Study of biogas as an alternative energy produced in landfills

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Abstract. This article estimates the energy power, as well as the net energy produced from biogas from landfills as a form of alternative energy production, and can be calculated as a theoretical form in cities where it is planned to build or there is already a landfill.

1. Introduction
Currently one of the most common problems in large cities in developing countries such as Quito is the final disposal of solid waste, since these, due to poor management, are a source of contamination both in the soil and in the atmosphere by the production of biogas, which can be used as an energy source due to its fuel properties [1].

The production of electrical energy from the decomposition of waste in landfills is not a very common technology in these cities, as is the production of alternative electrical energy [2]. The use of biogas as a fuel source for electric generators helps to improve the treatment and management of waste from any source that comes from agricultural, forestry or urban [3].

Given this argument, this article analyzes theoretically the power generation using biogas from landfill as alternative fuel source. For which, the quantity and quality of the biogas that can be obtained in the Quito Landfill must be analyzed and determined, and in turn its corresponding amount in electrical energy produced by the obtained biogas [4].

2. Materials and methods
The following methods were performed in this article: deduction methods, theoretical methods, and modeling methods. The place where the research was carried out and where the data were obtained was at the El Inga landfill located in the Pichincha province, outside the city of Quito in Ecuador [5].

The Inga Landfill began its activities in 2003, but the calculation of the biogas flow has been taken since 2012 because the amount of biogas that the landfill expels in this year is already considerable (table 1).

The gases that are generated at landfills are products of biological decomposition of the organic fraction of the stored waste. The source of biogas is fractions of biodegradable waste, on average 60-80% of the mass of landfill, which includes food waste, gardening, waste paper and other cellulose waste. The rate and integrity of waste biodegradation processes depend on the morphological, chemical composition, climatic and geographical conditions, and the stage of the life cycle of a landfill.

The biodegradation process includes phases of aerobic and anaerobic destruction. Anaerobic processes are the main emission of pollutants.

The main phases of the biodegradation of anaerobic waste are:
- Hydrolysis, when the polymer breaks down into short fragments and monomers;
- Acetogenesis: when acetic acid, H₂ and CO₂ are formed;
- Methanogenesis, when biogas synthesis occurs and biological activity decreases;
- Complete assimilation.

Table 1. Composition of waste in the sanitary landfill.

| Type                           | Percentage |
|--------------------------------|------------|
| Food waste                     | 57%        |
| Plastic                        | 14%        |
| diapers, toilet paper          | 9%         |
| Textile                        | 4%         |
| Paper                          | 2%         |
| Cardboard                      | 2%         |
| Glass                          | 2%         |
| Wood                           | 9%         |
| Black metals                   | 7%         |
| Friends                        | 1%         |
| Organic garden waste           | 5%         |
| Inert waste                    | 3%         |
| Electronic waste               | 2%         |
| Non-ferrous metals             | 2%         |
| Electronic waste               | 4%         |
| Waste less than one centimeter in size | 6% |
| Medical waste                  | 4%         |

The methanogenic phase includes two stages: active and stable. At the active stage, the enzymatic decomposition of acids formed in the acetogenic phase occurs, which is accompanied by a significant evolution of gases (methane, carbon dioxide, mercaptans, ammonia, etc.).

Hydrogen sulphide is a reduced sulfur compound that predominates in biogas. The concentration of methane in biogas increases to 40-60%. The maximum biogas yield occurs after a two-year aging of waste in the landfill and stabilization of decomposition processes [6].

As suggested by this method, the lower end of the calculation is 0.00312 Nm³/Kg and the upper one is 0.0125 Nm³/Kg. These extremes consider the criteria of worst-case scenario (PC) and best scenario (BC):

\[
BG = \text{scenario factor (PC / BC) Nm}^3/\text{kg} \cdot \text{ton/year} \cdot 1000\text{kg/ton} \cdot \text{year}/525600 \text{ min} \quad (1)
\]

Calculation feasible to estimate biogas:

\[
\text{Biogas generated Feasible} = \text{Biogas generated BC} - \text{Biogas generated PC} \quad (2)
\]

To calculate the energy that can be obtained from the Quito landfill, some parameters specific to the site must be taken into account, such as:

Methane concentration in the landfill we have a value of 56% (average) of CH₄ - concentration range (40% - 65%). The calorific value of methane which is 10 kWh/m³. The average efficiency of the internal combustion engine that in this case is 38%.

With the data described we calculate the energy potential of 1 m³ of landfill biogas, applying equation 1 we will have:

\[
\text{Biogas Energy Potential} = \text{CH}_4 \cdot \text{calorific value} \quad (3)
\]

\[
\text{Biogas Energy Potential} = 5.6 \text{ kWh/m}^3.
\]

With the value obtained in equation 2 we calculate the net electrical power per year:
Net electrical power = Biogas volume · Energy potential · motor efficiency

3. Results
These extremes consider the worst-case scenario (PC) and best scenario (BC) criteria and the feasible biogas estimation calculation. With this, the generation of biogas in the Inga landfill, for the year 2012 is:

\[ \text{Biogas generated PC} = 0.00312 \text{Nm}^3/\text{kg} \cdot 5322098 \text{ton/year} \cdot 1000 \text{kg/ton} \cdot 1 \text{year/525600 min} \]

\[ \text{Biogas generated PC} = 31.529 \text{m}^3/\text{min} \]  

\[ \text{Biogas generated BC} = 0.0125 \text{Nm}^3/\text{kg} \cdot 5322098 \text{ton/year} \cdot 1000 \text{kg/1 ton} \cdot 1 \text{year/525600 min} \]

\[ \text{Biogas generated BC} = 126.572 \text{Nm}^3/\text{min}. \]

Feasible calculation for biogas estimation:

\[ \text{Biogas generated Feasible} = 126,572 \text{Nm}^3/\text{min} - 31,529 \text{Nm}^3/\text{min} \]

\[ \text{Biogas generated Feasible} = 95.04 \text{Nm}^3/\text{min}. \]

Calculation with 2020 data:

\[ \text{Biogas generated PC} = 0.00312 \text{Nm}^3/\text{kg} \cdot 10918791 \text{ton/year} \cdot 1000 \text{kg/ton} \cdot 1 \text{year/525600 min} \]

\[ \text{Biogas generated PC} = 62.87 \text{m}^3/\text{min} \]

\[ \text{Biogas generated BC} = 0.0125 \text{Nm}^3/\text{kg} \cdot 10918791 \text{ton/year} \cdot 1000 \text{kg/1 ton} \cdot 1 \text{year/525600 min} \]

\[ \text{Biogas generated BC} = 251.884 \text{Nm}^3/\text{min}. \]

Feasible calculation for biogas estimation:

\[ \text{Biogas generated Feasible} = 251.884 \text{Nm}^3/\text{min} – 62.87 \text{Nm}^3/\text{min} \]

\[ \text{Biogas generated Feasible} = 189.01 \text{Nm}^3/\text{min}. \]

Therefore, with the use of these formulas, we can get the data of biogas produced from 2012 to the present (tables 2 and 3).

Table 2. Biogas generation projection by simple approximation.

| Year | Amount of waste ton | Biogas obtained Nm³/min |
|------|---------------------|------------------------|
| 2012 | 5322098             | 95.04                  |
| 2013 | 5983850             | 103.57                 |
| 2014 | 6652219             | 115.16                 |
| 2015 | 7327271             | 126.84                 |
| 2016 | 8009073             | 138.64                 |
| 2017 | 8697693             | 150.56                 |
| 2018 | 9393199             | 162.61                 |
| 2019 | 10137390            | 175.49                 |
| 2020 | 10918791            | 189.01                 |

Calculation with 2020 data:

\[ \text{Biogas Energy Potential} = \text{CH}_4 \cdot \text{calorific value} \]

\[ \text{Biogas Energy Potential} = 5.6 \text{kWh/m}^3. \]

With the value obtained in equation 2 we calculate the net electrical power per year:
Net electrical power = Biogas volume · Energy potential · motor efficiency (12)

Table 3. Calculation of net electrical power.

| Year | Biogas obtained m³/min | Biogas obtained m³/h | Percentage of methane | Biogas energy potential kWh/m³ | Net electrical power |
|------|-----------------|-----------------|---------------------|-----------------|-------------------|
| 2012 | 95.04           | 5702.4          | 3193.344           | 3193.44         | 12134.71         |
| 2013 | 103.57          | 6214.2          | 3479.952           | 34799.52        | 13223.82         |
| 2014 | 115.16          | 6909.6          | 3869.376           | 38693.76        | 14703.63         |
| 2015 | 126.84          | 7610.4          | 4261.824           | 42618.24        | 16194.93         |
| 2016 | 138.64          | 8318.4          | 4658.304           | 46583.04        | 17701.56         |
| 2017 | 150.56          | 9033.6          | 5058.816           | 50588.16        | 19223.5          |
| 2018 | 162.61          | 9756.6          | 5463.696           | 54636.96        | 20762.04         |
| 2019 | 175.49          | 10529.4         | 5896.464           | 58964.64        | 22406.56         |
| 2020 | 189.01          | 11340.6         | 6350.736           | 63507.36        | 24132.8          |

4. Discussion

The feasible biogas calculation made in table 2 is an estimate taking into account several factors, such as a scenario factor, data and approximate calculations to later be able to calculate the energy power and net energy. Thus, we have that the production of biogas since 2012 has been increasing since the landfill has not been in operation for many years, it is in the stage of methanogenesis, apart from the climate in the region helps the degradation of waste much faster and this that the biogas flow is much stronger and consequently much more convenient [9].

In tables 2 and 3 the amount of waste deposited in the landfill gradually increases each year. In 2020 it can be observed that the amount of waste is high but it does not grow gradually as in previous years, this is due to several factors, but the main factor is thanks to the "COVID-19" pandemic since not only in Quito if Not in the whole country it is under regulations because of the pandemic, for example: parties, celebrations, cultural events and any other event with an agglomeration of people cannot be organized, which always produce large amounts of waste.

In tables 2 and 3 we can see how the quantity produced in the Inga landfill is growing but there are several times in which the production of biogas is stronger, much faster or becomes constant, this happens for the following reason. The Inga landfill began operating in 2003, the quantities of biogas issued in 2003 onwards were not significant, since the waste stored was in the acetogenesis stage, since 2012 the waste stored in the landfill is in the methanogenesis stage where the amount of biogas produced in the landfill is at its maximum capacity (this lasts about 8 to 10 years). In 2020, it can be seen how the amount of biogas normalizes and is stable.

The calculation of the generated power, which could technically be obtained, was carried out in table 2, with this theoretical data of generated power it will be shown that the project is technically feasible and economically viable.

In tables 2 and 3 we can see how the amount of biogas is higher than that of methane, this happens because methane is found in an average of 40% - 60% in the biogas, in this case it is taken at 56% for the calculation because the geographical location, the climate and the type of waste stored in the sanitary landfill (in the Inga sanitary landfill urban waste is stored in which 60% is organic waste).

In tables 2 and 3 we can see the energy power is greater than the net energy produced, this is normal since the net energy is calculated from the energy power and the use of 4-stroke combustion engines.
5. Conclusion
The current situation of technological development and excessive consumption, due to the expansion of the global economy, translates into the problem of the generation of solid urban waste, creating a negative impact on the environment; therefore, within their controlled management modes, viability is sought for sustainable development with non-energy purposes [10].

The energy activity as fuel production for its subsequent use from the management of urban solid waste can be a complement to the social use of the economic and environmental profitability of said activity, being an option the generation of electrical energy.

The use of biogas obtained from landfills in developed countries such as Norway, Sweden, Germany or others is a reality that helps not only the environment but also the economy, if this technology could be used in developing countries such as Latin America it would be an incredible help in their economies that most of them are in chaotic situation.

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