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STUDY ENERGY RECOVERY POTENTIAL FROM MUNICIPAL SOLID WASTE IN FOZ DO IGUAÇU LANDFILL

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Abstract. *Municipal Solid Waste (MSW) management encompasses contemporary concerns of various orders in which social, environmental, economic and energetic aspects stand out. This situation demands a response and strategies from society in the form of public policies, which occurred in Brazil with the sanction of Law 12305/10 and the establishment of the National Solid Waste Policy. The guidelines for environmentally adequate final destination contained in the law open opportunity and stimulate the search for alternatives in energy recovery through thermochemical processes. This work presents a theoretical study about Foz do Iguaçu, Paraná Brazil, city that has had landfill since 2001 and, only in 2017 it received more than 80 thousand tons, of which more than 60% were organic material, according to the Municipal Plan of Basic Sanitation. These and other updated information enabled a simulation of the landfill gas production of the two enclosed cells, using the first-order decay model of the IPCC 2006. With the landfill gas flow obtained, a scenario of electric power generation using a motor generator set (GMG) was simulated. The results show a landfill gas flow rate recovered between 56.80 to 124.80($Nm^3/ton.year$). The generation of electric power indicate the possibility of meeting the demand of 433 residences.*

Keywords: *Energy recovery, Landfill gas, Solid wastes, Foz do Iguaçu.*

1. INTRODUCTION

The growing economic development of Brazil, together with the urban population expansion verified in the last decades (IBGE, 2018), presents a disturbing picture about the increase in energy demand and generation of waste (EPE, 2018). This relationship between economic development, disordered urbanization and increased consumption of energy have affected significantly the environment since the 18th century, with the beginning of the Industrial Revolution, which has given rise to a greater variety and quantity of waste with the amendment of the consumption habits of man.

In 2016, the Brazilian population generated 78.3 million tons of MSW, equivalent to 214.5 thousand tons per day. 91% (71.3 million tons) of this total, were collected, but only 41.7 million tons (58.4%) were properly disposed of in landfills (ABRELPE, 2017). Of the remainder, 24.2% were sent to controlled landfills and 17.2% to landfills, that is, a 29.7 million-ton share of the collected MSW were not adequately treated and provided for by legislation (treatment in landfills), becoming a threat to the environment and human health (ABRELPE, 2017).

One of the most common accepted techniques for environmentally appropriate disposal of waste is the use of landfills, where combustible gas is generated due to the decomposition of organic fraction of the MSW through an anaerobic process. According to the literature, the composition of landfill gas generated is mostly methane and carbon dioxide, and features in smaller amounts of carbon monoxide, hydrogen, nitrogen, hydrogen sulphide and ammonia (Thomazoni, 2014), (Tchobanoglous and Kreith, 2002), and due to the high concentration of methane enables your enjoyment as a source of energy, which in general is made using thermochemical processes in thermal machines, e.g., boilers, turbines and engines.

1.1 Landill Gas

The landfill can be compared to a biological reactor, where the entrances are basically solid waste and water from the rains, and the main exits are the gases that make up the landfill gas and slurry (Borba, 2006).

As mentioned above, landfill gas is a gas mixture rich in methane and carbon dioxide, Table 1 shows the typical percentage distributions of the gases identified in the gas composition, it is important to note that these values vary according to the composition of the organic matter disposed in the landfill and with the methodology followed by the author for the quantification of these gases.

Table 1. Typical gases and their concentrations identified in landfill gas.

Component	Center (2017)	Jucá Maciel (2003)	Persson *et al.* (2006)
CH_4	40-60%	35-65 %	35-65 %
CO_2	35-50 %	15-40 %	15-50 %
N_2	0-10 %	5-40 %	5-40 %
O_2	1-4 %	0-5 %	0-5 %
CO	< 0,1%	not rated	0 %
H_2S	0-70 ppm	0-100 ppm	0-100 ppm

Source: Adapted from (Center, 2017), (Jucá Maciel, 2003) e (Persson *et al.*, 2006).

The start of gas production will occur after a few months of MSW disposal. The IPCC 2006 guide calls this period a delay-time and stipulates a duration range of 6 to 18 months. Several authors have conducted research in the area and found that the degradation of the tailings occurs in 5 phases, being: Initial adjustment, Transition, Acid, Methanogenic and Maturation. The duration of each phase is influenced mainly by the composition of the residues, humidity, particle size, temperature, pH, residue age, landfill design and type of operation (Renou *et al.*, 2008), (Farquhar and Rovers, 1973) and (Pohland, 1982).

2. METHODOLOGY

The methodology used in this work was divided into 4 stages. Being the initial stage the research and knowledge of the MSW treatment situation in the city of Foz do Iguaçu. It was possible to obtain information regarding the landfill operation regime, history of MSW collection and gravimetric composition at 2012, through documents issued by the City Hall and information provided by the management company of the landfill. The second stage was the application of the proposed First Order Decay (FOD) model presented in Volume 5 of the IPCC-Guidelines for National Greenhouse Gas Inventories, that is based on the calculation of the rate of methane generation (k) and the amount of Degradable Organic Carbon Decomposed (DDOC) The (IPCC, 2006) provides an Excel spreadsheet, which is available for download on the IPCC website (https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol5.html) to assist in the calculations, the parameters considered for the analysis are:

- **Region**: the study area is the city of Foz do Iguaçu, located in Paraná west state, the clime considering for local is wet humidity, with average temperature, higher than 22°C in summer and less than 18°C in winter;

- **Study period**: the analysis was accomplished considering a study period of 30 years, since the beginning of the operation of the activities in the municipal landfill;

- **Gravimetric composition**: It Indicates the percentages of the components present in the MSW, and it is of utmost importance the knowledge of this data, because the generation of methane is calculated separately for each amount of these type of component. For the application of the methodology it was necessary adequacy of the information presented in the Municipal Plan of Sanitation (PMSB, 2012) as the IPCC (2006) classifies the waste more complete form, differentiating the types of organic matter in: Food, Garden and Wood;

- **Parameters MCF, k e DOC_i and DOC_f**:They were taken in accordance with the IPCC (2006) recommendations, it was considered that the landfill is being well operated, and therefore the value of the methane correction factor (MCF) can be taken as equal to 1. The constant generation of methane, denoted by k, is a unique and tabled value for each component, and its choice depends directly on the climate of the study area, in this case wet humidity. The DOC_f factor indicates that not all organic carbon present in the MSW will degrade or that its degradation will be too slow, the value recommended by the IPCC (2006) is 0.5, because the degradation of the RSU is considered to occur under anaerobic conditions and this fraction depends directly from factors such as: temperature, humidity, PH, and MSW composition. Already the values of DOC_i, were taken via the gravimetric composition of the residues, and considering MSW moist, due to the amount of organic matter deposited and also due to the slurry recirculation system;

- **Delay time**: it corresponds to the period between the start-up date of the landfill to an effective start of gas production, according to the IPCC (2006), the minimum time is 6 months.

The result returned through this worksheet is the mass of methane generated, CH_{4gT}, which will be applied in Eq.(1) and later in Eq.(2), returning as results values for the annual volumetric flow of gas produced and that can be extracted from the landfill.

$$LFG_{aT} = \left(\frac{CH_{4gT}}{\Delta h_{year}}\right) \cdot \left[\frac{1}{\rho_{CH4}} + \frac{MW_{CO2}}{MW_{CH2}} . \frac{1}{\rho_{CO2}} . \left(\frac{1 - F_{CH4}}{F_{CH4}}\right)\right] \quad (1)$$

Where, $\delta\ h_{year}$ is the total hours in 1 year (8760h) and the values of the specific mass of methane and carbon dioxide considering the normal conditions of temperature and pressure (0°C and 1 atm.) are, respectively, 0.72 kg/m^3 and 1.25 kg/m^3.

For practical purposes, in energy recovery projects, it is desirable to know the volumetric flow rate of landfill gas, which can be recovered by the extraction system. However, the value obtained through Eq.1 refers to the total gas flow generated by the landfill in the period of one year, which has significant losses mainly caused by leaks during collection. Thus, it is necessary to consider an extraction efficiency that allows to obtain the usable volumetric flow as shown in Eq.(2), Where ηc is the efficiency of the landfill gas extraction system (dimensionless).

$$LFG = \eta_c . LFG_{aT} \quad (2)$$

According to the IPCC guide, several factors influence this efficiency factor, for example, coverage layer, percentage of the volume of the landfill in which the extraction system operates, existence of the waterproofing barrier, operating conditions (shut down or still in operation), etc.Generally high values of ηc are related to closed landfills, reduced biogas flows, well designed and operated extraction system with thicker and impermeable covers. Low efficiency values are usually associated with landfills that are still active and with permeable or poorly waterproof cover.

The third stage consists of the theoretical evaluation of the thermal potential of the gas. Knowing the potential of the gas flow to be produced by the landfill it is of extreme importance to determine the Low Heat Value (LHV) of the gas for the elaboration of projects of energy utilization, for this there are experimental and theoretical means, the latter being composed by approximate empirical data methods.

In the present work we opted for using the theoretical method, the methodology chosen was Dulong's theory that proposes that the heat of combustion of a fuel is almost equal to the sum of the combustion heat of their compounds multiplied by their respective percentage in the analyzed mixture (Given *et al.*, 1986).

As previously mentioned, landfill gas is composed mainly of methane, carbon dioxide and other gases in smaller quantities, for the quantification of LHV using the adapted Dulong formula, Eq.(3), it is considered that only the fraction of methane present in the gas will contribute to the combustion heat, it was again considered that the methane fraction in the landfill gas was y_{ch_4}=50%, a value recommended by the IPCC (2006) .

$$LHV = 35.689, 52 . y_{CH_4} \quad (3)$$

In the fourth and last stage, an initial simulation of the conversion of the chemical energy present in the landfill gas to electric energy was developed. The more common energy conversion technologies applied to the landfill gas, are the group motor generation (GMG), turbine and micro turbines gas and steam turbines. The chosen technological route for this initial assessment was the GMG, since it is the most consolidated technology, therefore the risk associated with the investment is lower than the other technologies, whereas it presents a good efficiency range for small capacity plants, with installed capacity of 1 to 3 MW, in addition, stands out for the ease of operation and maintenance which significantly reduces its cost. The biggest disadvantage is related to high levels of CO and NO_x emissions (Bove and Lunghi, 2006).

According to Souza (2016, p.27) for the basic design of a GMG, the necessary parameters are: the low heat value of the landfill gas, the efficiency of the system motor generation, the flow of the landfill gas Nm^3/day and the time of use of the generation plant. Using the available gas production data calculate by using the IPCC method (2006) and the low heat value, the theoretical potential of electric energy production can be obtained by Eq.(4), where PTE is the electric theoretical potential (kWh/day), LHV is the low heat value (kWh/day) and LFG is the annual production of landfill gas (Nm^3/day).

$$PTE = LHV.LFG \quad (4)$$

The technical potential of electric production (PTCE) is obtained by considering the global conversion efficiency of the GMG system, according to Eq.(5). The global conversion efficiency value depends on the type of GMG system, that is, depends on Otto cycle engine adaptation for landfill gas operation, Souza (2016, p.28), recommends 0,25 for the value of η for a more accurate estimate.

$$PTCE = PTE.\eta \quad (5)$$

Following the methodology proposed by Souza (2016), knowing the ability of electric power production, it is possible to determine the plant's power in kVA (POT), by using Eq.(6). Where cos ϕ is the potency factor, which takes values of ϕ0.8 to 1 and HO the number of hours that the plant will be operating.

$$POT = \frac{PTCE}{HO.cos\phi} \tag{6}$$

3. RESULTS

The landfill is located in the northwest of the city between the neighborhoods of Porto Belo and Jardim California, occupies a total area of 389,737.44 m^2, and in the same place different activities of waste treatment are developed.The area destined to the packing of MSW is divided in 3 cells. Cells 1 and 2, are composed of 6 layers each and have an area of 58,387.15 m^2 and 61,584.01 m^2, respectively, the period of operation of the first one comprises from 2001 to 2010 and from the second from 2010 to 2017. The third cell that has an area of 64,780.63 m^2 and started its activities in July of 2017 PMFI.

Since the beginning of its operations, the landfill is managed by the private company Vital Engenharia Ambiental S/A, and it is estimated that the landfill receives approximately 224 tons/day of solid waste from Public Household Collection and Urban Cleaning (PMFI, 2018).

The figure 1 presents the history of waste storage for the landfill and in Table 2 the result of the study of gravimetric composition of the volume of MSW, both data were made available City Hall of Foz do Iguaçu, it should be noted that for the years 2012 and 2016 there were no data available to enable the application of the 2006 IPCC model, and therefore it was necessary to estimate the total number of RSUs collected by multiplying the number of inhabitants in the municipality by the generation theoretical per capita cost of RSU. It should be noted that the operation of the landfill began in October 2001, so there is only 3 months data for this year.

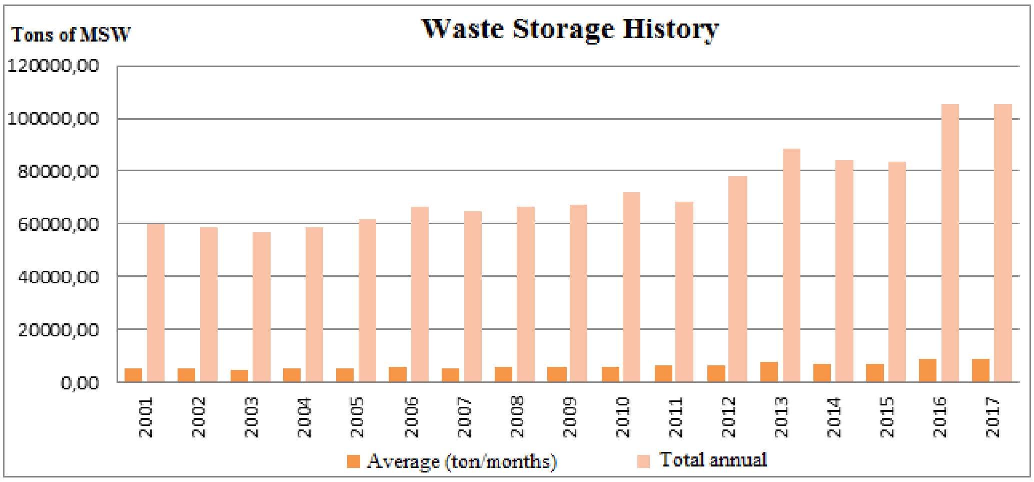

Figure 1. Waste Storage History
Source: (PMSB, 2012) and (PMFI, 2018)

Table 2. Gravimetric composition the of Foz do Iguaçu landfill.

% Waste in Foz do Iguaçu	Waste Category	Description
57,35	Organic Material	Food debris, flowers, tree pruning.
5,26	Paper	Box, magazine, newspaper, cards, paper, folder, notebook, book, dishes.
1,92	Metal	Electrical wiring, needle, steel wool etc.
9,52	Plastic	
3,72	Glass	
22,24	Several	Candle wax, soap and soap scum, charcoal, chalk, cigarette butts, credit card, crayons, long life packaging, metal packaging, sandpaper and other unidentifiable materials.

Source: Adapted from PMSB (2012).

The evaluation of the potential for the generation of gas in the landfill was carried out for a production period of 30 years from the beginning of operation of each cell, since according to (Jucá Maciel, 2003) the period of maximum gas production lasts approximately 20 to 30 years.

The application of the model First Order Decay - FOD, was carried out separately for each of the cells, being from 2001 to 2030 for the first cell, and from 2001 to 2040 for the second cell. The peak gas production for the first cell occurred in 2011, being equal to the 142.18 Nm^3/h , while for second cell the peak will occur in the year 2018 and will correspond to the 155.98 Nm^3/h .The figure 2 illustrates the intersection between the results obtained for each of the cells, showing the potential of landfill gas that can be retrieved Nm^3/h.

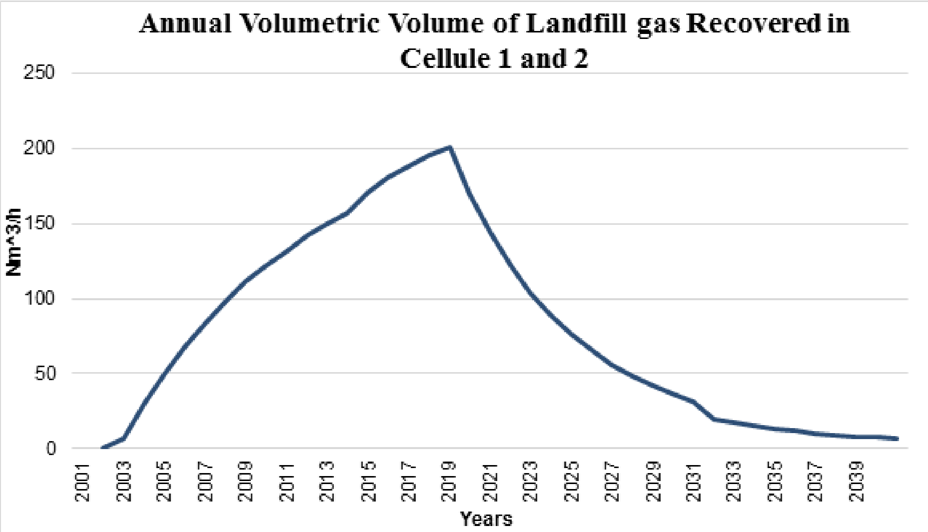

Figure 2. Annual Volumetric Volume of Landfill Gas Recovered in Cellule 1 and 2

In order to determine thermal potential of biogas from Duolong equation it is necessary to know the volumetric percentage of methane present in the landfill gas. Based on theoretical values recommended by the IPCC, it is considered as 50% fraction by volume of methane in the landfill gas, just by using the Eq.3 was obtained that the LHV of this landfill gas is 17,844.76 kJ/Nm^3, equivalent to 4.96 kWh/Nm^3.

The table 3 presents the results obtained through the application of Eq's.(4)(5) and (6), using as input parameters: LHV equal to 4.96 kWh/Nm^3, LFG = 1,913.95 Nm^3/day, average daily flow considering the production of the two cellule, η=25%, HO=10 hours a day and cos ϕ=0.8.

Table 3. Results for basic sizing of GMG.

PTE (theoretical potential of electricity)	9487.21 kWh/day
PTCE (theoretical potential of energy generation)	2371.80 kWh/day
POT (electrical power of the plant)	296.47 kVA

4. CONCLUSION

The estimates presented were based on dates from 2001 to 2011 and projections carried out since 2012 completing a period of 30 years from the beginning of operation of each cell, according to Maciel (2009), the period of maximum production of gas for approximately 20 to 25 years, what is corroborated in the obtained results for the landfill analyzed.

For the first cell the highest landfill gas production period is observed in the year 2011, corresponding to 142.18 Nm^3/h, for the second cell the highest landfill gas production period is observed in the year 2018, with average annual flow of 155.98 Nm^3/h .Analyzing the cumulative contribution of both of the cells, the highest flow occurs in the year 2019, being equal to 200 Nm^3/h, the order of magnitude of these values allow to affirm that exist a sufficient potential to recommend the installation of a thermal system for the energetic use of the landfill gas.

Compared to the results obtained in this work as to the landfill gas flow that can be collected per ton of MSW in the period of one year, the values varied from 56.8 to 124 $(Nm^3/ton.year)$. which is according to results found in the literature, for Thomazoni (2014) the flow found was between 32.6 and 199.2 $(Nm^3/ton.year)$, for Jucá Maciel, Felipe (2009) of 123.9$(Nm^3/ton.year)$ and Amini *et al.* (2012) from 13 to 170 ($Nm^3/ton.year$).

Among the technologies for converting the thermal potential of landfill gas to electricity, it was chosen to simulate the basic sizing of a GMG system, since it is the most consolidated technology in the landfill gas utilization segment. Applying the methodology presented by Souza (2016), it is concluded that the amount of gas available would be able to supply a system with installed power of 296.47 kVA, producing daily 2,371.80 kWh, supplying the energy need of 453 residences, considering that the average electricity consumption for the residential class is 157 kWh/month (EPE, 2017).

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