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A Preliminary Study to Forecast the Leachate and Biogas Generation in a Municipal Solid Waste Landfill in Latin America

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Abstract

During the decomposition process in a landfill is generated leachate and biogas that interact with the environment. An inadequate management can generate public health deterioration on the landfill influence area. The main objective of this paper is to forecast the leachate and biogas generation under active extraction conditions in a Latin American landfill (Bogota, Colombia). We evaluated the temporal behavior in leachate and biogas generation through two models: Corenostos model (CM) and Colombian biogas model (CBM). The results suggested a normal tendency in leachate generation. Higher leachate flows were observed during the MSW disposal period (9 months, Qmax = 3.45 L/s). Subsequently, we observed a decrease in the leachate flow (-80%, Q = 0.69 L/s) probably associated with the completion of MSW disposal operations and commencement of the final coverage construction. In relation to the temporal evolution of biogas generated, the results suggested a trend like that observed for the leachate. We observed a greater biogas production during the MSW disposal period. The maximum biogas generation was observed one year after the final landfill coverage was built (1894 Nm^3/h). Subsequently, we observed a decrease in biogas generation (-80.9%, 348 Nm^3/h). Temporal forecast of leachate flow with CM model showed that the trend was like that observed in landfill. Mean absolute percentage error of the monthly forecast of leachate flow with CM model was 66.6%. The results showed that the mean absolute percentage errors in annual biogas forecasts were 49.9% and 41.3% for the CM and CBM models, respectively. The findings also showed that the absolute percentage errors in forecasts for the total biogas volume during the study period through the CM and CBM models were 29.0% and 37.9%, respectively. Finally, in this study the CM and CBM models tended to overestimate and underestimate the biogas generation, respectively.

Keywords: Biogas, Leachate, Municipal solid waste, Landfill.

INTRODUCTION

When municipal solid waste (MSW) is deposited in a landfill it starts a decomposition process in which the materials are transformed into water, gas, and stable matter. During the MSW decomposition process are generated leachates and biogas that interact with the environment. Inadequate management can lead to deterioration in public health on the landfill influence area [1]. In Colombia there are no published studies about active biogas extraction in landfills. This generates a local ignorance on this matter that prevents forecasting the temporal behavior in leachates and biogas generation under these conditions. Therefore, it is necessary to study the biological stabilization associated with the active biogas extraction in Colombian landfills. Thus, it will be possible to estimate the temporal behavior in leachates and biogas generation for these areas of MSW disposal.

The biogas of a landfill is a natural product of the organic MSW decomposition by aerobic and anaerobic conditions. Aerobic conditions occur immediately after depositing the MSW due to atmospheric air capture. This initial phase is characterized by having a short duration and generating a biogas composed mainly of CO_2. When oxygen is consumed, prolonged anaerobic degradation is initiated with a significant energy value (biogas composition: CH_4 = 55%; CO_2 = 45%) [2-4]. Over time and after closing a landfill the MSW tends to stabilize in volume and mineralized due to the low biological activity that exists. Thus, it is said that a landfill is in stabilization process. During this stabilization process the biogas generation decreases, and pollutant concentrations associated with the leachates are also decreased [5].

In Colombia there are several mathematical models incorporated in computer programs, and among the most recognized are Corenostos Model (CM) and Colombian Biogas Model (CBM). CM model involves the following variables to monthly forecast the leachate and biogas generation for MSW landfills: waste quantity and monthly increments (ton), physical (%) and chemistry (C, H, O, N, and S) composition, MSW decomposition rate, design period (months), climate conditions, and type of surface coverage [6]. CBM model was developed by S.C.S. engineers under a contract with the Landfill Methane Outreach Program (LMOP) of U.S.EPA. Other models assessed during the development process included the Mexican Biogas Model and Intergovernmental Panel on Climate Change Model (IPCC). Namely, this model also incorporates the IPCC structure to better reflect the Colombian climate conditions [7]. CBM model requires the incorporation of specific information such as opening and closing date, annual MSW disposal indices, site climate, and including past and present physical conditions of the landfill. At the global level, the modeling of leachate and biogas generated in landfills is based mainly on three factors: (i) composition and age of the MSW deposited, (ii) design and operation of the landfill, and (iii) climate conditions (rainfall and temperature) [8,9].

The main objective of this paper is to study the leachate and biogas generation under active extraction conditions in a Latin American landfill (Bogotá, Colombia) using the CM and CBM models. A forecast and analysis of leachate and biogas generation with the CM and CBM models is carried out to establish a comparison scenario with the information observed in landfill. This paper would deepen the knowledge about these computational models for forecasts in developing country landfills.

MATERIALS AND METHODS

Description of the study area

The final disposal area for MSW was located within the 'Doña Juana' landfill in Bogotá, Colombia (40°29´50.59´´N; 74°08´43.28´´W). The study area was in operation for about 8 months, had an area of 2.98 ha, and received 465808 ton of MSW. Average elevation of the study area was 2920 masl, had an average rainfall of 655 mm, and an average temperature of 12 °C. This study area was in an oceanic climate (Cfb) according to the Köppen-Geiger classification, i.e., it was a subtropical climate with scarce rainfall. Landfill area was in adaptation phase since 17/04/2008. Then, the MSW disposal was initiated on 08/09/2008. MSW disposal ended on 02/05/2009. Finally, the final landfill coverage was built and the instrumentation for geotechnical control was installed. The biogas generated in this landfill area was extracted through active conditions.

Sampling system

Information collecting: We collected all the information generated by the landfill operator, auditing, contracting entity, and regional environmental authority. In this phase all the basic information of landfill was collected: location, design criteria, and information of adequacy, operation, and closure of the MSW disposal area.

MSW characterization: The characterization information of MSW was obtained from monthly reports of the landfill operator. MSW quantity deposited month-to-month in landfill during the study period was determined. MSW composition was determined from the monthly and yearly averages of characterization performed by the landfill operator.

Leachate and biogas: The flow (daily) and quality (monthly) of generated leachate were taken from information reported by the landfill operator between 10/09/2008 and 30/06/2012. Leachate characterization included the following parameters: COD, BOD_5, total suspended solids, and pH. Information on the quantity and quality of biogas generated was obtained from daily reports from the landfill operator. This information was added to obtain average monthly values. The following parameters were included in biogas characterization: CH_4 and CO_2. Biogas generation was reported in volume per unit of time under normal conditions of pressure and temperature (Nm^3/h).

Information analysis

Once collected and analyzed the information of MSW, leachate, and biogas: MSW quantity deposited (ton/month), MSW composition (%), daily and monthly flow of leachate, monthly quality of leachate (COD, BOD_5, SST, and pH), hourly generation and quality of biogas (CH_4 and CO_2), and piezometric and topographic parameters. Then we proceeded to evaluate temporarily the leachate and biogas generation, and to make the forecast of its monthly generation by the CM [6] and CBM models [7]. Comparison scenarios were established between the forecasted and observed values in landfill. Finally, the mean absolute percentage errors were determined for the forecasts made.

RESULTS AND DISCUSION

MSW characterization

Table 1 shows the information corresponding to MSW quantities deposited in landfill during the study period. They were deposited in total 246591 ton in 2008 and 219216 ton in 2009. Knowing the MSW composition is also essential to study the leachate and biogas generation. For example, the wood derivatives (paper and paperboard) are residues of slow degradation because they have in their chemical composition non-soluble organic molecules in water [4]. The waste of food, pruning, and gardening form the organic MSW group of fast degradation, since they have high moisture content and their deposit in large quantities in young landfills can delay the methane formation [10]. This is due to the decrease of pH that produces the high initial microbial activity, surpassed this phase, the biogas generation is recovered with force [11].

Table 1. MSW quantity in landfill

Date	Tons (month)	Tons (year)
September/2008	20219	246591
October/2008	77526	
November/2008	75206	
December/2008	73640	
January/2009	71354	219216
February/2009	42090	
March/2009	60289	
April/2009	45035	
May/2009	448	
Total MSW	465808	465807

Landfill operator carried out the monthly MSW characterization deposited and with this information the annual averages were determined in relation to the MSW composition during the study period (Table 2). As noted, organic matter (OM) decreased in the MSW composition deposited, i.e., between the years 2008 (OM = 78.4%) and 2009 (OM = 72.6%). It was also observed that during the study period there was an increase in fractions corresponding to plastic and rubber, and glass. Therefore, the previous findings probably generated a variation in the temporal behavior of leachate flow and biogas volume (quantity and quality) during the study period.

Table 2. MSW composition in landfill

Fraction (%)	Year	
	2008	**2009**
Organic matter	78.4	72.6
Wood	0.88	1.34
Metals	1.15	0.70
Minerals	0.00	0.10
Paper and paperboard	6.80	6.42
Plastic and rubber	8.70	14.8
Textile	2.75	2.19
Glass	1.41	2.25
Total	**100**	**100**

Leachate analysis

The leachate generation information (flow) in landfill corresponded to the period between 10/09/2008 and 30/06/2012 (Figure 2). This temporal information was used to establish a comparison scenario in relation to the leachate flow forecasts made by CM model. The results suggested a normal temporal behavior in leachate generation, i.e., higher flow rates were observed during the MSW disposal period in landfill (ended on 02/05/2008). Subsequently, we observed a decrease in leachate flow likely associated with the start of final coverage construction in this landfill area (initiated on 01/06/2009). It was also observed that the leachate flow tended to temporarily decrease towards a condition of equilibrium or stabilization between 0.15-0.30 l/s. It is important to mention that there were increases in leachate flows probably because of the rainfall regime (bimodal trend). In other words, the time periods that showed greater rainfall in the study area were the following: (i) between March and June, and (ii) between September and December.

We made the forecast of leachate flow with CM model. The forecast timescale used by the model was monthly. Figure 3 shows the comparison scenario between the observed leachate flow and the one foretold by CM model. Temporal trend of forecast was like that observed in landfill. The results showed that the mean absolute percentage error of the monthly forecast of leachate flow was 66.6%, and 85% of the forecasts were lower than those observed in landfill.

Quality analysis of the leachate generated in landfill was carried out monthly, between 10/09/2008 and 30/06/2012. Results showed that the highest concentrations of COD, BOD5, and TSS occurred during the MSW disposal phase and during the following three months after closing this landfill area; that is, until August 2009 (Figure 4). Subsequently, since September 2009, a constant decrease in concentrations was observed until reaching an average reduction between 95% and 99%. However, pH as time passed changed from acid (4.7) to basic (8.8). This probably due to internal reactions in the landfill waste mass.

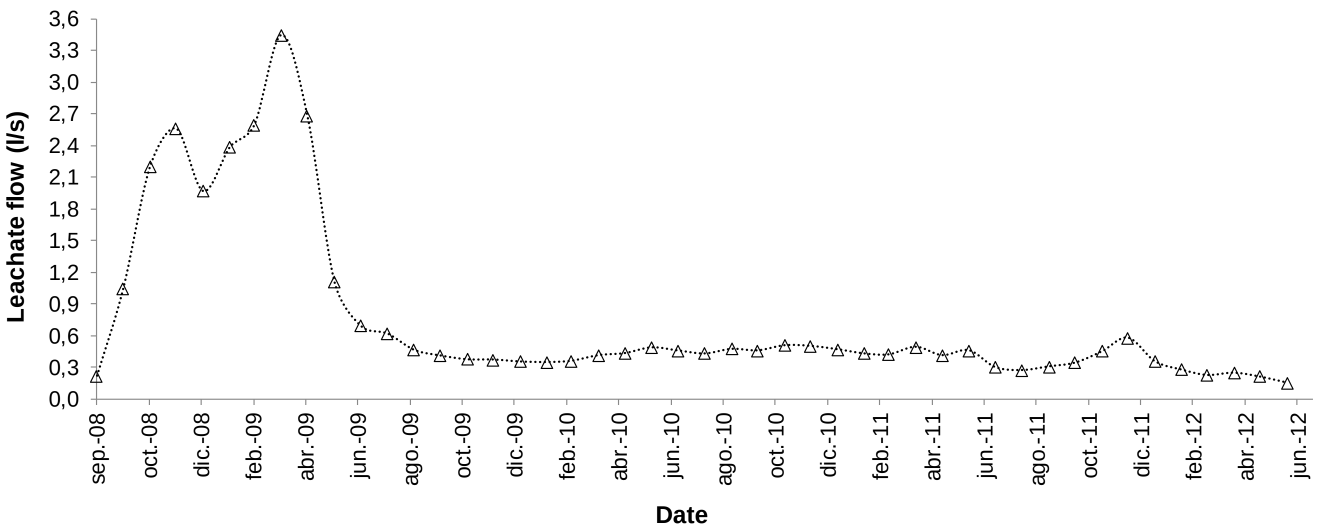

Figure 2. Average monthly leachate flow observed in landfill

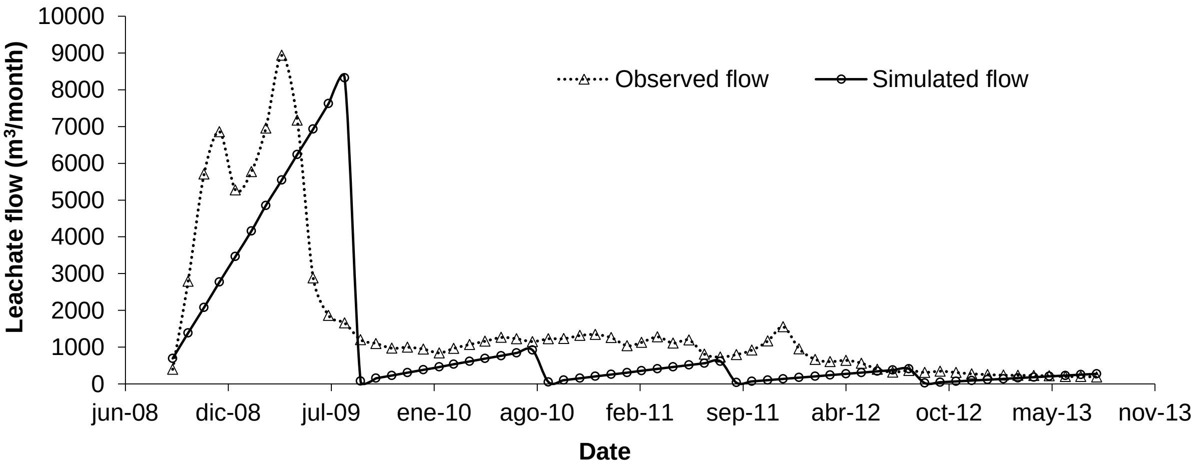

Figure 3. Comparison scenario between leachate flows observed in landfill and simulated by CM model

Therefore, the results suggested that these concentration variations (COD, BOD_5, and TSS) in leachates were probably associated with the MSW composition deposited and landfill age. In this study, the young leachate was characterized by a high ratio between BOD_5 and COD (between 0.31-1.80). Previous relationships were observed during the first 22 months after starting the MSW disposal (Figure 4). It is important to mention that the landfill had a shelf life of 8 months. During this period, high concentrations of OM were observed (e.g., BOD_5 between 1400-66900 mg/l). Instead, the mature leachate was characterized by a low relationship between BOD_5 and COD (between 0.05-0.23). Previous relations were observed between the months 23 and 36. In this study the landfill leachate was analyzed until the month 36. Martín [11] and Critto et al. [12] reported similar trends in their studies on leachate quality in landfills.

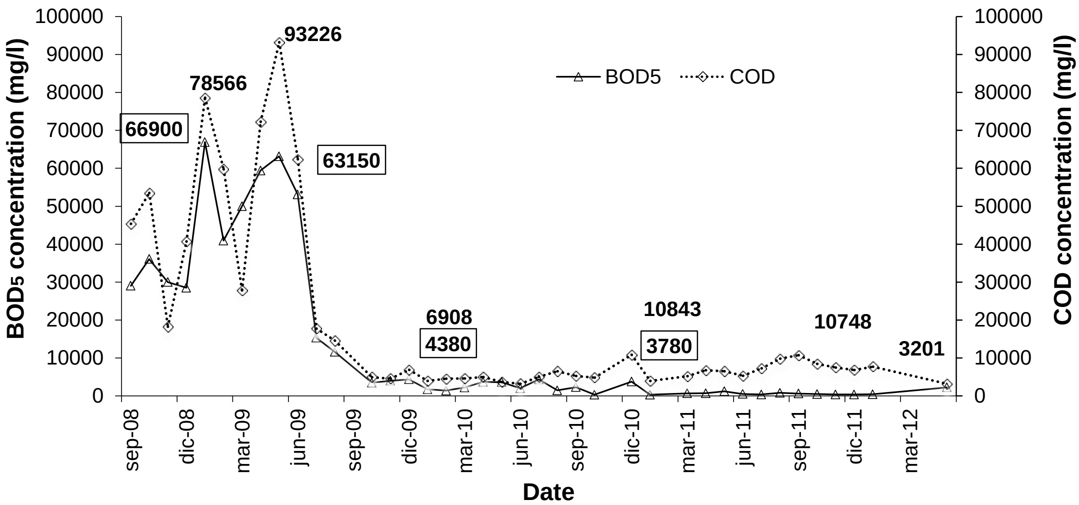

Figure 4. Temporal variation of BOD_5 and COD concentrations in landfill leachates

Biogas analysis

The preparation for active biogas extraction in the study area began in October 2009 with the construction and connection of 8 chimneys resting on the side slopes and 13 vertical chimneys of active extraction. In October and November 2009, the construction of primary and secondary networks for active biogas extraction in the study area was completed. Figure 5 shows the hourly biogas generation observed in landfill between October 2009 and October 2012. It is important to mention that since November 2009 the active biogas extraction system worked in its entirety. We note that the largest hourly biogas generation occurred between December 2009 (1784 Nm^3/h) and July 2010 (1816 Nm^3/h). Subsequently, biogas generation began to decline steadily from August 2010 to a minimum hourly generation of 348 Nm^3/h in October 2012 (Figure 5). In other words, during this time interval a reduction of 80.9% in biogas generation was demonstrated. It was also evident that this temporal trend in biogas generation was like that observed for the leachate flow in landfill (Figure 4).

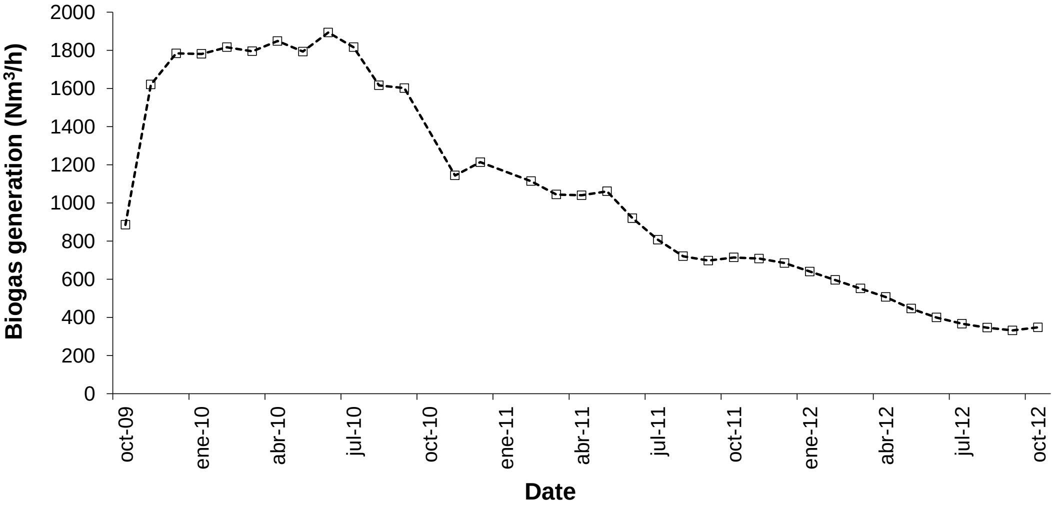

Figure 5. Hourly biogas generation observed in landfill

Figure 6 shows the biogas composition generated in landfill between October 2009 and October 2012. Results showed that since the onset of active biogas extraction the percentage composition of CH_4 and CO_2 has remained constant, specifically, between 49-54% and 37-39%, respectively. In this study, it is important to mention that the active biogas extraction began after 6 months of closed the MSW cell and that the biogas analysis was carried out for 40 months. Merz and Stone [13] reported similar results. In this study found 48% of methane in biogas after 24 months of closed the MSW cell. Monreal [14] reported that the biogas composition in Chilean landfills remained between 50-54% for CH_4 and 45-48% for CO_2. It has also been reported that the usual proportions for CH_4 and CO_2 in landfill biogas were between 40-60% [10,11].

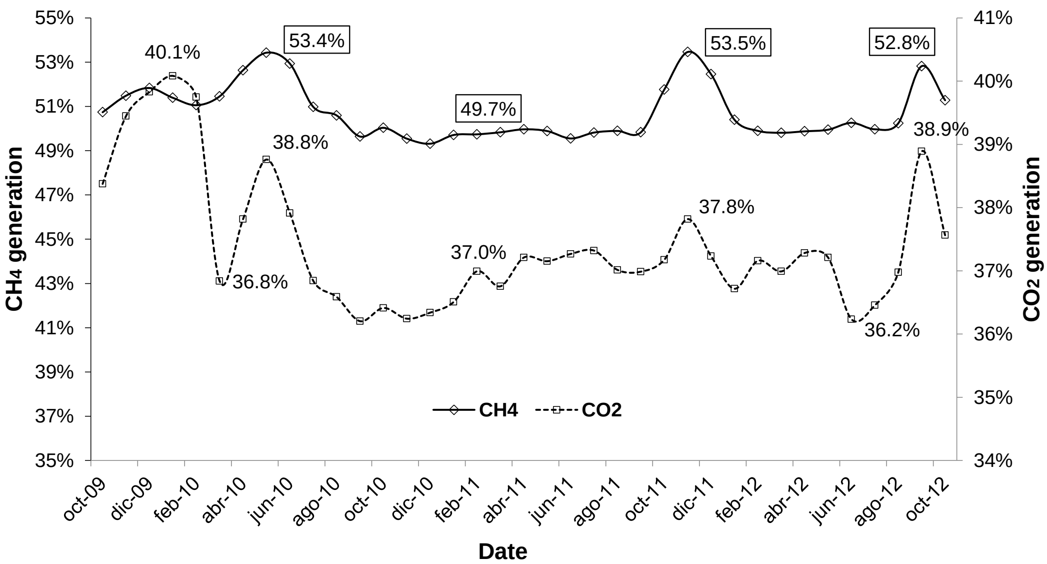

Figure 6. Observed generation of CH_4 and CO_2 in landfill biogas

Table 3 shows the results for annual forecasts of biogas generated and the forecast error percentage in relation to the biogas generation observed in landfill. The results displayed that the mean absolute percentage errors in annual forecasts were 49.9% and 41.3% for the CM and CBM models, respectively. Findings also showed that the absolute percentage errors in forecasts of total biogas volume generated during the study period using CM and CBM models were 29.0% and 37.9%, respectively. CM model tended to overestimate the biogas generation observed. On average, 75% of annual forecasts during the study period were above the biogas volume extracted in landfill. In contrast, the results showed that CBM model tended to underestimate the biogas generation observed. On average, 75% of annual forecasts were below the biogas volume extracted in landfill. The maximum absolute errors in annual biogas generation forecasts were 64.2% and 64.8% for the CM and CBM models, respectively (Table 3).

Table 3. Annual forecasts of biogas generation using CM and CBM models

Year	CM model	CBM model	Generation observed	CM model	CBM model
	m^3/h	m^3/h	m^3/h	Error (%)	Error (%)
2009	951	504	1430	-33.5	-64.8
2010	2735	874	1666	+64.2	-47.5
2011	1347	739	865	+55.7	-14.6
2012	663	626	453	+46.4	+38.2
Total	5696	2743	4414	+29.0	-37.9
Mean absolute error				49.9	41.3

CONCLUSIONS

The results suggest a normal tendency in leachate generation. In other words, higher leachate flows are observed during the MSW disposal period (9 months, Qmax = 3.45 L/s). Subsequently, we observed a decrease in the leachate flow (-80%, Q = 0.69 L/s) probably associated with the completion of MSW disposal operations and commencement of the final coverage construction. There is an influence of the rainfall regime on the temporal behavior of leachate flow. The findings also show a normal tendency in the leachate composition. During the first 22 months of landfill operation the BOD_5/COD relations are between 0.31 and 1.80. The leachate flow forecast with CM model shows that the temporal trend is like that observed in landfill. Monthly, the results display that the mean absolute percentage error of forecast is 66.6%, and that 75% of forecasts are lower than the value observed in landfill.

In relation to the temporal evolution of biogas generated, the results suggest a trend like that observed for the leachate. In other words, we observed a greater biogas generation during the MSW disposal period. However, the maximum biogas generation is observed one year after the final landfill cover was built (1894 Nm^3/h). Subsequently, we observed a decrease in biogas generation (-80.9%, 348 Nm^3/h). In relation to the biogas composition generated, we observed that between 49-54% and 37-39% corresponds to CH_4 and CO_2, respectively. On an annual basis, the results display that the mean absolute percentage errors of biogas forecast are 49.9% and 41.3% for the CM and CBM models, respectively. Results also show that the absolute percentage errors of forecast for the total biogas volume by the CM and CBM models are 29% and 37.9%, respectively. Finally, in this study, CM and CBM models tend to overestimate and underestimate the biogas generation observed in landfill, respectively.

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REFERENCES

[1] C. A. Zafra, F. A. Mendoza, and P. A. Montoya, "A methodology for landfill location using geographic information systems: a Colombian regional case", Ingeniería e Investigación, Vol. 32, pp. 64-70, Apr. 2012.

[2] R. E. Sims, "Sustainable energy future for New Zealand", Renewable Energy, Vol. 9, pp. 1049-1054, Jan. 1996.

[3] R. L. Meraz, A. M. Vidales, and A. A. Dominguez, "Fractal-like kinetics equation to calculate landfill methane production", Fuel, Vol. 83, pp. 73-80, Jan. 2004.

[4] N. Miroslav, R. Therrien, R. Lefebvre, and P. Gélinas, "Gas production and migration in landfill and geological materials", J. Contamination Hidrol., Vol. 52, pp. 187-211, Nov. 2001.

[5] C. H. Hettiarachchi, J. N. Meegoda, J. Tavantzis, and P. Hettiaratchi, "Numerical model to predict settlements coupled with landfill gas pressure in bioreactor landfills", Journal of Hazardous Materials, Vol. 139, pp. 514-522, Jan. 2007.

[6] H. Collazos, Diseño y operación de rellenos sanitarios, Bogotá D.C. (Colombia): Escuela Colombiana de Ingeniería, 2005, 233 p.

[7] G. A. Stege, Manual del usuario. Modelo Colombiano de Biogás, Washington D.C. (USA): Agencia para la Protección del Ambiente (U.S. EPA), 2009, 31 p.

[8] A. F. Al-Yaqout, M. F. Hamoda, "Evaluation of landfill leachate in arid climate-a case study", Environmental International, Vol. 26, pp. 593-600, Aug. 2003.

[9] A. Camba, S. González-García, A. Bala, P. Fullana-i-Palmer, M. T. Moreira, G. Feijoo, "Modeling the leachate flow and aggregated emissions from

municipal waste landfills under life cycle thinking in the Oceanic region of the Iberian Peninsula", Journal of Cleaner Production, Vol. 67, pp. 98-106, Mar. 2014.

[10] G. Tchobanoglous, H. Theissen, and R. Eliassen, Desechos Sólidos. Principios de Ingeniería y Administración, Mérida (Venezuela): CIDIAT, 1982, 542 p.

[11] S. Martín, Producción y Recuperación del Biogás en Vertederos Controlados de Residuos Sólidos Urbanos: Análisis de Variables y Modelización, Oviedo (España): Universidad de Oviedo, 1997, 220 p.

[12] A. Critto, C. Carlon, and A. Marcomini, "Characterization of contaminated soil and groundwater surrounding an illegal landfill (S. Giuliano, Venice, Italy) by principal component analysis and kriging", Environmental Pollution, Vol. 122, pp. 235-244, Apr. 2003.

[13] R.C. Merz, and R. Stone, Special Studies of a Sanitary Landfill, Washington, D.C.: U.S. Department of Health, Education, and Welfare, 1970, 51 p.

[14] J. Monreal, La Recuperación de Biogás en Rellenos Sanitarios en Santiago de Chile, Santiago de Chile (Chile): Siglo XXI, 1999, 12 p.