Research & Reviews: Journal of Ecology and Environmental Sciences
e-ISSN:2347-7830
p-ISSN:2347-7822

Characterization of the Parameters and Estimation of Potential Biogas of A Landfill in Tropical Area: Case Study of the Principal Landfill of Abidjan Akouedo Landfill

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Research Article

Received: 06/11/2017
Accepted: 22/12/2017
Published: 29/12/2017

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Keywords: Biogas, Parameters, Energy, Environment, Organic matter

ABSTRACT

The use of fossil fuels in large-scale has resulted in the reduction of energy reserves and global warming. Why the use of renewable energy such as biogas from solid waste is appropriate to solve the problem of energy as well as climate problem. Thereby, in this study, the landfill gas (LFG) generation was estimated in order to determine the amount of energy potential from the Akouedo landfill in Abidjan, Cote divoire. To evaluate the LFG generated, the methane generation rate (k) and methane generation potential (Lo) was modified in the version 2.0 Mexico Landfill Gas Model proposed by Stearns, Conrad and Schmidt Consulting Engineers, Inc. (SCS Engineers). To be done the following data were used: (a) waste characterization studies for a year, (b) observations of characteristics and performance of landfill, (c) interviews with the managers of the landfill and (d) some IPCC (Intergovernmental Panel on Climate Change) model constants. The values of k=0.1492 yr^{1} and L0= 107.56 m^3/t were obtained. The peak landfill production was estimated to occur 1 year after the landfill closure with the rate of 15377 m^3/h. Thereby the results show that the energy potential that can be obtained from the landfill over the period 2009-2032 is of 6189 GWh. The peak energy potential is obtain in 2018 and is of 554.3 GWh. Based on an LFG collection efficiency of 66% and energy efficiency of 33% this energy represented approximately 2.36% of the electric energy required for Cote d'Ivoire in 2015.

INTRODUCTION

Landfilling is one of the most economic common ways of municipal solid waste (MSW) disposal in developing countries. The main environmental impacts of such landfills, containing high amounts of biodegradable organic matter, are caused by emissions of leachate and biogas. Quantity and quality of leachate and landfill gas (LFG) depend upon MSW characteristics, landfill design and operation, climatic conditions, and site-specific variables [1]. Energy recovery from waste rich in organic matter can mitigate significantly to the growing demand for fossil fuels. Therefore, the production of biogas through anaerobic digestion is a good example of biomass conversion to sustainably solving critical problems caused by unhealthy and bulky waste. Anaerobic digestion is proving to be an effective tool to reduce organic pollution and energy production. In Abidjan, Cote d'Ivoire, according to the National Agency for the Urban Public Health (ANASUR), agency who manages the granting of the Akouedo discharge, the amount of waste landfilled in this one was about 1 million t per year since 2007. As for the studies of Sane et al. they showed that the Akouedo landfill is essentially biodegradable waste disposal [2]. Moreover, studies of Adjiri et al. have shown that the landfill of Akouedo is a source of biogas production consisting essentially of methane and carbon dioxide. The percentage of methane estimated was between 50% and 70% [3]. However, these studies do not make it possible to quantify the biogas this landfill nor the electrical energy available. The aim of the present work is to estimate the LFG generation in order to determine the amount of energy that could be generated from the decomposition of MSW disposed in the Akouedo landfill site, in Abidjan, Cote d'Ivoire.

MATERIALS AND METHODS

Site Description

The Akouedo landfill is a landfill site with a total area of 153 ha, the only one in the district of Abidjan, located in southeast

Côte d'Ivoire. This discharge has been set up since 1965. It is situated at 18 km from the center of Abidjan, Northeast of the district, in the commune of Cocody. The district of Abidjan, with a land area of 2,119 km^2 is the largest one in Côte d'Ivoire. The district's population, which is 4,800,000 in 2014, represents 20% of the urban population of Côte d'Ivoire. Its location is at 5°20' north and 4°1'west. The average annual precipitation in Abidjan is 1500 to 2100 mm, with a tropical humid climate, characterized by four seasons whose major rainy season (May to mid-July), the small dry season (mid-July to mid-September), the small rainy season (mid-September to November) and the great dry season (December to April). The Akouédo landfill has a final waste height of 20 [4]. **Table 1** presented the composition of municipal solid waste (MSW) of Abidjan. The organic and the inorganic fraction are 70.17% and 29.83% respectively. The moisture contain of these waste on the site was of 43%, determined according to the French standard AFNOR XP X30- 408,1996.

Table 1. Annual average of MSW composition of Abidjan.

Categories	Percentage (%)
Putrescibles	45.42
Paper-cardboard	14
Leaf	2
Wood	4
Bones and straw	3.42
Textiles	2.75
Glass	2.5
Metals	1.75
Plastics	8.5
Stone	1
Batteries	1.41
Sand, dust	13.25

Prediction Model of Biogas Production

Concentration of methane in biogas

The composition of biogas real municipal organic waste is always variable. The variation of the concentration of CH_4 is between 58 and 66% [5]. According to this study, the biogas used as industrial fuel is obtained from fermentation of organic matter contained in MSW. Based on earlier published study of Aguiri et al. [6]. We have chosen the concentration of methane, carbon dioxide and traces of other components and other atmospheric pollutants respectively as follows: 60%, 39.5%, and 0.5%.

Estimation of generated biogas

To estimate generated biogas from the landfill of Akouédo, the Mexico LFG Model Version 2.0 was used, but before the constants of the biogas generation were modified [7].

Parameters of biogas generation k and L_o

The modification of the constants of biogas generation used in the biogas model take into account the following studies:

(a) Waste characterization studies for a year;

(b) Observations of characteristics, and performance of landfill, and

(c) Some IPCC model constants.

The constants k and L_o were determined according to the *in situ* characteristics. To be done, *in situ* observations were done in the months of April, June, August, and November. Furthermore, interviews were conducted with the general manager and operations manager of the National Agency for the Urban Public Health (ANASUR) the company that manages granting of the Akouédo landfill. Based on observations and interviews, the constants and the estimation of LFG generation were determined. The constant k **(Table 2)** provided by the MBM 2.0 taking into account the climate Mexican that best describes the climate of Abidjan was modified with the percentage of waste of each category of waste see Eq.(1).

$$k_{weighted} = \sum_{(i=1)}^{1} (\%r_i.Vp) \quad (1)$$

Where; $\%r_i$: the percentage of waste in each category; V_p : the k value predetermined by the MBM 2.0 in each degradation categories; The IPCC methodology [8,9] was used for the determination of L_o, shown in Eq. (2).

$$L_O = M_{CF}.D_{OC}.D_{OCF}.F.\frac{16}{12} \quad (2)$$

Where; L_0 is the methane generation potential (m^3/t); M_{CF} is the correction factor for methane; D_{OC} is the degradable organic carbon (fraction), D_{OCF} is the fraction of degradable organic carbon assimilated, F is the fraction of CH_4 in the biogas, 16/12 is the stoichiometric factor. M_{CF}: This fraction varies depending on the depth of the waste and landfill type. The M_{CF} values applied by the model are given in **Table 3** [9,10]. D_{OC}: The D_{OC} content is showed in Eq. (3) and is important in the calculation of the methane generation, which depends on the composition of the waste and varies from city to city [11-13].

$$D_{OC} = 0.40(A) + 0.17(B) + 0.15(C) + 0.30(D) \quad (3)$$

Where, A : the percentage of residues corresponding to paper, cardboard, and textiles; B : the percentage of residues corresponding to garden waste, park waste, or other putrescible organic waste (other than food);

C : the percentage of residues corresponding to residues from food; and D: the percentage of residues corresponding to wood and straw. D_{OCF}: This constant is the portion of the D_{OC} that is converted into biogas (Eq. 4).

The estimation is based on the theoretical model that varies only with temperature in the anaerobic zone of a landfill.

$$D_{OCF} = 0.014T + 0.28 \quad (4)$$

Where; T is the temperature in degrees centigrade (^0C); F: fraction of CH_4 in landfill gas.

Table 2. Values for k and L_0 in the Southeast region of Mexico.

Category of waste	k	L_0
Residues with very fast degradation (R^+)	0.300	69
Residues with moderately fast degradation (R^-)	0.130	115
Residues with moderately slow degradation (L^-)	0.050	214
Residues with very slow degradation (L^+)	0.025	202

Table 3. Methane correction factor.

Management site	Depth <5 m	Depth ≥ 5 m
Without management	0.4	0.8
With management	0.8	1.0
Semi-aerobic	0.4	0.5
Condition unknown	0.4	0.8

Estimation of Biogas Potential Generation

To estimate the amount of LFG generated from the landfill of Akouedo, Eq.(5) of MBM 2.0 developed by SCS Engineers was used [6].

$$Q_{LFG} = \sum_{t=1}^{n}\sum_{j=0.1}^{1} 2.k.L_{0.}[\frac{M_i}{10}](e^{-kt_{ij}}).(M_{CF}).(F) \quad (5)$$

In addition to the amount of LFG generated, it is also possible to estimate by the model the amount of biogas recovery, only is required multiply the generate biogas by collection efficiency of biogas. Inputs into the model included information about *in situ* observations and interviews, such as the following: (1) annual disposal of MSW from most recent year, (2) years when the landfill opened and closed, (3) estimated annual increase of disposal, (4) average depth of the landfill, (5) fires in the landfill, (6) percentage of area with waste with daily cover ,intermediate and final, (7) the percentage of waste area having a clay/geomembrane, compact waste, leached outcrops at the surface of the landfill, and waste composition. The Excels spreadsheet published by SCS Engineers was modified using the values of the constants k and L_0. Furthermore, the maximum power of plant was calculated [14].

Energy potential,

$$E_{th\,(\mathrm{GWh/year})} = \frac{\dot{m}_{\mathrm{LFG}}.\mathrm{LHV}_{CH_4}.\,\mathfrak{R}}{3600000} \quad (6)$$

Electrical power,

$$E_{el\,(\mathrm{MW})} = \frac{E_{th\,(\mathrm{GWh/year})}}{8.76}\eta_{el} \quad (7)$$

Where; $\dot{m}_{LFG}$ is the biogas flow rate (m^3/an), $\Re$ is the collection efficiency, LHV_{CH4} Lower heating value of CH_4 (MJ/m^3), η_{el} is the energy efficiency.

RESULTS AND DISCUSSION

Energy Content of MSW

Lower heating value of waste was calculate using Eq.(8) [15].

$$LHV = \left(35.19P_{pa} + 36.24P_{te} + 71.17P_{pl} + 48.26P_{wo} + 42.21P_{fo} + 44P_{mi}\right)\left(\frac{100-w}{100}\right) - 6W\ \left(kcal/kg\right) \quad (8)$$

Where; Ppa: paper and cardboard (wt%) ; Pte : textiles (wt%) ;Ppl: plastics (wt%); Pwo: wood (wt%) ; Pfo: food waste (wt%); Pmi: miscellaneous combustible component (wt%).

LHV= 1727.585 kcal/kg = 7228 MJ/t.

The LHV obtained for Abidjan's MSW indicates that incineration with energy recovery is possible if considering a minimum calorific value of 1,700 kcal/kg is necessary for MSW to be incinerated with energy recovery [16].

However the obtained LHV value in Abidjan is close to that found in Mostaganem in Algeria (1700 kcal/kg) and is low compared to that of Ouagadougou in Burkina Faso (4780 ± 956 kcal/kg) who are both in developing countries.

Determination of Biogas Generation Parameters k and L_o

Determination of the constant k

Table 4. Determination of k according to the site.w

Waste category	Percentage of waste%	Category degradation	Value k$^\alpha$ Region1	value k Abidjan
Putrescibles	45.42	R$^+$	0.300	0.13626
paper-cardboard	14	L$^-$	0.050	0.0070
leaf	2	R$^-$	0.130	0.0026
wood	4	L$^+$	0.025	0.001
Bones and straw	3.42	L$^+$	0.025	0.00085
Textiles	2.75	L$^-$	0.050	0.001375
Glass	2.5	Inert	-	-
Metals	1.75	Inert	-	-
Plastics	8.5	Inert	-	-
stone	1	Inert	-	-
batteries	1.41	Inert	-	-
Sand, Dust	13.25	Inert	-	-
			$k_{weighted}$	0.1492

Note: $^\alpha$ Values determined in MBM 2.0; region 1: Southeast region of Mexico.

According to the calculations presented by **(Table 4)** the k value is of 0.1492 yr^{-1}. It was determined using Eq. (3). This value is within ranges reported in research of Amini et al. that mentioned values in the ranges from 0.01 to 0.21 yr^{-1} [17]. However, add that 0.04 yr^{-1} is the commonly applied value. In other study Willumsen et al. reported a range of values of 0.014-0.28 [18].

Determination of the constant L_o

This constant was determined using Eq. (4) but before the calculation of L_o, it was necessary to obtain the values of constants used in this Eq. as follows:

M_{CF}: Its value is 0.8 because the landfill is considered without management.

D_{OC} Using Eq. (7) this value is estimated to be 0.1565 **(Table 5)**. This value is within ranges reported in others research and is also found in the default value ranging from 0.08 to 0.21 set by Johari A et al. [19,20].

Table 5. Determination of DOC for the landfill.

Waste category	Percentage of waste (%)	Category(A, B, C, D)	Value DOC
Putrescibles	45.42	0.15	0.0681
paper-cardboard	14	0.40	0.056
Leaf	2	0.17	0.0034
wood	4	0.30	0.012
Textiles	2.75	0.40	0.011
straw	2	0.3	0.006
Total			0.1565

DOC_F: For this constant the default value of 0.77 used by the IPCC, 2002 was applied. **F:** Based on the studies of AGUIRI et al. a value of 0.60 was used for F. The value of L_0 was 107.56 m^3/t. This value is within ranges with the values obtained by Amini, of 93-140 m^3/t. On the other hand, it is greater than that established by Quetzalli et al. of 59-79 m^3/t. The difference between this study and that of Quetzalli et al. may be that their study was conducted in a Mediterranean climate whereas this study was in a tropical one.

Estimation of biogas in Akouedo landfill site

To obtain inputs to the model, *in situ* observations and interviews with the site manager were done as follows: (1) the annual disposal of the MSW in 2015 was 1 011,385.34 t, (2) the landfill operation began in 1965 and its closure will be in 2017, (3) there have been fires in the landfill site, (4) the average depth is 30m (5) before depositing waste, a Cover bottom geomembrane coat is not installed, (6) the deposited waste is covered daily, but there have not final cover, (7) the waste is 75% compacted, and (8) leached outcrops were observed. According to quantities given by the ANASUR in 2015, the annual increase in the waste disposal in ABIDJAN is 9.34%. The LFG predictions for Akouedo's landfill are shown in **Figure 1**. These results were obtained using the previous information, the modification of the constants k and L_0, Eq. (5), and the modified Excel® spreadsheet originally published by SCS Engineers [7]. Furthermore an LFG collection efficiency of 66%, an energy efficiency of 33% and a CH_4 lower calorific value of 5,370 kcal/m^3 was presupposed. It can see that the peak LFG generation will take place 1 year after the landfill closure (2018) with the rate estimated to be 13.47 × 10^7 m^3/year with a maximum capacity of 20.9 MW. Then, the capacity will decrease every year [21].

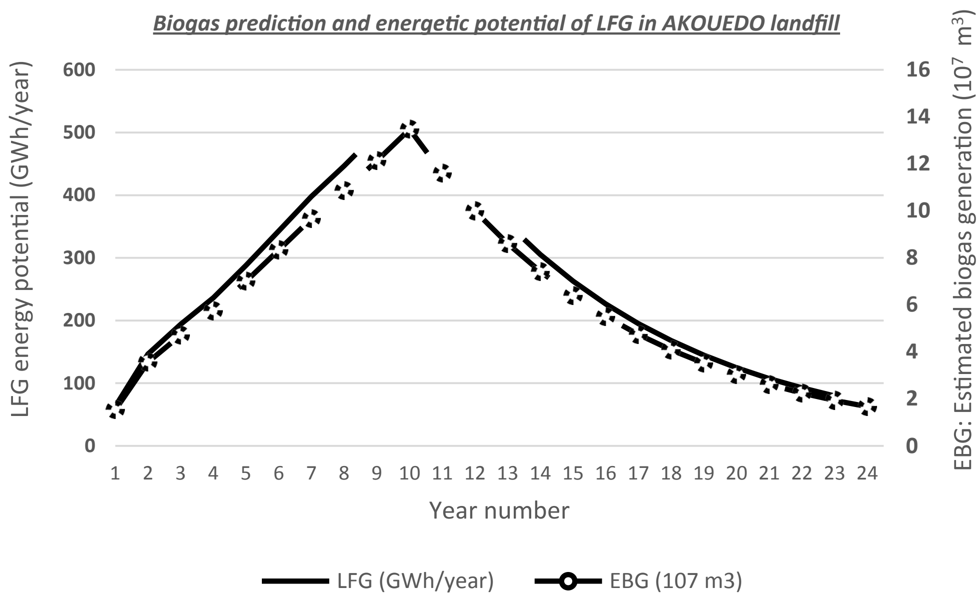

Figure 1. Biogas prediction and energetic potential of LFG in Akouedo landfill.

In addition, The LFG generation rate will decrease exponentially after the landfill closure parallel to the decrease of the amount of decomposable matter in the landfill. This decrease occurs because the model [13] assumes that the maximum generation normally occurs in the closing year or the following year, and the LFG generation decreases exponentially as the organic fraction of the waste is consumed. The concentration of the biogas decreases with the age of the final disposal site this fact is included in the model with the parameters k and L_0 [22,23]. The amount of electric energy potentially available in the landfill of Akouedo is of 554.3 GWh in 2018 and, in 2032, the recovered landfill biogas will be sufficient to generate 68.6 GWh, providing a significant power generation opportunity. In fact these amount of electric energy potentially available in 2018 represent the 2.36% of total electricity consumed in 2015 in Côte d'Ivoire. These percentage are determined by using an energy efficiency of 33%, a biogas capture efficiency of 66%, and the reference data from the annual report 2015 of the CIE (Ivoirian Company of Electricity). In other countries, other studies in Tunisia on LFG generation conducted in the landfill of JEBEL CHAKIR situated in Tunis city showed in the year following the closing (2011), the biogas recovery of 4030 m^3/h. On the other hand, at the landfill of Batna city in Algeria, in 2014, 1 year after the landfill closure, an LFG recovery of 2192 m^3/h was estimated. Unlike this study, in the previous, the landgem model was used. In addition, the annual disposal was lower. It is of 91,400 t in Batna city and of 608,000 t in Tunis while at the landfill of Akouedo it is of 867,026 t. In addition, these landfills are closed, but in the present study, the closure of the landfill is not yet effective.

CONCLUSION

For the use of biogas, a renewable energy source, as industrial fuel, it is very important to know the composition of wastes in organic matter biodegradable. This study showed that the waste of the city of Abidjan has a proportion of organic components of approximately 70.17%. This component and the type of climate influence directly the values of the parameters k and L_0. In this work, we have studied the use of biogas produced by MSW from the landfill of Akouédo (Abidjan) as industrial fuel. In the first place we modified the constant k and L_o. The modified values of k was 0.1492 yr^{1} and that of L_o was 107.56 m^3/t. Secondly we estimated the biogas amount(LFG) produced by the Mexico model. Taking into account this model, the expected peak LFG production, 1 year after the landfill closure is about 15377m^3/h. Thereby the energy potential that can be obtained from the landfill over the period 2009-2032 is of 6189 GWh. It is also important to mention the positive environmental consequences that would occur using the LFG in Akouedo landfill.

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e-ISSN:2347-7830
p-ISSN:2347-7822

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