Methane generation efficiency through anaerobic co-digestion of landfill leachate and effluents from municipal wastewater treatment

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Highlights:

- Average CH4 yield achieved 435,4 ± 13,2 mL. g VS-1
- CH4 composition of biogas stabilized at 73% by the end of tests
- Hydrolysis showed to be the limitation step of the digestion process.

Keywords: Energy recovery; Organic matter conversion; Sustainability.

INTRODUCTION

Municipal waste management is a major concern for city administrative authorities around the world. Landfilling municipal solid waste (MSW) is the most frequent practice for managing this waste, in Brazil about 60% of MSW generated are disposed in sanitary landfills according to data from the Brazilian Association of Waste and Environment (Abrema). The landfill leachate (LL) generated is a liquid that present high concentration of organic matter and biological adverse compounds and may cause several problems if returning to environment (Qian et al, 2024). Biological treatment, mainly anaerobically, is a cost-effective technique for managing LL due to its ability to conserve energy through digestion, forming methane (CH4) (Abdel-Shafy et al, 2023).

Anaerobic co-digestion (AcoD) uses a mixture of two or more substrates and co-substrates mixtures to make the process more stable and maximize CH_4 generation and is considered a suitable alternative to fossil fuel use (Siddique & Wahid, 2018). This study aims to demonstrate the potential CH_4 yield that the AcoD of LL in mixture with residues from municipal wastewater (MWW) treatment may achieve. Thus, residues such as residual activated sludge (WAS) and scum (SS) from MWW treatments were used as co-substrates to the LL, since disposal in landfills is a common practice for the management of these wastes (Yusuf et al, 2023).

METHODOLOGY

The methodology consists in analyzing the methane generated through AcoD of LL, WAS and SS in a biomethane potential (BMP) test. A mixture of 33,33% each substrate was inoculated in three different 1,0L borosilicate glass bottles with 500mL of headspace for biogas produced, 50mL of biological support media and 450mL of working volume. Three reactors were inoculated with 100% of each substrate to verify the methane production in mono-digestion. The reactors were inoculated in a substrate/inoculum ratio of 0,5 (volatile solids basis) according VDI-4630 (2016) and were incubated at mesophilic temperature.

The LL was collected from sanitary landfill located in Cascavel, Paraná, and the SS collected in the surface of a UASB that receives MWW from the same city. The WAS was collected in sedimentation step of an activated sludge reactor from MWW treatment of Corbélia, Paraná.

The biogas generated was daily measured with manometer and syringe with volume indicator. The methane composition was analyzed by gas chromatography every two weeks. The tests were conducted for 58 days, when the daily variation of biogas measured was lower than 1,0%. The methane yield results were analyzed in terms of volatile solids mass added in the reactors (VS). The modified-Gompertz Model was used to identify the kinetics of methane formation.

To verify the real contribution of the mixture studied the synergistic effects were analyzed. The interaction between the substrates leads to positive, negative or just additional effects, the co-digestion impact factor (CIF) is the ratio of methane yield measured in BMP to the weighted methane yield of mono-digestions (KUMARI & CHANDEL, 2023).

RESULTS AND CONCLUSIONS

These results are part of a full research of BMP with the three substrates presented in a simplex centroid design, aiming the optimization of the mixture as part of the author master's degree research. A single mixture with 33,33% proportion each substrate was prepared and separated in three reactors. Affluent pH of 7,9 was not corrected and the mixture presented an affluent total alkalinity of 987,5 mg $CaCO_3$. L^{-1}. The mixture presented total COD of 37,8 g. L^{-1}; the final mixture was then diluted four times to avoid organic overload. VS added to the reactors was 7,0 g. L^{-1}.

The average methane yield achieved by all three reactors at the end of the BMP tests was 435,4 ± 13,2 mL CH_4. g VS^{-1}. Methane composition of biogas was stable in 73% by the end of the experiment. These results are comparable to other AcoD of these substrates in different variations. Gao et al (2021) presented a 110,0 mL CH_4. g VS^{-1} yield in AcoD of WAS with 10% addition of LL, otherwise Aromolaran et al (2022) reached 493,6 mL CH_4. g VS^{-1} by studying the addition of 40% of SS to LL digestion.

The coefficients of the modified-Gompertz for each reactor are presented in Table 1. A significance level (α) of 10% was established, the adjustments of data to the model presented coefficients of determination (R2) higher than 0,997. The average lag-phase was 333,0 ± 16,0 h, demonstrated some hydrolysis limitation. Figure 1 illustrates the adjustment of the collected points with the model curve for R2, which showed the best methane yield, being able to have the visual perception of the lag phase in relation to the experiment duration.

Table 1 Coefficients of the modified-Gompertz model

Reactor	β0 (mL. g VS^{-1})	k (mL. g VS^{-1} .h^{-1})	λ (h)	R2
R1	427,57	0,61	337,65	0,999
R2	471,86	0,63	352,38	0,999
R3	453,27	0,63	308,96	0,997

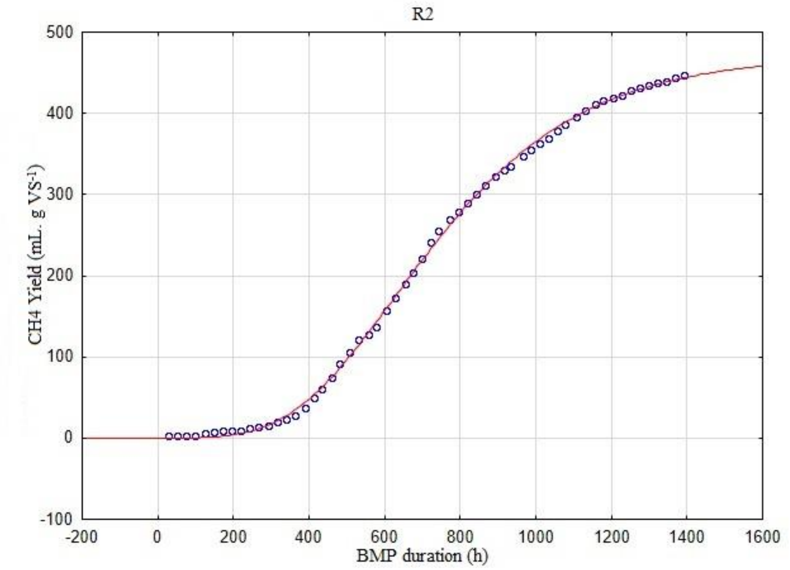

Figure 1 Adjustment of modified-Gompertz model for R2

Table 2 shows the CIF of the mixtures tested in the BMP test. It is remarkable that the LL does not generate any biogas in 58 days of experiment. Nevertheless, the three repetitions of central point had the CIF above 1,10, this means that the co-digestion of the substrates in 33,33% mixture presented positive synergy. This can be explained by the fact that LL present recalcitrant organic matter (Abdel-Shafy et al, 2023), that is difficult to be degraded by anaerobic conversion, however it provides the alkalinity necessary to improve methanogenesis synergistically: 2650 mg $CaCO_3$. L^{-1} in LL and only 107 and 675 mg $CaCO_3$. L^{-1} of total alkalinity in WAS and SS respectively.

Table 2 Co-digestion Impact Factor of mixtures tested for synergistic effects

BMP mixture	BMP - CH_4 Yield (mL CH_4. g SV^{-1})	Weighted CH4 Yield (mL CH_4. g SV^{-1})	CIF
100% LL	0,00	0,00	-
100% WAS	374,27	374,27	-
100% SS	380,42	380,42	-
33,33% LL; WAS; SS	427,57	251,54	1,70
33,33% LL; WAS; SS	471,86	251,54	1,88
33,33% LL; WAS; SS	453,27	251,54	1,80

It is notable the feasibility of methane generation through AcoD of LL, WAS and SS in a 33,33% proportion. this means that there is the possibility of associating these substrates to obtain a valuable energy product in MWW treatment plants. Mathematical models are important to know the behavior of the digestion of these residues and to guide further studies, as well as possible future operations of full-scale reactors.

ACKNOWLEDGMENTS

We gratefully acknowledge the financial support from Coordination for the Improvement of Higher Education Personnel (Capes), which has been instrumental in advancing our research, as well as the Western Paraná State University (Unioeste) and the Graduate Program in Agricultural Engineering (PGEAGRI).

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