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Comparison of Biogas Production in a Municipal Solid Waste Landfill Using Default and Experimentally Measured Parameters

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Abstract. In municipal solid waste (MSW) landfills, a great part of the organic waste conversion process occurs under anaerobic conditions, producing biogas composed mostly by carbon dioxide and methane. The potential energy of methane may be used as a renewable source, thereby decreasing greenhouse gas emissions. In the literature, there are several models to predict generation of biogas; however, results from most of them give overestimated prediction. This work proposes to experimentally measure in laboratory tests the potential biogas generation in samples from a closed landfill in Brazil, with determination of the corresponding parameters, in order to carry out comparative analysis using both the experimental and the recommended default parameters. The biochemical methane potential was estimated from eudiometer pipe tests and the biogas generation was predicted using a first order decay model from the IPCC (Intergovernmental Panel on Climate Change) guidelines. Results indicate that the use of experimentally measured parameters may significantly improve the accuracy of models to predict biogas production.

Keywords. IPCC model, GB21 test, landfill, gas emission, MSW.

1. Introduction

The municipal solid waste (MSW) generated by society can be disposed of in several ways, including some emerging techniques that allow the use of MSW either as a material (waste-to-material - WtM) or energy (waste-to-energy - WtE or energy-from-waste - EfW) [1,2,3]. MSW may be composed of organic or inorganic compounds, but the largest composition is generally of the first type due to food waste. In several countries, sanitary landfills have been used as a safe disposal technique instead of dumps. In landfills, the technique allows the confinement of residues in cells, i.e. layers of waste. Hence, an anaerobic environment is generated by microorganisms, converting organic matter into biogas. These gases are composed essentially of methane and carbon dioxide. In addition, trace gases such as H_2S, SO_2, SO_3, HCl and others can be detected. The gas production does not only occur close to the time of burial, but continues generating after stopping the waste deposition.

Although landfills are not considered as a disposal method for the energetic use of biogas, these gases can be used as an energy source, which in turn can be considered as

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a measure to reduce the emissions to the atmosphere. This supports government policies to achieve greenhouse gas emission reduction targets, which is a global concern and which has recently been reaffirmed through the new Paris Agreement signed in 2016.

As part of the commitment of government policies related to the use of methane as an energy source, it is necessary to establish technically and economically viable projects, which should be supported by surveys based on studies of methane generation, using mechanisms to predict its production. The mechanism could include methodologies based on mathematical models, such as IPCC, LandGem, GasSim, Afvalzorg, E-PRTR, SWM-GHG and others [4-8]; theoretical models for chemical composition, including approaches such as elemental composition from component elements analysis proposed by Symons and Buswell in 1933 and McCarty in 1972 [9-11]; and experimental tests such as aerobic and anaerobic tests. Wagland *et al.* [12] provide a summary of aerobic and anaerobic test methods developed by several authors.

The first experimental method to determine the biochemical methane potential (BMP) was presented by Owen *et al.* [13] and it was used for Minnesota peat. Subsequent changes, such as the use of different inoculum, seeds, headspace volumes were proposed. Angelidaki *et al.* [14] proposed a protocol for these essays, but two year later, Raposo *et al.* [15] still reports on a wide range of batch and reinforces the need for standardization. Since then, numerous surveys have used a wide range of residues, generated by agro-industry (manure, dairy faeces, pig fatteners, and lignocellulosic biomass – [16,9]), waste from urban activities as yard waste [17,18], some kinds of papers (bleached, unbleached, with or without coating – [17]) and food waste [19,20].

Investigation also been developed in landfills [21-23]. Mehta [24] focused on methane production at different depths in landfills in Yolo County, California. In Brazil, a small number of studies were conducted on the topic BMP from landfills in which most samples were fresh MSW [25,26] and sampled from shallow depths [27,28].

Although there is a diversity of possibilities for assessing gas emissions, mathematical models are used most widely, the most common being the IPCC and LandGEM models, but it is known that these models generally overestimate the emissions from landfills. Based on this context and trying to solve this deficiency, this paper investigates the experimental parameters affecting the potential biochemical production of biogas from samples taken in a closed landfill in Brazil. The batch test as a BMP was conducted to obtain the parameter Lo, the methane production potential, and the coefficient k, the methane production rate constant. These determined parameters are then used as input data in the gas emission prediction model.

2. Materials and methods

2.1. Sampling of waste

Waste samples were obtained from one Brazilian landfill which was no longer receiving waste when the sample extractions were performed. It was started as a dumpsite, but in 1996 has undergone a considerable transformation to a controlled landfill. This landfill occupies an area of 130 hectares and received around 6.5 ton of MSW per day.

Three samples were collected at five meter depth from three different boreholes. The sample from borehole A contains the newest material while the sample from borehole C is composed by the oldest residue. The holes were excavated using a drilling machine with a bucket auger. The sampler has a cylindrical shape, open at one extremity. At the bottom, there are several teeth that, during the rotation and advancing of the perforation, are responsible for breaking and detaching the material that is collected into the sampler.

2.2. Batch test for determining BMP

The essay was done in batch, according to the procedure established in German standard DIN 38 414, Part 8. The biochemical methane potential process evaluations were carried out in eudiometer pipes, where the biogas generation was assessed for 21 to 60 days, until saturation was reached, that is when the accumulated volume of biogas remained constant. The equipment consists of a glass vessel, where the samples of MSW were deposited, and an eudiometer pipe connected to this vessel. The system measures the gas volume changes from decomposition of organic matter that results in biogas production.

In this study, the experiment was carried out in a triplicate batch test. For each sampling collected, 5 g OFMSW (organic fraction of municipal solid waste) was used. This fraction was mixed with 50 mL of an activated sludge from sewage treatment and tap water to make up 300 mL of solution. After the vessel was flushed with a nitrogen gas, it was sealed and put into an incubator at 35 ºC during the experiment. In addition, a blank batch, which only contained water and inoculum, with the same set up was performed. Measurement of the amount of biogas from batch tests with fraction organic mass and blanks were made at the same time. The corrected methane contents were calculated according to methods described by DIN. The BMP was reported as NL of biogas per gram of wet MSW (NL/g wet MSW).

2.3. Prediction of methane emissions

One of the main inputs to the mathematical models is the weight of the waste mass buried over time. In this study, it was considered that the residue deposited between 1978 and 1993 has already extinguished its capacity of gas emission because there are no operating records for this period. Records of the buried waste during the period from 1993 to 2007 were published in the CDM-ONU publication - *Project Design Document Form – Version* 03.1. Input data corresponding to 2008 until 2012 were obtained through the company that owns the operation concession, the Nova Gramacho. Table 1 shows the input data regarding the amount of MSW for each year considered in this analysis.

Table 1. Amount of weight of MSW by year at AMJG.

Year	Weight of MSW (ton)
1993	1,646,374
1994	1,669,443
1995	1,800,209
1996	2,325,161
1997	2,414,508
1998	2,390,021
1999	2,403,311
2000	2,454,563
2001	2,417,409
2002	2,473,918
2003	2,359,715
2004	2,333,759

Table 1. (*continued*) Amount of weight of MSW by year at AMJG.

Year	Weight of MSW (ton)
2005	2,337,625
2006	2,474,464
2007	2,450,064
2008	2,500,916
2009	2,373,953
2010	2,533,875
2011	1,275,471
2012	800,947

For the estimation of methane generation, both the default parameters suggested by the IPCC model, as well as the parameters fit from experimental curves, were considered.

3. Results and discussion

Table 2 shows the parameters k and Lo obtained from fitting the experimental data, obtained from the BMP batch tests, to the von Bertalanffy curve described by eq. 1:

$$y = L_o(1 - e^{-kt}) \quad (1)$$

Table 2. Parameters fit from experimental data.

Sample	Lo (NLbiogas/kgwet)	k (1/day)
A	172.03	0.01037
B	12.35	0.03634
C	2.22	0.09381

The k parameter, in terms of decay per day, ranged between 0.01037 to 0.09381. This parameter indicates the time for the material to be degraded or decomposed. The results indicate that the sample from borehole C has the greater decay rate, suggesting that in a short time its gas emission capacity will cease. The values differ by an order of magnitude from those reported by Caldas *et al*. [27] (0.001) but are close to Sel *et al* [22] (average value is 0.023) measured in a Turkey landfill.

The Lo parameter indicates the rates of methane emission. Sample from borehole A has the highest result, close to the value recommended by the US EPA LandGEM model, while C presented the lowest response. This behaviour suggests that sample A contributes for larger emissions, compared to the other samples. In the literature, a wide range of Lo values can be found. Maciel *et al.* [25] obtained similar values for the Lo parameter, considering the potential with age (189.6), while Alves [28] presented a very different result (75.8). In a study conducted by Mehta [24], there was no clear trend of variation of L_0 with depth and, consequently, with age. For 5 m depth, the results ranged from 7.4 to 137.8 with an average of 57.28 L of biogas per kg of waste. These researchers found values that differ by 1 or 2 orders of magnitude in comparison to those obtained in this work.

The IPCC model used in this study considers the Lo parameter. However, it is used as a function of dissolved organic carbon (DOC). Three different hypotheses were made in this investigation with respect to the input values (Table 3): 1) admitting the default

DOC values; 2) using the calculated DOC values based on the characteristics of the waste of the landfill; 3) establishing DOC values from a back-analysis of the experimental data.

The $DOC_{default}$ and the $DOC_{calculated}$ parameters are practically the same. With respect to the $DOC_{back\text{-}analysis}$, for the sample A the $DOC_{default}$ is quite similar while the values for samples B and C were nearly one order of magnitude lower. This result corroborates the degradation behaviour of the organic matter, where the greater the degradation time, the smaller the value of DOC. This reduction occurs due to the organic load being consumed by the degrading microorganisms present in landfills.

Figure 1 shows the gas emission prediction considering both the cases using the $DOC_{default}$ and $DOC_{calculated}$ values. The analysis with $DOC_{default}$ resulted in a generation of approximately 12,300 ton of CH_4 greater than that obtained with $DOC_{calculated}$.

Table 3. Values of DOC considered in this research.

Sample	DOC default	DOC calculated	DOC back-analysis
A	0.16	0.18	0.1740
B	0.16	0.18	0.0443
C	0.16	0.18	0.0211

Note: DOC is a dimensionless quantity

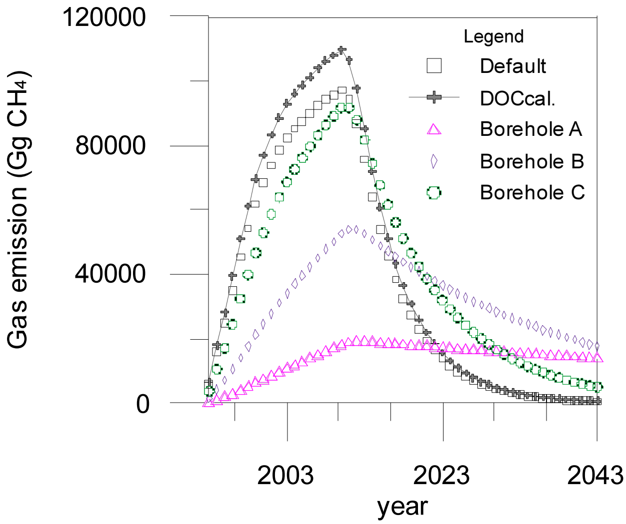

Figure 1. IPCC model using $DOC_{default}$ and $DOC_{calculated}$ values.

In addition to the analysis using the default parameters, the hypothesis that the entire mass of waste has a single behaviour, (i.e that k and DOC are fixed and constant for any and all input of waste), as is assumed by the model, was tested by using experimentally derived parameters. In order to incorporate the diversity of parameters obtained experimentally, two assumptions were considered:

1. the residue decay parameter k was assumed equal to the value obtained experimentally;
2. both k and DOC parameters have values equal to those obtained both experimentally and by back-analysis.

Figure 1 shows the results using $DOC_{calculated}$ with the k parameter obtained experimentally for each sample. The influence of the parameter k in the prediction of methane generation is demonstrated, resulting in greater decay for sample C than for samples A or B. It was also observed that a decrease of the k parameter resulted in the lowest decay for sample A. However, looking 20 year ahead, sample B will be the one with the highest generation. In the horizon extension for another 10 years, there will be a convergence of generation for samples A and B, being 3.6 times greater than that corresponding to sample C.

Figure 2 shows the results according to the second consideration. Results indicate a further reduction of estimated emissions, which were lower for samples buried for a long period. The peak emissions calculated from the back-analysis data ranged from 10.730 to 18.751 Gg of CH_4. This result demonstrates a reduction from estimates made using default parameters of 9.8 times in relation to the first value (0.16) and 5.6 times in the higher value (0.18).

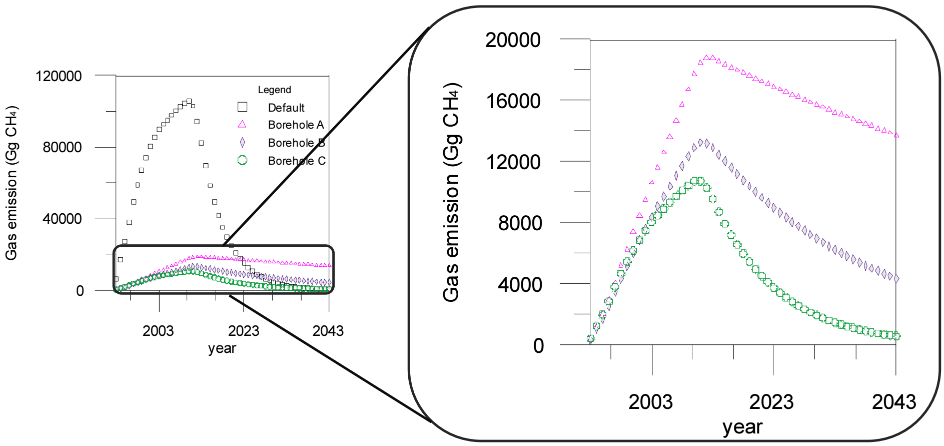

Figure 2. IPCC model – $DOC_{back-analysis}$ and k experimental.

After 20 years, emissions values for samples A and B resulted higher than the default, while sample C showed the lowest values of all over time. After an additional ten years, both samples C and the default have almost the same values, however samples A and B still yield higher values, over 27 to 8 times higher than C or the default.

Even though all analysis used the proposition that the parameters DOC and k do not vary in time, experimental results suggest that both parameters do vary over time. Thus, if these variations were considered, it is believed that the emissions forecasts would be smaller than predictions made using constant values.

4. Conclusion

The IPCC model has been widely used to estimate gas emissions from sanitary landfills. Default parameters are usually used for this estimation, which in turn can overestimate real emissions. In this paper, both default and experimental parameters were used in the prediction of gas emissions. Based on the experimental data, the results reveal lower emissions than those obtained using the default parameters. When considering both experimental DOC and k values, the longer the decomposition time of the waste inside landfill, the lower the gas emissions.

Results indicate that the use of experimentally measured parameters may significantly improve the accuracy of models to predict biogas production. Even not considering the variation in time, results suggest that the use of default parameters may cause considerable miscalculation of emissions if the specific characteristics of the waste are not taken into account, especially in closed landfills.

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