ºC);
- thermo-anemometer Unity model 208, with 0.2 - 20 m s^{-1} range, resolution of 0.1 m s^{-1} and accurate to 3%;
- digital manometer Dwyer 477-2 (measuring range of 0-10 kPa, accurate to Pa);
- PVC pipe with cap of 100 mmdiameter;
- several tools (hoe, digger, shovel, knife etc).

Methods used to evaluate the emission of gas in the landfill of Londrina, Paraná State

To characterize the gases emitted by the landfill of Londrina, Paraná State, three methods were used, described as follows:

Monitoring of gases that escape through the surface layer

It was chosen five sites for testing on the surface layer of the landfill. Three sites (EP-01, EP-02 and EP-05) were located in the area 1 of the landfill.

The other two sites (EP-03 and EP-04) were positioned in the area 2, where the age of the solid wastes did not exceed 5 years. On the area 3, with wastes with disposal age above 5 years, static chamber tests have not been performed.

There is a great diversity of static chamber employed under the most variable situations and places, and mentioned by the literature. In the tests on gases released by the landfill cover, it was used amodel called static chamber, illustrated in the Figure 1.

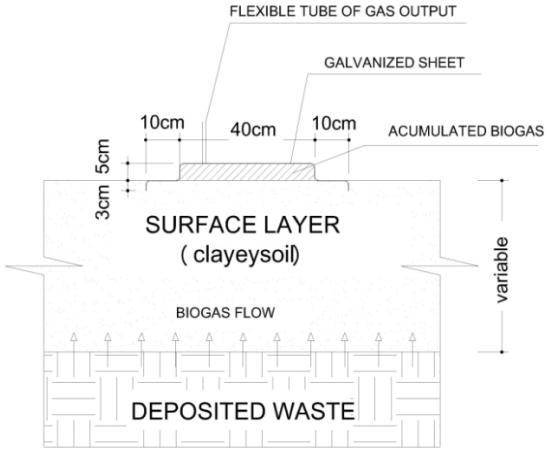

Figure 1. Schematic cross-section of the chamberused.

During the fixing of the plate, the hoses remained open so that gases do not accumulate before starting the test. After fixing the plate on the soil, the devices were immediately coupled to measure the concentration of CH_4, CO_2, O_2 and H_2S, and to read temperature and internal pressure in the static chamber.

The readings were made at time intervals ranging from 2 to 10 minutes (5 minutes, on average). The total time of the tests varied between 30 and 40 minutes. The lasting time of each test was necessary for the stabilization of the concentration readings, according to a typical procedure with chamber under static regime.

Monitoring of gases below the landfill cover

The tests with inspection tubes aimed to verify the characteristics of the gases below the cover layer. After each test with a static chamber plate, a 100 mm-hole was opened using an auger, at the exact place of the static chamber (tests T-01 to T-05). Then a 100-mm-diameter PVC pipe was inserted, with a closing cap adapted for coupling a plastic hose, where the gas meter was installed. The PVC pipe remained closed for about 1 hour to later characterize and quantify the biogas produced below the landfill cover and accumulated inside the pipe.

Another five particular tests with inspection tubes were conducted(T-06 to T-10), without performing tests with static chamber at these sites.

Monitoring of gases from the drains

The characterization of the biogas that escapes through the vertical drains was done by measurements at the upper end of the drains of gas in the landfill of Londrina, Paraná State (DV-01 to DV-12). These measures had the purpose to characterize quanti- and qualitatively the biogas percolated through the drains.

The biogas composition was determined with the device employed in theother tests, the portable detector Draeger X-am 7000, using a probe inserted from the end of the vertical drain to capture the biogas.

The flow of the biogas in the drains was checked by using a digital anemometer. The biogas speed was measured in three positions of the exhaust tube, commonly on the axis and at two peripheral points. From the partial measures, we determined the average speed and the biogas flow rate in the drain.

Results and discussion

The studies performed aimed to characterize quali- and quantitatively the emissions of biogas in the landfill of Londrina, Paraná State. For this, the tests were done on the landfill cover, below the landfill cover, and in the existing drains of gas. The Figure 2 shows the planialtimetric survey of the landfill of Londrina, separating the areas 1, 2 and 3 according to the age of the solid waste disposed, and with the location of the sites where the tests were conducted.

Emission of gases through the landfill cover

Five tests were conducted with static chambers to qualify and quantify the gas flow at those sites, called EP-01 to EP-05. The gas trapped inside the plate had a volume variation over time. The base time of test interruption was 30 minutes to minimize the effects of increase in pressure, concentration and temperature inside the compartment of the static chamber. The results in the Figure 3 show the curves obtained from data gathered in field with readings taken every 5 minutes. The unit of measure used to quantify the volume of gas in constructing the graph is Normal Liter (NL), resulting in a surface percolation in NL h^{-1} m^2.

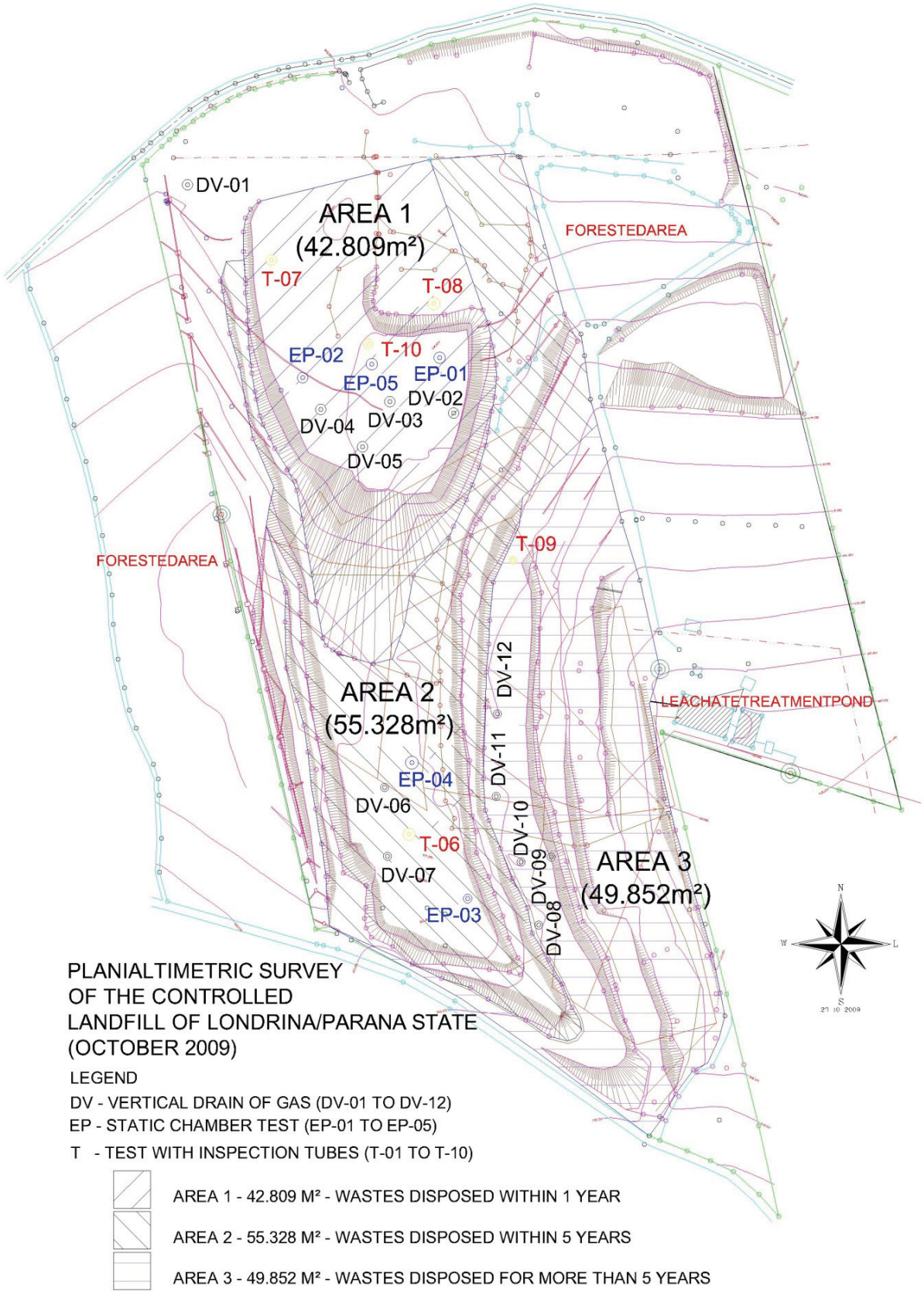

Figure 2. Plan of the landfill of Londrina, Paraná State, with the location of the sites of the tests and delimitation of the areas 1, 2 and 3.

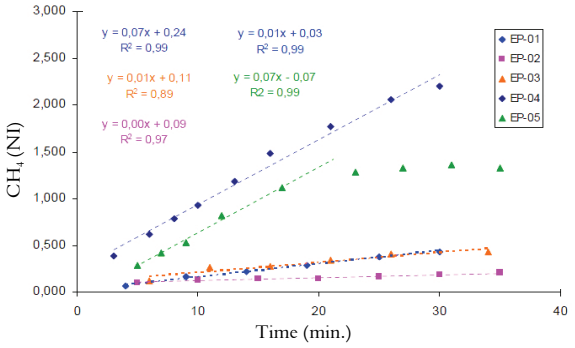

Figure 3. Variation in the CH_4 volume in the plate over time.

The results presented values ranging from 1.3 to 30.6 NL h^{-1} m^2, with a mean value of 13.9 NL h^{-1} m^2 (Table 1). This value is relatively higher than the mean observed in literature.

The cover layerof the landfill of Londrina, Paraná State was very humid, due to the heavy rainfall that have occurred in that period. For this reason, bubbles of gas were observed in several points, visually indicating the percolation of gases. The soil moisture determined in laboratory for the soil samples collected varied between 32.5 and 35.4%.

Concentration and pressure of gas under the landfill cover

In the tests with inspection tubes (T-01 to T-10), it was collected data of concentration of CH_4, CO_2 and O_2, and thickness of the cover layer at each test site (Table 2). The concentration of CH_4 varied between 2.1 and 42% (mean of 16.3%), of CO_2, between0.8 and 50% (mean of 17.1%), and of O_2 between 0.6 and 19.7% (mean of 12.9%). The most likely reason for the presence of O_2 at high amounts is the percolation of rainfall through the surface layer, carrying dissolved oxygen, and inhibiting thus the anaerobic decomposition in this region.

The average pressure of the biogas below the layer was 1,225 Pa. This value was probably associated with the great amount of liquid under the cover layer, observed in 70% of the holes performed in the tests. The presence of the liquids, mainly derived from infiltration of the rainfall, played a pressure on all the massive waste under the cover layer of the landfill. The thickness of the landfill cover varied between 0.35 and 1.00 m (mean of 0.48 m), an indicative of the need to correct the operational procedures to make this layer more homogeneous.

Emission of gases through the vertical drains

The drains monitored in the landfill (DV-01 to DV-12) were located in distinct regions, with diverse age of solid waste deposition (Table 3). The drain DV-01 was positioned near the entrance of the landfill by the Estrada do Limoeiro. The drains DV-02 to DV-05 were located next to the region of immediate disposal of solid wastes by the operator of the landfill. The drains DV-06 and DV-07 were situated at a lower level, at the back of the landfill, with waste aged more than 5 years.

The flow of CH_4 in these drains varied between 0 and 190.2 Nm^3 h^{-1}, evidencing the great emission of biogas by some drains, and possibly, the clogging of others. The maximum flow was observed at DV-07, in the lower part of the landfill, and built in concrete tube with 500 mm diameter. The drains externally made up by metal tubes with 73 to 80 mm have presented flows lower than the others, between 0 and 36.9 Nm^3 h^{-1}. The possible cause for this is the bottleneck at the end of the drain for the installation of the gas burner. The bottleneck led to a great loss of load for the gas flow, allowing the leakage by other pathways, such as the own bottom edge of the drain.

Table 1. Results of the static chamber tests.

Test	Surface emission of CH_4 (NL h^{-1} m^2)	Moisture density of the soil (g cm^{-3})	Moisture level of the soil (%)	Dry density (g cm^{-3})	% of fines in the soil (sieve n. 200)
EP-01	5.8	2.03	32.5	1.53	90.8
EP-02	1.3	2.01	33.3	1.51	92.5
EP-03	5.5	1.93	35.4	1.43	93.4
EP-04	30.6	1.94	33.7	1.45	90.6
EP-05	26.4	2.03	33.4	1.52	89.9

Table 2. Results of the tests with inspection tubes below the landfill cover.

Test	Concentration below the layer (%)				Thickness of the layer (m)	Pressure below the cover (Pa)	Observation
	CH_4	CO_2	O_2	H_2S^*			
T-01	42.0	32.5	4.5	28	0.60	2,640.0	Presence of liquid in the tube
T-02	40.0	50.0	0.6	12	0.35	1,803.0	Presence of liquid in the tube
T-03	13.0	27.5	11.5	0	1.00	470.0	Presence of liquid in the tube
T-04	2.0	1.4	19.6	0	0.45	3,200.0	Presence of liquid in the tube
T-05	28.0	37.0	5.8	5	0.25	9.0	No liquid detected
T-06	5.0	3.6	18.6	0	0.60	2,500.0	Presence of liquid in the tube
T-07	12.6	8.0	15.6	0	0.25	0.0	No liquid detected
T-08	2.1	0.8	19.7	0	0.45	1,167.0	Presence of liquid in the tube
T-09	10.2	3.8	16.0	0	0.55	0.0	No liquid detected
T-10	8.2	6.0	17.4	0	0.30	470.0	Presence of liquid in the tube

*concentration in ppm.

Table 3. Summary of the results of the evaluation of the biogas in the vertical drains of the landfill of Londrina, Paraná State.

Drain	Biogas concentration (%)				Biogas temperature (°C)	Pressure atm (mbar)	Average velocity (m s^{-1})			Mean velocity (m s^{-1})	Internal diameter of the tube (m)	Biogas flow (Nm^3 h^{-1})	CH_4 flow (Nm^3 h^{-1})
	CH_4	CO_2	O_2	H_2S*			1	2	3				
DV-01	10.4	5.2	10.2	0	17.0	951.8		Absent		**	0.080	**	**
DV-02	19.0	15.5	12.5	28.0	27.3	951.8	1.2	1.2	1.3	1.23	0.073	20.2	3.8
DV-03	This drain was not investigated because it was burning throughout the study												
DV-04	50.0	40.0	0.4	34.0	27.0	950.7	1.7	1.6	1.5	1.60	0.073	26.2	13.1
DV-05	50.0	38.0	0.3	29.0	32.5	950.7	1.0	1.6	1.4	1.33	0.073	21.5	10.7
DV-06	2.4	1.2	19.7	2.0	23.4	950.7	0.3	0.7	0.4	0.47***	0.500	***	***
DV-07	38.0	27.0	6.5	49.0	34.1	950.7	0.6	0.8	0.6	0.67	0.500	500.6	190.2
DV-08	54.0	36.0	0.8	60.0	40.5	950.7	3.5	3.8	3.6	3.63	0.080	68.4	36.9
DV-09	0.7	0.4	20.0	0	23.6	950.7	0.3	0.3	0.3	0.30	0.080	6.0	0
DV-10	52.0	33.0	1.0	3.0	28.0	950.7	1.3	0.9	0.9	1.03	0.080	20.3	10.5
DV-11	49.0	29.0	2.0	3.0	31.3	950.7	0.5	0.8	0.9	0.73	0.080	14.2	7.0
DV-12	54.0	35.0	0.6	94.0	40.9	950.7	1.6	2.2	2.2	2.00	0.080	37.6	20.3
											Total	715.0	292.5

*concentration in ppm; **gas flow not detected with the equipment whose lower limit is 0.2 m s^{-1};***this measures was not considered because apparently the flow was in reverse, influenced by the wind. It was not possible to measure correctly because of the height of the drain (above 2.5 m).

In general, the CH4 concentration ranged from 0.7 to 54%. The drain DV-01 had a worthless reading by a possible clogging. The drain DV-03 could not be investigated since it remained burning throughout the period. The drains DV-02, DV-06 and DV-09 presented a reading incompatible to the age of the disposed wastes. The drain DV-02 was close to the solid wastes discharged by the trucks, which could justify the low performance. The drains DV-04, DV-05, DV-07, DV-08, DV-10, DV-11 and DV-12 presented biogas composition typical of the methanogenic phase of decomposition of urban solid wastes.

Quantification of the methane released in the landfill of Londrina, Paraná State

Despite the insufficient number of tests performed to draw a reliable assessment of the estimate of emission of gas in the landfill, it was carried out a preliminary evaluation of the emission of methane aiming to attain a preliminary parameter of analysis, by adopting some criteria:

a) the landfill of Londrina was divided into areas 1, 2 and 3, according to the age of solid waste disposed (Figure 2). The information about the respective areas was provided by the landfill operator and by the Prefecture of Londrina.
b) the results of the tests were considered within their respective area. In the case of the static chamber tests, it was considered the average of the tests performed in the respective catchment areato evaluate the emission of methane by the cover layer of the landfill. The tests EP-01, EP-02 and EP-05 were located in the area 1, the tests EP-03 and EP-04, in the area 2, and in the area 3, the surface emission of methane was not considered because it was not conducted tests of this nature in this area.
c) the readings obtained for the methane flow in the vertical drains were added up in the context of the catchment areaconsidered. In the area 1, it was summed up the readings of the methane flow of the drains DV-01, DV-02, DV-04 and DV-05; in the area 2, it was added up the reading of the drains DV-06 and DV-07; and in the area 3, it was added up the readings of the flows of the drains DV-08 and DV-12.
d) the total surface emission of methane in each area resulted from the multiplication of the average emission of methane in the area by the own area.

From the basic parameters, the survey of the flows was carried out for each area considered in the landfill, so that it was achieved the total flow of methane. The total emission considered for the landfill was obtained by adding up the surface emissions of the cover layer and the methane emission from the vertical drains, totaling 16,840,830 Nm^3 $year^{-1}$, presented in the Table 4.

The upper part of the Table 4 lists the data relative to the surface emission of methane in the landfill. For the calculation of the mean values of the results of the static chamber tests, it was used an interpolation method called Inverse Square of Distance (ISD), considering the coordinates of the test sites.

The methane emission measured in the area 1 was 5,530,067 Nm^3 $year^{-1}$ and in the area 2 was 8,748,463 Nm^3 $year^{-1}$. In the area 3, the area with older solid wastes, no plate flow tests were carried out. The total emission of methane by the surface layer was 14,278,530 Nm^3 $year^{-1}$.

Table 4. Results of methane flow on the surface and in the vertical drains of the controlled landfill of Londrina, Paraná State.

Methane emission detected in the chamber tests and drain measures												
Landfill area	Area 1 (42,809 m^2) – waste disposed within 1 year			Area 2 (55,328 m^2) – waste disposed within 5 years			Area 3 (49,852 m^2) – waste disposed for more than 5 years			Total emission on the surface	Total emission in the drains	Total emission in the landfill
Static chamber test	Mean of CH_4 emission-ISD** (NL m^{-2} h)	CH_4 emission (Nm^3 m^{-2} year)	Annual emission in the area 1 (Nm^3 $year^{-1}$)	Mean of CH_4 emission – simple*** mean (NL m^{-2} h)	CH4 emission (Nm^3 m^{-2} year)	Annual emission in the area 2 (Nm^3 $year^{-1}$)	Mean of CH_4 emission (NL m^{-2} h)	CH_4 emission (Nm^3 m^{-2} year)	Annual emission in the area 3 (Nm^3 $year^{-1}$)	Surface annual emission (Nm^3 $year^{-1}$)		Total annual emission (Nm^3 $year^{-1}$)
EP-01	5.8	50.81		*	*		*					
EP-02	1.3	11.39		*	*		*					
EP-03	*	*		5.5	48.18		*					
EP-04	*	*		30.6	268.06		*					
EP-05	26.4	231.26		*	*		*					
Surface emission	14.75	129.18	5,530,067	18.05	158.12	8,748,463	*	*	*	14,278,530		
Vertical drains measure	CH_4 emission (Nm^3 h^{-1})		Annual emission in the area 1 (Nm^3 $year^{-1}$)	CH_4 emission (Nm^3 h^{-1})		Annual emission in the area 2 (Nm^3 $year^{-1}$)	CH_4 emission (Nm^3 h^{-1})		Annual emission in the area 3 (Nm^3 $year^{-1}$)		Annual emission in the drains (Nm^3 $year^{-1}$)	
DV-01	0			*			*					
DV-02	3.8			*			*					
DV-03						Drain not investigated						
DV-04	13.1			*			*					
DV-05	10.7			*			*					
DV-06	*			0			*					
DV-07	*			190.2			*					
DV-08	*			*			36.9					
DV-09	*			*			0					
DV-10	*			*			10.5					
DV-11	*			*			7					
DV-12	*			*			20.3					
Emission by drains	27.6		241,776	190.2		1,666,152	74.7		654,372		2,562,300	16,840,830

*Readings not performed in the area; **ISD – Inverse Square of Distance (method of interpolation); ***on the area 2 the mean considered was the arithmetic given only two sampling data.

The vertical drains had heterogeneous flows, with great variations in the flow. The value calculated for the emission of methane in the area 1 was 241,776 Nm^3 $year^{-1}$, in the area 2 was 1,666,152 Nm^3 $year^{-1}$, and in the area 3 was 654,372 Nm^3 $year^{-1}$. The total emission recorded in the drains was 2,562,300 Nm^3 $year^{-1}$.

Quantification of the emissions of methane by the model USEPA for the controlled landfill of Londrina, Paraná State

In order to estimate the emissions of methane it was used the model adopted by the United States Environmental Protection Agency, specific for municipal solid waste landfills (USEPA, 1998). The simplified model calculates the production of methane during the lifespan of the landfill, as well as the reduced production of methane from the closure of the landfill activities.

The mathematical equation adopted is presented below:

$$Q_{CH_4} = L_o.R.\left(e^{-k.c} - e^{-k.t}\right)$$

where:

Q_{CH4} = amount of methane generated in the year"t", (m^3 CH_4 $year^{-1}$);

L_0 = potential of methane generation by ton of disposed waste (m^3 CH_4 $ton.^{-1}$ of waste);

R = annual mean of input of waste in the landfill(ton waste $year^{-1}$);

k = production rate of methane ($year^{-1}$);

c = years from closure (c = 0 for active landfills);

t = years from the start of the activity (years).

The annual mean of waste input in the landfill was estimated using the information obtained with the Prefecture of Londrina (R = 127,750 ton. $year^{-1}$). It was considered 31 years of contribution of solid waste in the landfill for the production of methane (start of activities in 1979). The values relative to the variables k and L_0 were standardized for all years of operation of the landfill of Londrina to the values suggested by USEPA (1998): L_o = 170 m^3 CH_4 ton^{-1} waste, and k = 0.05 $year^{-1}$.

By applying the values, it was obtained the estimate of methane production of 17,332,601 m^3 CH_4 for the year 2010.

The graphic behavior of the mathematical model showed an increase in the production of methane over years, with the maximization of the production planned for the year of closure of the landfill activities (2010). From the closure, the model presented a downward estimate of methane production as presented in Figure 4.

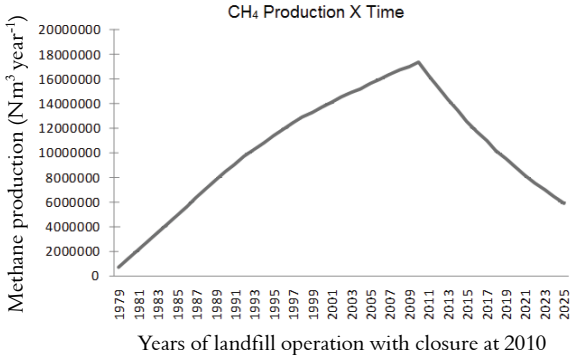

Figure 4. Graphic behavior of the mathematical model (USEPA, 1998) applied to the landfill of Londrina, Paraná State.

Conclusion

The preliminary tests to characterize the biogas emitted through the cover layer of the landfill of Londrina were performed during two days. Regarding the methane, surface emissions between 1.3 and 30.6 NL h^{-1} m^2 were registered. With the obtained emissions, it was preliminarily calculated the value of 16,840,830 Nm^3 $year^{-1}$ of methane.

The emission of methane observed through the cover layer of the landfill was higher than the flow by the vertical drains. The value preliminarily calculated was 14,278,530 Nm^3 $year^{-1}$, registering 84.8% of total methane emissions.

In the drains of biogas of the landfill we calculated the flow of 2,562,300 Nm^3 $year^{-1}$ of methane, representing 15.2% of the total flow calculated to the gas. The amount of drains was not enough to collect the gases generated inside the solid wastes disposed. The internal drainage of methane inside the garbage mass was also ineffective.

The monitoring of gas emission through the surface layer has indicated high levels of methane. Most part of the waste, producer of biogas met the characteristics of the methanogenic phase, with ages ranging from 0 to 5 years.

The quantification of the methane attained with the preliminary tests presented values close to those estimated by the mathematical model suggested by USEPA (1998). Further studies performing tests might confirm or not our results.

References

BORJESSON, G.; SUNDH, I.; TUNLID, A.; SVENSSON, H. Methane oxidation in landfill cover soils as reveales by potential oxidation measurements and phospholipid fatty acid analisys. **Soil Biology and Biochemistry**, v. 30, n. 10/11, p. 1423-1433, 1998.

FRÉSCA, F. R. C.; PUGLIESI, E.; MASSUKADO, L. M.; SCHALCH, V. Determinação da composição gravimétrica dos resíduos sólidos domésticos do Município de São Carlos. **Revista DAE**, v. 178, p. 48-57, 2008.

MACIEL, F. J.; JUCÁ, J. F. T. Laboratory and field test for studying gas flow through MSW landfill cover soil. **ASCE Geotechnical Special Publication**, n. 99, p. 569-585, 2000.

MACIEL, F. J.; JUCÁ, J. F. T. Evaluation of landfill gas production and emissions in a MSW large-scale Experimental Cell in Brazil. **Elsevier - Waste Management**, v. 31, n. 5, p. 966-977, 2011.

MARIANO, M. O. H.; JUCA, J. F. T. Ensaios de campo para determinação de emissões de biogás em camadas de cobertura de aterros de resíduos sólidos. **Engenharia Sanitária e Ambiental**, v. 15, n. 3, p. 223-228, 2010.

USEPA-United States Environmental Protection Agency. **Municipal solid waste landfills**, 1998. Available from: <http://www.epa.gov/ttn/chief/ap42/ch02/final/c02s04.pdf>. Access on: Nov. 20, 2010.

Received on October 18, 2010.
Accepted on March 28, 2012.