Effects of climate conditions variation on methane recovery in a municipal solid waste landfill: a Brazilian case study

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Official data from the Brazilian government inform that almost 79 million people are not adequately served with collection and final disposal of municipal solid waste (MSW). In order to face this situation, the Brazilian government encourages the implementation of larger MSW landfills since they require smaller financial investments per capita. Considering the installed capacity and the technologies available in Brazil, it can be said that there is an official policy to encourage the use of sanitary landfills, even though this solution presents significant negative environmental impacts. Furthermore, it can be stated that the existing sanitary landfills received and will continue to receive MSW for a considerable period of time due to the slow evolution and implementation of selective collection systems and reverse logistics in Brazil.

Therefore, in the Brazilian context, the challenge is to implement landfills as a structural measure to reduce the deficit in the provision of basic sanitation services and, simultaneously, fully meet the premise of considering MSW as material and energy resources that must be valued, beside promoting initiatives aligned with the concept of circular economy and combating the climate crisis with income generation and social inclusion. One of the consolidated strategies for facing this challenge is the use of biogas, recovered from landfills, to generate electric and/or thermal energy by stationary gas engines, boilers, ovens or gas stoves, injection into the natural gas network and use as vehicle fuel after biogas purification and conversion to biomethane. In Brazil, despite the well established potential, the use of landfill biogas as fuel for the generation of electricity is still incipient and represents 0.16% of the entire energy matrix.

Several factors influence methane generation in landfills, from variations in cells geometry and operating techniques to MSW characteristics and environmental factors. Consideration for the characteristics of the external environment, the effects of precipitation and infiltration of rainwater, atmospheric pressure and ambient temperature should be paramount. Wreford et al. (2000) concluded that prolonged precipitation on the mass of waste in a landfill caused an increase in humidity leading to the stimulation of the metabolism of anaerobic microorganisms and resulting in the dilution of potentially toxic substances. These authors pointed out that these factors were crucial for favouring the production of biogas with higher concentrations of methane. However, investigation of the effect of climate variables on methane recovery in landfills operating in tropical countries is scarce in the scientific literature.

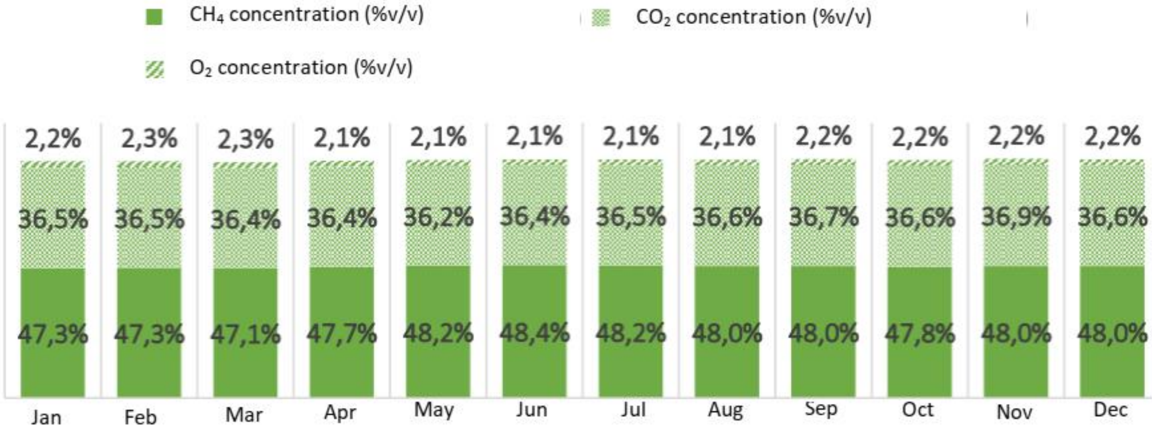
Considering this context, the aim of this study was to investigate the effects of climate variables on the production, recovery and composition of biogas collected at the Metropolitan Center Sanitary (MCS) landfill, located in Salvador, Bahia, Brazil (12°51′56″S 38°21′49″).

The MCS landfill has an active collection system that directs the entire flow of captured biogas to a centralized biogas pre-treatment station. Subsequently, the impurity-free biogas is sent to a thermoelectric plant. The system has been in operation since 2011 and is equipped with 19 motor-generator groups with a total installed capacity of 19.74 MW, enough to supply for approximately 200,000 inhabitants. Measurements of biogas flow, pressure in the discharge pipe, concentrations of methane (CH_4), carbon dioxide (CO_2) and oxygen (O_2) in volumetric fraction, electrical consumption and energy generation are carried out, processed and saved automatically every minute. All data generated is integrated into a supervisory system that allows for assisted process operation. The methane flow data were calculated using the product between biogas flow data ($Nm^3.h^{-1}$) and the volumetric percentage of methane for the period between the years 2015 and 2020. The arithmetic average of the daily records of two analogue rain gauges installed in the MSC landfill was considered as rain precipitation data. The temperature, atmospheric pressure and relative humidity data were extracted from the National Institute of Meteorology (INMET) database.

Considering that the quantitative variables are continuous, it was decided to correlate them using the Pearson method and analyze them using dispersion diagrams. In addition, Scatter Diagrams were also generated, which helped to understand the degree of correlation between the variables and to assess the linearity of the dispersion of results.

The value of the annual average methane flow in the MCS landfill is equal to 4,523.8 ± 363.9 $Nm^3.h.^{-1}$ It can be stated that the composition of the biogas is relatively stable since small fluctuations (between 47.1 ± 1.8% and 48.4 ± 1.2%) were observed in the studied period (Figure 1).

Figure 1. Average values of CH_4, O_2 and CO_2 in MCS's biogas (2015 to 2020).



The influence of precipitation on recovered methane flow could be described by a positive and statistically strong correlation (Pearson's coefficient of relationship r = +0.79), indicating that in the months with higher rainfall rates, an increase in methane flow was recorded. On the other hand, the statistical correlation found between precipitation and methane concentration in biogas was classified as weak (r = +0.41). This result suggests that, although precipitation can generate an increase in the amount of biogas recovered, there is no significant increase in the quality of biogas in terms of methane concentration.

The relationship observed between rainfall and the flow of biogas recovered in the MCS landfill indicates the relevance of mass transfer. This relationship was also observed by Wreford et al. (2000), who considered precipitation as the most relevant factor for Biogas production since the humidity of the mixed waste stimulates the metabolism of anaerobic microorganisms. In addition, the increase in precipitation results in an increment in the generation of the landfill leachate, favouring the solubilization of a greater volume of biogas trapped in the interstices of the waste mass. This phenomenon allows the directing of the biogas flow to the drainage system, improving the overall performance of the process.

The ambient temperature was the most significant factor for the quality of biogas from the MCS landfill and was inversely and strongly related to methane concentration. It is important to emphasize that the increase in air temperature generates greater agitation of atmospheric particles, which favours the transfer of mass from the interior of the waste cell (where the concentration of biogas is higher) to the atmosphere (where the concentration is reduced), that is, the occurrence of high temperatures increases the fugitive emissions of biogas (and methane, consequently). This transport phenomenon confirms the inversely proportional correlation between changes in ambient temperature and in the quantity and quality of recovered methane.

The analyzed data showed that the simultaneous occurrence of temperatures above 25°C, low relative humidity (< 75%), atmospheric pressure below 1,010 mbar and dry season exert considerable influence on the recovery and quality of biogas in terms of methane concentration. These conditions apparently increase the occurrence rate of fugitive emissions and allow the intrusion of atmospheric air into the waste mass, probably causing serious reduction in the anaerobic microorganism's activity, resulting in a drop in methane concentration.

References

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