# Comparative evaluation of kinetic models to produce biogas from the anaerobic co-digestion of landfill leachate, sanitary sewage and crude glycerin

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**Highlights:**

- The modified logistic model had the best fit to the experimental data.
- The majority of runs showed performance above theoretical.
- The lowest yield obtained was only 0.93 times below the theoretical yield.

**Keywords: Modified-logistic model; Transfer-function model; Methane.**

## INTRODUCTION

Anaerobic co-digestion (AC) can be seen as a technology approach aimed at energy security and climate change mitigation that has become popular in recent years for improving methane and nutrient recovery and for offering several advantages including better methane yield and process stability due to synergistic interactions, nutrient balance, and dilution of toxic compounds. Furthermore, a wide range of raw materials can be used for co-digestion (Karki et al., 2021).

The search for raw materials that can be used in this process and bring benefits such as increased biogas production, was the subject of works such as Sampaio De Mello et al. (2024) and Almeida et al. (2023), which sought to study the relationships between glycerol and other substrates using AC considering that this material has a high amount of biodegradable organic matter.

Hance et. al (2020) sought to improve energy recovery and treatment of municipal wastewater from AC with sugarcane molasses, which also contains large amounts of organic matter. Another important wastewater is landfill leachate, whose formation mechanism includes physical and chemical characteristics of decomposition of solid waste disposed of in landfills and other topics that make the composition of this wastewater variable and relevant to be the subject of studies involving treatments.

Therefore, this paper aims to unite municipal wastewater, landfill leachate and crude glycerin in different proportions, in volume, to address the behavior of the parameters of kinetic models selected and used to elucidate the production of biogas from mixtures formed for AC in batch reactors.

## METHODOLOGY

Initially, it was collected an anaerobic reactor sludge to serve as inoculum for the tests and the three wastewaters under study: municipal wastewater (MWW), landfill leachate (LL) and crude glycerin (CG). After the collect, the liquid effluents were characterized and arranged in different proportions, by volume, and incubated in batch reactors with the inoculum. It was tested three different incubation times (20, 30 and 40 in days), three initial pH corrections (7.0, 7.5 and 8.0), three proportions of LL (2.0, 3.5 and 5.0%) and three proportions of CG (1.0, 1.5 and 2.0%). The yield was calculated based on the removal of soluble COD (Chemical Oxygen Demand), since the determination of total COD after the batch tests would have a contribution from the inoculum used. We sought to compare the maximum production data provided by adjusting the models with the theoretical yield of 1 gCOD = 0.35 L $CH_4$ and discuss whether the incubation time would have influenced it.

| Run | Incubation time (day) | Initial pH | %LL | %CG |
|---|---|---|---|---|
| R1 | 40 | 7.0 | 2.0 | 2.0 |
| R2 | 40 | 8.0 | 2.0 | 1.0 |
| R3 | 40 | 8.0 | 2.0 | 1.0 |
| R4 | 20 | 8.0 | 5.0 | 2.0 |
| R5 | 40 | 7.0 | 5.0 | 2.0 |
| R6 | 20 | 8.0 | 2.0 | 2.0 |
| R7 | 20 | 7.0 | 5.0 | 1.0 |
| R8 | 20 | 7.0 | 2.0 | 1.0 |
| R9 | 30 | 7.5 | 3.5 | 1.5 |

*Table 1: experimental runs in this study.*

The models chosen for analysis were the modified-logistic model and the transfer function model(Ohale et al., 2023; Zahan et al., 2018; Zwietering et al., 1990). The adjustment was made using non-linear regression by the Levenberg-Marquadt method in STATISTICA 7.0®. The comparison of models was based on the coefficient of determination $R^2$.

## RESULTS AND CONCLUSIONS

Based on the coefficient of determination presented in Table 2, it can be noted that for the most of the runs the modified-logistic model was the one that best fitted the data. Some adjustments presented inconsistencies such as negative lag phase time and estimated maximum yield much higher than what was obtained experimentally. Regarding the theoretical yield compared to the experimental yield, Table 1 also shows that run R3 presented a yield almost 16 times higher than the theoretical, being the highest value obtained in all runs and having remained in incubation for 40 days. The lowest experimental yield was obtained for run R4, which remained only 20 days in incubation. However, its yield was just 0.93 times below the theoretical one, suggesting that the time was sufficient to degrade at least the soluble portion of COD that was used for this assessment.

| | R1 | R2 | R3 | R4 | R5 | R6 | R7 | R8 | R9 |
|---|---|---|---|---|---|---|---|---|---|
| Theoretical yield ($L_{NCH4}$/gDQO) | 0.370 | 0.428 | 0.141 | 0.336 | 0.329 | 0.265 | 0.211 | 0.424 | 0.393 |
| **Experimental Yield** | | | | | | | | | |
| Y ($L_{NH4}$/gDQO) | 0.971 | 0.797 | 2.25 | 0.312 | 0.663 | 0.362 | 0.723 | 0.565 | 0.862 |
| **Transfer-function model** | | | | | | | | | |
| Y ($L_{NCH4}$/gDQO) | 1.069 | 2.569 | 17919.42 | 0.3209 | 3448.398 | 0.3566 | 2.7671 | 1.3293 | 1.0702 |
| Rm ($L_{NCH4}$/gDQO.d) | 0.0828 | 0.0282 | 0.1 | 0.0411 | 0.0110 | 0.0876 | 0.0391 | 0.0398 | 0.0724 |
| λ (d) | 1.518 | 1.998 | 0.8 | 0.1937 | -7.2090 | 0.6429 | -0.7018 | 0.9321 | 1.5557 |
| $R^2$ | 0.9827 | 0.9700 | 0.8962 | 0.9885 | 0.8576 | 0.9826 | 0.9894 | 0.9921 | 0.9910 |
| **Modified-logistic model** | | | | | | | | | |

| | R1 | R2 | R3 | R4 | R5 | R6 | R7 | R8 | R9 |
|---|---|---|---|---|---|---|---|---|---|
| Y ($L_{NCH4}$/gDQO) | 0.967 | 0.833 | 12015.4 | 0.2880 | 1669.546 | 0.3412 | 0.8405 | 0.5697 | 0.8667 |
| Rm ($L_{NCH4}$/gDQO.d) | 0.0550 | 0.0343 | 166.53 | 0.0225 | 15.965 | 0.0492 | 0.0373 | 0.0409 | 0.0545 |
| λ (d) | 1.775 | 6.434 | 158.750 | -1.1482 | 196.235 | 0.2097 | -0.0529 | 2.2621 | 2.1220 |
| $R^2$ | 0.9969 | 0.9954 | 0.9846 | 0.9628 | 0.9007 | 0.9728 | 0.9722 | 0.9960 | 0.9948 |

*Table 2: experimental and model-estimated values for yield (Y), maximum production rate ($R_m$), lag time phase (λ) and coefficient of determination ($R^2$)*

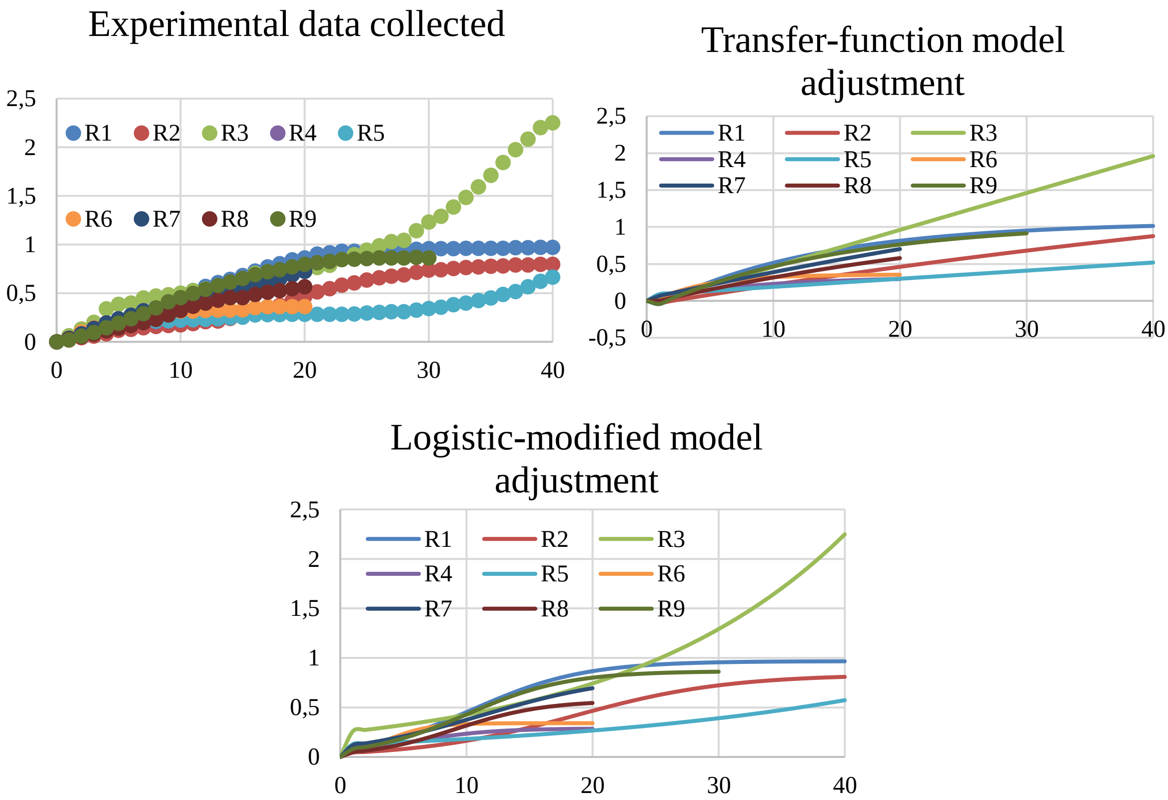


*Figure 1: methane volume measured along the 40 days of experiment and models adjustment to data collected*

In Figure 1, it is notable that the fit of the experimental data to runs R3 and R5 proved to be less adequate to the transfer-function model compared to the other fits. Furthermore, according to Mahmoodi-Eshkaftaki et al. (2017) it is possible to obtain maximum methane yield between 30 and 35 days of operation in batch reactors, however in Figure 1 it is verified that some runs had not yet formed the typical plateau of the Biochemical Methane Potential (BMP) curves. This possibly shows that the yields obtained do not correspond to the maximum use of the selected mixtures.

Even so, except for run R4, the other runs presented yields higher than the expected theoretical values, which demonstrates the feasibility of combining landfill leachate with sewage and crude glycerin for biogas production. It is also highlighted that the proportions used to prepare the mixtures may have affected the methane yield, as well as other variables intrinsic to the anaerobic process and which are not addressed in this paper.

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