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Effect of Solid Wastes Composition and Confinement Time on Methane Production in a Dump

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ABSTRACT

In developing countries, illegal dump structures or even some landfills do not include methane collecting systems, even if local environmental laws exist. In this condition, the greenhouse gas escapes to the atmosphere uncontrolled and practical solutions to tackle this problem are not obvious. To make a solution approachable, first-hand reliable data from dump emissions are required as starting point. The methane production is not homogeneous throughout the dump, therefore to estimate its global methane emissions, various representative gas monitoring sites distributed along the dump becomes necessary. This research work presents the measures of biogas emissions collected in the final disposal site located at Morelia (Mexico), along with an evaluation of the organic fraction and confinement time participation on biogas production. Biogas emission data were taken with a portable analyzer from 49 ventilation pipes for 52 weeks. For the composition and degradability analysis of solid wastes, the required samples have been collected from 16 sites. The results show a heterogeneous composition of solid wastes: 38 separate components are present, from those, 19 belong to organic categories and 28 of total components accounts for almost 99% of the waste. The mean biogas concentration detected was: 45.5% CH_4, 32.4% CO_2, 3.1% O_2, and 18.9% balance gas (i.e., N_2, CO or H_2S). The ANOVA procedure clearly corroborated the influence of composition, biodegradability and time of confinement of solid wastes on the production of methane, despite the deficiencies in the final soil layer cover in these sites.

***Keywords**: Mexico, Biodegradability, Emissions, Biogas, Methane*

1. Introduction

Intergovernmental agencies worldwide are making attempts to create awareness about the contribution to global warming of landfill gas emissions from decomposing municipal solid wastes (MSW), recommending the use of biogas emissions as a source of alternative energy instead of their release to the atmosphere [1]. The amount of landfill gas generated largely depends on climatic conditions, geography, waste characteristics and other local factors [2]. Several researchers have identified the factors influencing the degradation of MSW and have assessed their individual effects on the methane production. These factors include presence or absence of oxygen and hydrogen [3-5]; temperature [6,7]; MSW confinement time [8]; MSW field capacity and hydraulic retention time [9-11]; compaction and compressibility of MSW [12]; pH [13,14]; type of material used as final cover layer and the codisposition of wastes from the construction and demolition industry [15,16]; humidity content and water flow [17,18] and; the use of inoculants such as biosolids and compost, and leachate recycling [19-26]. Although the aforementioned factors are interdependent, [27] identified pH and humidity content as being most critical, whereas [28] emphasized humidity and nutrient contents as the main factors affecting the stabilization of MSW. However, only the solid wastes containing cellulose are degraded in a landfill, such as food and yard wastes and two thirds of the paper and cardboard; the degradation of other materials is often incomplete [29].

There is clearly a need to extend the knowledge on biogas emissions in MSW disposal sites in order to optimize measures for landfill gas capture and to minimize emissions to the environment [30], but such information is still very limited in developing countries, and when available, comparisons and the determination of precise data is difficult. The available information derives from short-term studies made in final disposal sites that have heterogeneous composition, different climatic conditions, while management and measuring techniques vary widely [2,31-33]. **Table 1** shows the results of some studies of biogas composition.

In the present research the composition of landfill gas emission was analyzed at the final disposition site in the city of Morelia (Mexico), the scope was to determine the effect of MSW composition in the production of biogas. The specific objectives were: 1) To determine the physicochemical characteristics of confined MSW, and 2) to study the amount and composition of the biogas generated in the studied site.

2. Materials and Methods

2.1. Description of the Studied Site and Sampling of Solid Waste

The present study was conducted in final disposal site that was closed for operation four years ago, after 20 years of activity. The dump is located 15 km west of Morelia, the capital city of the state of Michoacán, in Mexico (19˚41′40″N, 101˚20′54″W), at an elevation of 2075 m.a.s.l. (**Figure 1**). The predominant climate in the area is of the temperate subtype Cwa, with a mean annual temperature of 18.7˚C, intermediate humidity, a summer rainfall regime of 700 - 1000 mm and an average of 5 mm of winter precipitation. The site has an extension of 17 ha, an irregular topography, an approximate slope of 15˚; disposal cells have a maximum depth of 10.1 m and the estimated amount of deposited MSW is of 3,859,642 t [34]. At the time of its closure, 49 venting pipes were installed at a 3 m depth.

2.2. Sampling and Characterization of Solid Waste Composition

The study area was divided into four quadrants according to the confinement period of MSW, the oldest being quadrant I and the more recent, quadrant IV. Using a simple random design, 16 boreholes were perforated at a depth of 3 m and from each one approximately 4 kg of refuse were collected in transparent plastic bags. The

Table 1. Composition of landfill gas (LFG) in different world regions (% volume).

		LFG composition				S	D	W
Landfill location	Year	CH_4	CO_2	O_2	Balance			
P. de Montaña, Mexico	2000-2001	46	34.6	2.6	16.86	16	S/D	Horizontal
Nakhonpatho, Thailand	2003	64.1	31.1	1	3.82	8	3	Vertical
Samutprakan, Thailand	2004	50.6	38.9	1.1	8.5	3	50	Horizontal
Site of Study	2010-2011	45.5	32.4	3.1	18.9	7	3	Vertical

Sources: [2,31,32]. **S** (Sampling period (months)); **D** (Depth (meters)); **W** (Wells).

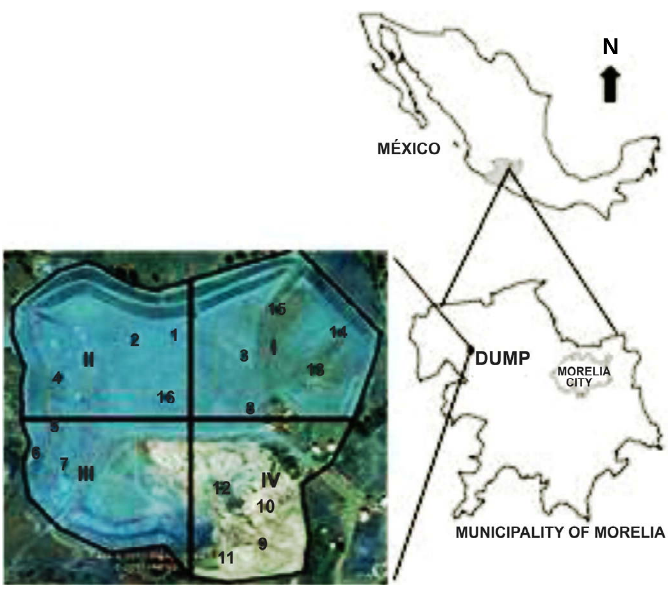

Figure 1. Location of the Morelia, Michoacán dump.

numbers of boreholes and venting pipes in each quadrant are shown in **Table 2**.

2.3. Physical and Chemical Analyses of Solid Waste Samples

Physical and chemical analyses of samples were conducted in triplicate. Samples were grinded to homogenize the components to one inch fractions. These analyses included: characterization of waste components (NOM-AA-22-1985) [35], temperature (NMX-AA-25-1984) [36], pH (NMX-AA-25-1984) [36], moisture content (NMX-AA-016-1984) [37], total solids (TS) (APHA, 1998), volatile solids (VS) [38], ashes (NMX-AA-018-1984) [39] and methane emission (using a GEM-2000 plus (Landtec) portable analyzer).

2.4. Measurement of Biogas Emissions

Measurement of biogas emissions were made in the 49 venting pipes using a GEM-2000 plus (Landtec) portable analyzer. Measurements for methane (CH_4), carbon dioxide (CO_2), oxygen (O_2) and hydrogen sulfide (H_2S) were periodically made during 52 weeks.

Measurements were made during morning time (between 9:00 AM and 13:00 PM) to assure less interference from external factors such as changes in humidity and temperature, placing both plastic connectors of the analyzer inside venting pipes.

2.5. Data Statistical Analysis

Field and laboratory data from the physical and chemical analyses of composition of residues and of emission of methane in the dump were captured in the program Excel (Microsoft Office XP). The JMP program (Version: 6.0. SAS Inc. Institute, 2005) was used for the statistical analysis. Descriptive statistics and three series of one-way analysis of variance (ANOVA) were performed to establish the influence between the production of gas and the surveyed variables. Those variables showing a statistically significant difference were analyzed by means of the Tukey test.

3. Results and Discussion

3.1. Composition of Solid Wastes Samples

The composition of solid waste included 38 components, as described in the Mexican norm. **Table 3** shows a high heterogeneity of results among quadrants. It is likely that these differences result from the different factors such as: a seasonal variation in the consumption and the modification in consumption patterns due to economic and demographic challenges experienced in the country [40,41]. **Table 3** also shows a variety of the more abundant components of the 38 categories, of which, food waste/Unidentifiable fraction was dominant; it is noteworthy that the organic fraction content is inversely proportional to the confinement period of the solid residues, showing the influence in the organic fraction content of time of disposition of solid wastes in the site. Oldest quadrants have a lower content of organic waste, as can be seen in the quadrant I to the more recent (quadrant IV).

Of the total solid waste composition in the site of study, the organic fraction (fine residue, food and yard wastes, hard plant fiber, bone, wood, feces, cardboard, leather, paper, cloth, shoes, hair, coating and wax) averaged 63%, a proportion that is relatively high, which reflects that although the city of Morelia has experienced economic challenges these have not been widespread for all the population, and also that a rural life style consumer pattern prevails.

Also, despite the implementation in Morelia of MSW separation programs, some recyclable components such as cardboard, rigid and film plastics, and glass, continue to be elevated in the solid waste stream. It was also observed that only those materials having high economic value and demand, such as aluminum, polyethylene terephthalate

Table 2. Number of wells and venting pipes in each quadrant of the study site.

Quadrant	Boreholes	Ventilation pipes
I	5	15
II	4	11
III	3	11
IV	4	12

Table 3. Composition of solid waste in the study site (%, w/w, fresh basis).

	Quadrant			
Category	I	II	III	IV
Food Waste/Unidentifiable fraction*	31.6	36.3	66.4	60.3
Paper and Cardboard	7.1	10.2	4.4	3.9
Yard Waste	3.3	2.3	4.7	1.5
Wood	2.2	1.4	0.0	2.4
Cloth	1.3	1.5	4.1	2.7
Other Organics**	1.2	1.5	0.4	0.6
Diapers	4.6	5.3	1.4	2.6
Metals	3.2	3.7	0.1	0.1
Glass and Ceramics	4.9	2.5	2.2	3.6
Plastics	16.8	21.2	9.5	12.2
Stones	19.7	13.2	6.8	8.0
Other Inorganic	4.3	0.3	0.0	2.1

*Organic components difficult to identify due to the stage of degradation; **Organic components such as cotton, leather, bone, wood, etc; ***Inorganic components, such as synthetic fibers, cellophane, aluminum foil, electrical material, cigarette butts, modeling clay, and shoes, etc.

and ferrous materials have been diminishing their amounts with respect to previously measurements in the solid waste stream [40].

3.2. Results of Physical and Chemical Analyses of Solid Waste Samples

An increment in temperature was observed related to the depth of the layer and to the season (results no shown). Nonetheless all the studies boreholes presented mesophilic temperatures (35˚C to 40˚C) (**Table 4**) during the sampling period and methane production was detected in all ventilation pipes in the site, which is in agreement with the report of [42] that a mesophilic range of temperature is a critical factor for the optimal degradation of the organic fraction of the wastes.

Moisture values ranged between 29% - 38% for all boreholes, commonly this value is 25% - 60% [42], and is linked to its composition. However, obtained data did not show a clear difference in the moisture content between the quadrants within the 3 m depth at which solid wastes samples were taken.

Solid waste pH values were detected in the range of 8 - 8.4 (**Table 4**), which is indeed a suitable range for the optimal degradation of solid wastes; pH is an important parameter in the optimum decomposition of solid wastes because the acidic/basic conditions influence the methanogenic phase [19].

The results of TS showed values of between 62% - 68%, the highest being concentrated in stratum III, which is related to the lower content of humidity in that level.

Volatile solid values ranged from 33% - 56% (**Table 4**), an ample range that reflects the level of degradation of MSW among quadrants. Higher values of volatile solids and of the organic fraction in quadrant IV are showing a relation with the stage of degradation of the organic contents and the confinement time of the solid wastes. The volatile solid content has been used to express the total organic matter present in solid wastes. According to [43], volatile solids are a reliable parameter to indicate the degradation of the organic materials throughout time, and consequently, an indicator of the potential for methane production.

Table 4. Physical and chemical characteristics of waste samples.

	Quadrant			
Parameters	I	II	III	IV
Physical Characteristics				
Temperature (˚C)	35.7	28.5	28.3	36.9
pH	8.4	8.4	8.3	8.0
Moisture Content (%)	34.2	35.0	37.1	31.7
Chemical Characteristics				
Total Solids (% w/w)	65.8	65.0	62.9	68.2
Volatile Solids (% TS)	33.5	47.3	53.5	55.7
Ash (% TS)	66.5	52.7	46.5	44.3

3.3. Measurement of Biogas Emissions

The biogas generated in the studied site contained an average of 45.5% CH_4, 32.4% CO_2, 3.1% O_2, 18.9% balance gas (*i.e.*, N_2, H_2S, CO) and emissions differed between quadrants (**Table 5**). **Figure 2** shows the average methane emissions in the four quadrants during the sampling period.

The observed seasonal variation in methane generation is shown in **Figure 2**, a fluctuation that reinforces the effects of corresponding changes in temperature and precipitation. An increase in methane emission was observed during the rainy season (July-October, weeks 5 to 21) and a decrease in such activity was registered during the dry season (November-June, weeks 23 to 52), the latter due to low water availability. The lower level of methane generation observed in quadrants I and IV suggests the effect of the time of solid wastes confinement and, hence, their degradation stage. In the case of quadrant I, which is the oldest deposit, it was expected that after 20 years a large proportion of the organic fraction had already been degraded. In contrast, in quadrant IV which is the most recent deposit, the methanogenic phase has not yet reached its maximum level.

The average generation of methane observed in the study site (45.5%) was below according with the values reported by [33], but some boreholes had values that fall within the range reported in other studies (58% - 64%) [2,31,32]. The aforementioned studies also report the influence on methane generation of climate, solid waste composition and type of cover. Most landfills commonly used in developing countries lack infrastructure for capturing methane; nevertheless, being able to identify the level of biogas production is relevant in order to assess both its environmental impact and the economic feasibility of building sanitary landfills having methanecapture systems.

3.4. Statistical Data Analysis

The ANOVA test revealed a statistically significant difference ($P < 0.05$) among quadrants in temperature, pH,

Table 5. Composition of the biogas in the site of study (average per quadrant % volume).

Composition of Biogas (% volume)								
Q	CH_4	SD	CO_2	SD	O_2	SD	B	SD
I	41,3	15,1	27,7	10,3	4,4	4,9	26,5	21,0
II	49,4	8,4	35,4	5,3	2,2	2,9	12,7	10,6
III	48,5	5,9	35,4	4,5	2,7	2,0	13,4	8,4
IV	44,5	16,6	32,8	9,2	2,5	3,3	20,2	22,9

Q (Quadrant); **SD** (Standard Deviation); **B** (Balance).

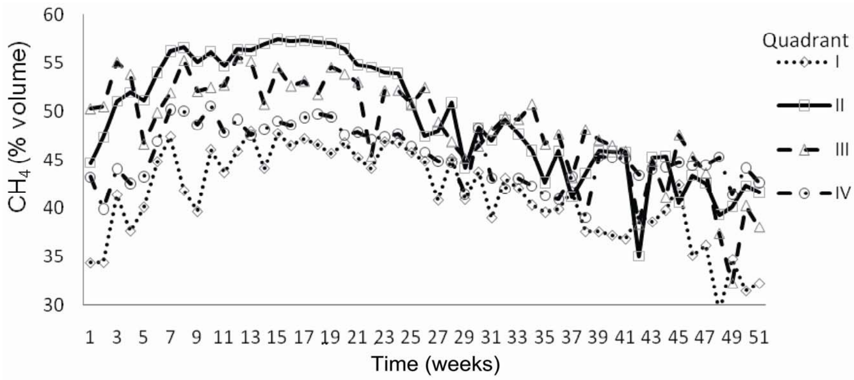

Figure 2. Methane emissions in the site studied (average per quadrant % in volume).

ashes, VS, organic and inorganic fractions and methane production (**Table 6**).

The results of the Tukey test for temperature showed a statistically significant difference ($P < 0.05$) between quadrants I and IV with respect to quadrants II and III. The pH did not show a statistically significant difference between quadrants II and IV, while quadrants I and III indicated such a difference ($P < 0.05$). Ashes did not show a difference between quadrants II and III, while quadrants I and IV did show a statistically significant difference ($P < 0.05$). In the case of VS, quadrants II and III did not show differences but a statistically significant difference was observed between quadrants I and IV ($P < 0.05$). The organic and inorganic fractions were similar between quadrants I and II as between quadrants III and IV, a statistically significant difference existing between both groupings ($P < 0.05$). Concentration of methane showed a statistically significant difference ($P < 0.05$) of quadrant III with respect to the other three quadrants.

Our study showed that the differences in methane production were related to the different stages of degradation of solid wastes, although the effect of residue composition is also to be considered together with the fact that the dump operated without an efficient cover of solid wastes. The statistical analyses corroborate the existence of a statistically significant difference between sampled quadrants.

Table 6. Results of ANOVA for the studied variables.

Source	No. parameters	DF	Sum of Squares	F Ratio
Temperature	3	3	1331.6439	35.5321
pH	3	3	10.817776	6.5915
Humidity	3	3	244.122	1.5909
Ashes	3	3	5125.5327	4.7511
TS	3	3	245.23178	1.6077
VS	3	3	5125.5327	4.7511
Organic fraction	3	3	2647.4535	4.4391
Inorganic fraction	3	3	2647.4535	4.4391
Methane	3	3	2018.2282	28.3443

4. Conclusions

1) Statistical analyses reveal heterogeneity of solid waste composition within the studied site, differences which are due to differences in confinement chronology.

2) A larger amount of organic fraction was found in more recent quadrants, likewise, the ANOVA and the Tukey test showed a statistically significant difference between quadrants corroborating the effect of time of confinement of solid wastes, despite the deficiencies in their covering.

3) The contents of VS observed in the solid wastes together with the statistical analyses of the four studied quadrants confirm existing differences in organic matter content (degradability) and in degradation stages of the latter.

4) Differential methane generation between quadrants and the statistical analyses corroborated the effect in biogas production of solid wastes composition (organic matter and its degradability) and of the time elapsed since their confinement.

5) The way in which variables were analyzed over time allowed for corroboration of differences in methane generation, not only between different sites but also within the same site.

6) Studies like the present are relevant to increase the information regarding biogas production in final disposal sites that have no control over the variables known to have an effect on methane generation.

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