Enhancing methane generation by anaerobic codigestion of landfill leachate and cassava wastewater

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Highlights:

- Anaerobic codigestion was successfully implemented for landfill leachate and cassava wastewater treatment.
- CH_4 generation was achieved up to 75% of biogas produced and a yield of 342.89 mL $CH_4.gVS^{-1}$.
- Modified Gompertz model presented as a good fit for the collected data.

Keywords: biogas; sustainability; biological treatment.

INTRODUCTION

Waste generation is a concern in modern world, as environmental laws grow restrictive. Finding a way to generate energy by waste treatment can be an alternative to incentivize both public and private entities. Anaerobic co-digestion (AcoD) is an option, as a biological treatment that, when proper scaled, can generate methane while treating organic matter, since CH_4 can be used as a biofuel or to generate electric energy when combusted. The challenge is to find wastewaters that can be used to enhance methane generation in AcoD.

Landfill leachate is a wastewater generated during decomposing process in a landfill, by bacteria, fungi, and other microorganisms. It has a high concentration of organic matter, ammonia, xenobiotic compounds, among others (Guzmán-Fierro et al., 2023). Cassava wastewater (CW) is generated by the water used in starch industry, composed mainly by starch, fibres, minerals and cyanogenic compounds (Sánchez et al., 2017). This study aims for CH_4 generation, by AcoD, between both cited wastewaters, in different concentrations, while also applying a mathematical model to represent the collected data.

METHODOLOGY

The experiment started with wastewater obtaining. The leachate was obtained from the municipal waste landfill of the city where the experiment was conducted, which consists in the combined wastewaters of all garbage cells, of different ages (ranging from 1995 to 2024), being collected before the landfill own treatment system. The cassava wastewater was obtained from a starch industry localized in a nearby city, and is the combined water used for cassava roots cleaning and processing.

The experimental set-up consisted in batch reactors for AcoD, with a total of 1 L each, half of it being headspace and the other half the working volume, 10% of that being filled with HDPE support medium. The reactors were maintained at 37 ± 2 °C. Five mixtures between the leachate and cassava wastewater, as shown in table 1, were elaborated and incubated in each reactor with a substrate/inoculum rate of

0.4 gCOD.gVS^{-1}. Two reactors for each mixture were made, for a total of 10, and the results shown are the average between similar reactors. The proportion between substrates for reactors 2, 3 and 4 were defined based on the alkalinity of mixtures, in order to avoid mixtures with expected low methane production, based on literature values for this parameter, while also balancing C/N ratio.

Table 1 Mixtures elaborated in this experiment, by total volume proportion

Mixture	Leachate	CW	Alkalinity (mgCaCO$_3$.L^{-1})	C/N ratio
M1	1	0	2650,0	1,68
M2	2/3	1/3	1751,5	11,08
M3	1/2	1/2	1480,5	15,77
M4	1/3	2/3	1045,5	20,47
M5	0	1	0	29,87

The total hydraulic retention time (HRT) was 50 days, being defined as the day of experiment in which the daily biogas production became less than 1% of the total produced biogas. The pH of the mixtures was not corrected, in order to evaluate if the synergy of substrates was enough to establish an efficient anaerobic digestion process.

The volume of biogas was daily measured, and at least once a week its concentration was analysed by gas chromatography. The modified Gompertz model was then applied to the methane yield, in order to evaluate the treatment behaviour during the experiment.

RESULTS AND CONCLUSIONS

Most reactors started producing biogas on day 1, with only mixture 1 not producing biogas. The gases produced during the first few days were mainly CO_2 and H_2. Mixtures 2 and 3 started producing methane after a lag phase, and achieved 75% of CH_4 concentration after 20 days of experiment. Mixtures 4 and 5 did not produce methane during the experiment, stopping biogas production before 15 days of HRT.

Mixtures 2 and 3 had methane generation, while mixture 4, although having an initial pH near 7, did not have enough alkalinity to prevent the process inhibition, as the effluent pH was 5.98, while 2 and 3 had a pH effluent of 7.67 and 7.76. Ferdes et al. (2023) comments that substrates with high C/N ratios, (such as CW), produce more volatile acids, and need to be supplemented with substrates richer in nitrogen (such as leachate). The proportion between substrates in mixture 4 may have not been enough to assure process stability.

Figure 1 shows the modified Gompertz model applied to mixtures 2 and 3. The existence of a lag phase of approximately 13 days for mixture 2 and 18 days for mixture 3 indicates that the substrates are biodegradable after a short period of time, mainly due to hydrolysis being the limiting step in anaerobic digestion (Filer et al., 2019). Guzmán-Fierro et al. (2023) comments that in landfills with more than 10 years of operation, the leachate is mainly composed of slow or non-biodegradable organic matter. Since the leachate of this study comes from a landfill in operation since 1995, that can explain the lag phase observed during the experiment.

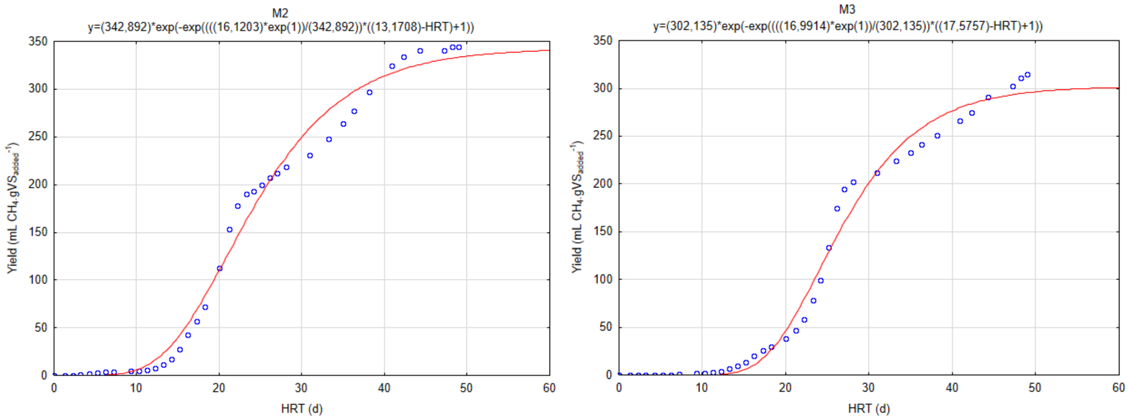

Figure 1 Modified Gompertz model for mixtures 2 and 3, respectively.

The total produced biogas for mixtures 2 and 3 were, respectively, 1664,6 and 2260 mL, while methane production reached 816,2 and 1042,3 mL, respectively. As expected, mixture 3 reached a higher total biogas and CH_4 production, since it has more organic matter available (as shown in C/N ratio), but had a lower methane yield, being, for mixtures 2 and 3, respectively, 342.89 and 302.14 mL $CH_4.gVS^{-1}$, meaning that mixture 2 had a better balance between nutrients to assure process stability. This indicates that an intermediary mixture (i.e. leachate proportion between 50 and 66%) may balance both variables and allow maximizing results.

The fit for modified Gompertz model is good, with R^2 being 0.988 and 0.989 respectively, for mixtures 2 and 3. Martins et al. (2022), also used modified Gompertz, while testing different mixtures between CW, cassava bagasse and dairy manure at mesophilic temperature range, and found 146.29 and 126.85 mL $CH_4.gVS^{-1}$ (respectively in CW mono-digestion, and 2/3 dairy manure with 1/3 of CW and bagasse) as the best yield results.

In conclusion, it is possible to combine landfill leachate and CW for methane production, as leachate provides the necessary alkalinity for allowing methanogenesis during CW digestion. The mixture proportion of 2/3 leachate and 1/3 CW presented shorter lag phase and greater CH_4 yield than the other mixtures. The modified Gompertz model had a good fit for the collected data, meaning that it can be used to explain and predict CH_4 production in anaerobic digestion in batch reactors.

The results indicate a viable option for agro-industrial organic effluent treatment, targeting the necessity of integration between Brazil's largest economy sector and environmental protection. The results also indicate that it is possible to apply codigestion between leachate and CW for larger scale bioreactors, as a future research topic.

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