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Analysis of the feasibility of the recovery of landfill gas: a case study of Mexico

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ABSTRACT

Electricity is a vital component in the development of societies and industrial progress. The growing demand and environmental degradation from current sources forces us to search for alternative methods of generating it. The use of biogas generated in landfills enables the recovery of the remaining energy in waste and reduces the environmental problems caused by burning coal, oil, and natural gas. Certainty in the generation projections is required for an energy source to be considered useful. The usefulness of biogas power generation depends on accurately estimating the amount of possible biogas generation. Considering this uncertainty, the objectives of this research were to (a) determine the methane generation rate (k) and methane generation potential (L_0), and (b) estimate the biogas generation in the final disposal sites (FDS) of two urban communities and two rural communities in Baja California, Mexico. To determine the constants used in biogas models, the following experiments were performed: (a) waste characterisation studies, (b) observations of the characteristics and performance of the FDS, (c) interviews with the managers of the FDS, and (d) IPCC model parameters. Predictions of biogas utility were made using the modified constants in the Mexico LFG Model Version 2.0 proposed by SCS Engineers. The results show that k averaged 0.0429 yr^{-1} and L_0 was 68.69 m^3/ton. In the period of 2013–2030, there will be a power generation potential of 760492.8 MW/h (USD $142.21 million). The potential reduction in CO_2e emissions would be approximately 5.2 $MtCO_2$e during the same period (USD $57.16 million).

1. Introduction

At present, one of the ongoing challenges facing humanity is the continual production of energy in usable forms, such as electricity and gasoline, despite declining fossil fuel reserves, growing populations, and increasing concerns about global warming (Wang et al., 2013). Due to these circumstances, the use of renewable energy resources has become a global strategy for sustainable energy use, which is of particular importance for coping with the increasing stress from the energy crisis and global warming. Biogas is being developed rapidly and globally as an effective method to generate renewable energy and is playing an increasingly important role in energy production and environmental protection (Wang et al., 2013; Zhang et al., 2013).

Biogas produced in landfills (landfill gas, LFG) is the result of the physical, chemical, and microbial processes that occur in the waste. Due to the organic nature of most waste, microbial processes govern the process of biogas generation. These processes are sensitive to their environment, and therefore, there are a number of factors that affect the microbial population and thus the biogas generation. The main components of biogas are methane (CH_4), carbon dioxide (CO_2), and traces of several other compounds (Karapidakis et al., 2010; Machado et al., 2009; Marshall, 2007; Zamorano et al., 2007). Estimations of biogas emissions in final disposal sites (FDS) have been studied by several researchers (Bidart et al., 2013; Chiemchaisri et al., 2007; Garg et al., 2006; Johari et al., 2012; Karapidakis et al., 2010; Kumar et al., 2004; Machado et al., 2009; Melikoglu, 2013; Niskanen et al., 2013; Pathak et al., 2009; Rubio-Romero et al., 2013; Thompson et al., 2009; Wangyao et al., 2010; Wanichpongpan and Gheewala, 2007; Zamorano et al., 2007), primarily for their potential as a renewable source of energy and greenhouse gas emissions mitigation.

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The most important factors in evaluating the potential of biogas generation at a site are the amount of waste, waste composition, moisture content, temperature, and lag time in gas generation (Amini et al., 2013, 2012; Bidart et al., 2013; Dudek et al., 2010; Karapidakis et al., 2010; Kong, 2008; Machado et al., 2009; Tsai, 2007; US EPA, 2012; WBG, 2004). Over the years, a large number of numerical and mathematical models have been developed to estimate LFG based on zero-, first-, and second-order approaches (such as the tier-three method (Walter, 2003), the IPCC method (Chiemchaisri and Visvanathan, 2008; IPCC, 2006; Johari et al., 2012; Machado et al., 2009; Tsai, 2007), the EPA model (Dudek et al., 2010; Garg et al., 2006; Karapidakis et al., 2010; Machado et al., 2009; Wanichpongpan and Gheewala, 2007), and the Mexico LFG Model (SCS Engineers, 2009)). However, second-order models are not commonly used because the required parameters in each model are often so uncertain that they negatively affect the accuracy of the model (Amini et al., 2013). Likewise, zero-order models do not reflect the biological LFG generation processes. Because of these limitations, simplified approaches have been developed based on first-order decay (FOD). The FOD model is widely used by industry, state regulators, the Intergovernmental Panel on Climate Change (IPCC), and the US Environmental Protection Agency (US EPA) to estimate LFG generation. Most of these models are based on two primary model parameters: an ultimate methane generation potential and a first-order decay rate constant (Amini et al., 2013, 2012).

1.1. Mexico LFG model

The Mexico LFG Model uses a first-order decay equation that assumes that biogas generation reaches its maximum before methane generation. This model requires that the user enter specific data, such as the opening year, closing year, annual waste disposal rates, annual rain precipitation, and collection system efficiency. The model estimates the biogas generation rate for each year using the first-order decay equation (see Eq. (1)), which was modified by the US EPA in the LandGEM model version 3.02 in 2005 (SCS Engineers, 2009),

$$Q_{\mathrm{LFG}} = \sum\nolimits_{i=1}^{n}\sum\nolimits_{j=0.1}^{1} 2kL_0\left[\frac{M_i}{10}\right]\left(e^{-kt_{ij}}\right)(\mathrm{MCF})(F) \quad (1)$$

where Q_{LFG} is the maximum expected biogas generation flow rate (m^3/yr), i is the increase in time in 1-year increments, n is the number of years since the initial year, j is the increase in time in 0.1-year increments, k is the methane generation rate (yr^{-1}), L_0 is the methane generation potential (m^3/ton), M_i is the mass of the solid waste disposal in the ith year (tons), t_{ij} is the age of the jth section of the waste mass (M_i) disposed in the ith year (decimal years), MCF is the methane correction factor, and F is the fire adjustment factor.

The model automatically provides values for the methane generation rate and methane generation potential (SCS Engineers, 2009). Despite having presets, these parameters can be modified according to the *in situ* characteristics.

Methane generation rate (k) represents the first-order biodegradation rate of the methane generated after the disposal of the waste in the FDS and is related to the lifetime of the waste. As the value of k increases, the methane generation in an FDS also increases (provided that the FDS is still receiving waste) and then decreases with time (after the FDS is closed) (IPCC, 2006, 2002; SCS Engineers, 2009; WBG, 2004).

Several studies have indicated that typically the range of k values is from 0.02 for dry sites to 0.07 for wet locations (ETEISA, 2006; WBG, 2004). The most rapid rates ($k = 0.2$ or an average life of approximately 3 years) are associated with conditions of high humidity and highly degradable materials, such as food waste. Slower rates ($k = 0.02$ or a half-life of approximately 35 years) are associated with dry conditions and slowly degradable materials, such as wood or paper (Amini et al., 2013; IPCC, 2006).

In version 2.0 of the Mexico LFG Model (MBM 2.0), k values are assigned for four categories of waste degradation (very fast, R+; moderately fast, R−; moderately slow, L−; and very slow, L+) for each of the five climatic regions of Mexico (see Table 1). These values vary based on the average annual precipitation in the region where the FDS is located and the type of waste.

Methane generation potential (L_0) is the total amount of methane that can potentially be produced by a unit mass of waste when the waste has degraded and depends almost exclusively on the characterisation of the residues in the FDS, in particular the organic fraction of the material (Amini et al., 2013; ETEISA, 2006; IPCC, 2006; SCS Engineers, 2009; WBG, 2004). This value is estimated based on the carbon content of the residue, the biodegradable carbon fraction, and the stoichiometric conversion factor (ETEISA, 2006). A higher content of cellulose corresponds to a greater value of L_0. L_0 units are in cubic metres per ton of waste (m^3/ton). The theoretical values of L_0 vary from 6 to 270 m^3/ton (Amini et al., 2013; Machado et al., 2009; SCS Engineers, 2009), and typical values of this parameter are between 125 and 310 m^3/ton (ETEISA, 2006). The US EPA uses a typical value of 170 m^3/ton (Karapidakis et al., 2010; WBG, 2004).

In MBM 2.0, L_0 values are assigned for the four categories of waste degradation (R+, R−, L−, and L+) for each of the five climatic regions of Mexico. These values vary according to the waste composition at the FDS, and it is assumed that these values remain constant for all climates, except for category 2 in which there is a change in climate due to differences in the type of local vegetation. The values for the climatic region where the Ensenada's sanitary landfill (SL) is located (Region 5: Northwest and Northern Interior) are presented in Table 1.

The particularities of each community in Baja California, Mexico, are an impediment to estimate biogas generation in different FDS considering the preset values, as it may underestimate or overestimate. Therefore, to more accurately estimate the potential of biogas generation, and thus the potential for electricity generation in the FDS in two urban (Mexicali and Tijuana) and two rural (San Quentin and Vicente Guerrero) communities of Baja California, Mexico, the objectives of this research were (a) to modify the constants L_0 and k, and (b) to estimate the biogas generation in the FDS of Baja California, Mexico, with modified constants.

1.2. Study area

Fig. 1 shows the four communities that comprise the study area. Mexicali (MXL) is the capital of Baja California State and is located at northwest of Mexico in 32.65, −115.47. It has a warm dry climate with very little annual precipitation. Mexicali temperatures range from −5 °C in winter to 50 °C in the shade in the summer and have an average annual rainfall of 132 mm. The city of Tijuana (TIJ) is located at 32.53, −117.02. The historical annual average precipitation is 196 mm, with a Mediterranean climate and mild temperatures most of the time that range from 15 °C to 36 °C. The

Table 1
Values for k and L_0 in the Northwest region and Northern Mexico.

Waste category	k	L_0
Residues with very fast degradation (R^+)	0.100	69
Residues with moderately fast degradation (R^-)	0.050	149
Residues with moderately slow degradation (L^-)	0.020	214
Residues with very slow degradation (L^+)	0.010	202

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