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Article Original

KINETIC CHARACTERIZATION OF BIOMETHANE MESOPHILIC AND THERMOPHILIC PRODUCTION FROM ANAEROBIC DIGESTION OF FILTER CAKE AND VINASSE

CARACTERIZACIÓN CINÉTICA DE LA PRODUCCIÓN MESOFÍLICA Y TERMOFÍLICA DE BIOMETANO POR DIGESTIÓN ANAERÓBICA DE CACHAZA Y VINAZA

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ABSTRACT

Introduction:
As part of the path toward a sugarcane biorefinery scheme, it is necessary to study the utilization of byproducts such as sugarcane filter cake and vinasse, particularly as energy sources through their anaerobic conversion to biomethane.
Objective:
To generate a kinetic characterization of this conversion.
Materials and Methods:
A sample from a slaughterhouse wastewater treatment plant was used as the inoculum and substrates were samples of vinasse and filter cake, cultured in mesophilic and thermophilic ranges, useful for scaling-up.
Results and Discussion:
Mesophilic conditions, with vinasse as a substrate, produced a higher amount of accumulated biomethane (1466.7 NmL) compared to the vinasse and filter cake mixture

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(832.8 NmL) using an I/S of 1 (g VS/g VS). Anaerobic digestion in the thermophilic range decreased biomethane production by 67.71% (vinasse) and 91.34% (filter cake-vinasse) under identical operating conditions. Biomethane production was reported at 90% on the second day.

Conclusions:

Under mesophilic conditions, biomethane production increased by an average of 79.52%. A higher Biomethane Potential (BMP) was achieved using only vinasse as a substrate. Of the ten kinetic models evaluated, the Hill equation is flexible for high and low biomethane production; however, it only generates one kinetic parameter. The Gompertz equation is recommended because it showed an R^2 greater than 0.99 for high production and three kinetic parameters. The Avrami and modified Avrami equations are suitable for low biomethane production.

Keywords: biomethane; filter cake; kinetic model; vinasse.

RESUMEN

Introducción:

Como parte de la vía hacia un esquema de biorrefinería de caña de azúcar, es necesario estudiar el aprovechamiento de subproductos como la cachaza y la vinaza, particularmente como fuentes de energía mediante su conversión anaeróbica a biometano.

Objetivo:

Generar una caracterización cinética de esta conversión.

Materiales y Métodos:

Muestra de planta de tratamiento de aguas residuales de rastro como inóculo. Sustratos: muestras de vinaza y cachaza, cultivo en rango mesófilo y termófilo, lo cual es útil para su escalamiento.

Resultados y discusión:

Las condiciones mesófilas, con vinaza como sustrato, produjeron una mayor cantidad de biometano acumulado (1466,7 NmL) en comparación con la mezcla de vinaza y cachaza (832,8 NmL) utilizando una I/S de 1 (g VS/g VS). La digestión anaeróbica en el rango termófilo disminuyó 67,71% (vinaza) y 91,34% (cachaza-vinaza) en la producción de biometano, bajo condiciones de operación idénticas. Se reporta la producción del 90 % de biometano al segundo día.

Conclusiones:

Bajo condiciones mesofílicas la producción de biometano se incrementó 79,52% en promedio. Se alcanzó un mayor BMP utilizando únicamente vinaza como sustrato. De los diez modelos cinéticos evaluados, la ecuación de Hill presenta flexibilidad para producciones altas y bajas de biometano, sin embargo, solo genera un parámetro cinético. La ecuación de Gompertz se recomienda por haber presentado un R^2 mayor a 0,99 para altas producciones y tres parámetros cinéticos. Avrami y Avrami modificado son adecuadas para bajas producciones de biometano.

Palabras clave: biometano; cachaza; modelo cinético; vinaza.

1. INTRODUCTION

Research studies on the use of two of the main byproducts (filter cake and vinasse) of a complete sugarcane biorefinery scheme have been made in order to attain knowledge about the different paths (El Bari & Habchi, 2024; Montiel et al., 2022; Tena et al., 2022; Nadaleti & Lourenço, 2021; Rodriguez et al., 2018; Parsaee et al., 2019; Janke et al., 2016; Yono et al., 2014). The investigation into the use of these byproducts is also linked to an endeavor to avoid their pollution impact. The natural biodegradation of organic material through the four steps of anaerobic digestion producing biogas (CH_4, CO_2, H_2S) is the basis for the later use of biomethane as an energy source. The basic engineering design of a plant for biomethane production from any organic material needs kinetic reaction information, among other data. Therefore, in this study that information has been obtained. The filter cake and vinasse were collected from a factory in Veracruz, the main Mexican producer state of sugarcane derivatives. Automated anaerobic bioreactors were used in the experimental part. Considering that a sigmoidal response is linked to biomethane production through anaerobic digestion promoted by microorganisms, ten equations related to this type of response were chosen to evaluate their proximity to the experimental results.

2. MATERIALS AND METHODS

2.1 Inoculum and substrate

The digested sludge used as the substrate was obtained from the abattoir wastewater treatment plant from Medellín Slaughterhouse located in Medellín, Veracruz, México. The filter cake and vinasse used as substrates were collected from the Modelo sugar mill in Cardel, Veracruz, México and La Gloria sugar mill in Úrsulo Galván, Veracruz, Mexico, respectively. The digested sludge and filter cake were stored at room temperature, while vinasse was maintained at 4 °C, prior to the experiments.

2.2 Method of characterization

Five parameter determinations were based on gravimetric methods: % w/w Total Solids (TS); % w/w Moisture; % w/w Ash; % w/w Volatile Solids, dry weight (VS_{DW}); % w/w Volatile Solids, wet weight (VS_{ww}), according to the equations based on APHA (2005).

2.3 Mixture selection

A 27-73% proportion of filter cake-vinasse (VS basis) was selected, due of what was reported by López et al. (2017), where there was an increase of 10.86% in biomethane production for this proportion.

2.4 I/S selection

To deduce the S/I or I/S ratio to work with, it is considered that for easily biodegradable substrates, where the rapid accumulation of fermentation intermediate products such as VFA (volatile fatty acids) can inhibit anaerobic digestion, inoculum volume should be greater than that of the substrate or an S/I less than or equal to 0.5 should be applied, (for example, S/I of 0.5 or 0.25), to minimize the possibility of acidification or inhibition problems, or apply an I/S$\geq$ 4.

For substrates that have a high content of organic substances that are not easily biodegradable, an S/I greater than 0.5 or I/S ≤ 1 should be applied (Holliger et al., 2016; Filer et al., 2019).

According to Raposo et al. (2006), occupying an I/S ratio with values close to 1 can be toxic for microorganisms. However, Moset et al. (2015) report that the optimal I/S ratio varies depending on the substrate occupied, for example, the ideal I/S range for wheat and whole corn is 0.5-2.5 and 1-1.5 respectively.

Subsequent to the line of research by Filer et al. (2019), where they state that different S/I or I/S ratios should be tested for each substrate to find its ideal range, in this study we worked with the I/S ratio of 1 g VS/g VS (López et al., 2017; Marin et al., 2016; Caillet et al., 2019; Moset, et al., 2015).

2.5 Temperature range

According to the literature Yadvika et al., (2004); Gebreeyessus & Jenicek, (2016), temperature is one of the factors that has the greatest effect on the biogas production process. This can be carried out at three different temperature ranges: psychrophilic, below 25 ºC; mesophilic, from 25 ºC to 40 ºC; thermophilic, from 50 °C to 70 ºC (Campos & Flotats, 2004), most activity being in the mesophilic and thermophilic temperature ranges (Desair & Madamwar, 1994).

In order to evaluate the influence of temperature on biomethane production, the optimal values reported in literature (37 °C and 52.5 °C) were studied (Angelidaki & Ahring, 1994; Kardos et al., 2011; Pandey & Soupir, 2012).

2.6 Anaerobic bioreactors

The experiments for the anaerobic digestion were carried out in an automated system, AMPTS II Light (BPC or Bioprocess Control AB, Lund, Sweden), which comprises three units (figure 1).

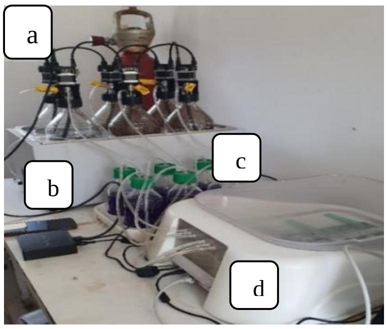

Figure 1. AMPTS II Light system. (a) Anaerobic bioreactors with regulable agitation (b) Thermostatic water bath (c) Absorption Unit of CO_2 and H_2S (d) Gas Volume Measuring Device

The incubation unit comprised six bioreactors, four of them containing the substrate-inoculum mixture and two of them blanks. The total capacity of each bioreactor was 2 L, filled with 1 L of the mixture or were left blank. The agitation applied was 20 seconds per minute at 40 rpm (López et al., 2017).

Before starting the run, the pH of the content in each bioreactor was adjusted to 7 using 1 M HCl or 1M NaOH solutions. With an operating volume of 10 L of water, the Grant Sub Aqua Pro US 12 L thermostatic water bath was utilized to regulate the temperature.

The incubation temperature was for experiments A and C 37 °C (mesophilic range) and for experiments B and C 52.5 °C, corresponding to a thermophilic range. The bioreactors were flushed with nitrogen by a flow of 2.5-10 L/min through a ARMCO RO-841 high pressure regulator for 120 s to make the anaerobic condition.

The gas volume device measures the biomethane generated. It works "according to the principle of liquid displacement and buoyancy. An integrated embedded data acquisition system is used to record, display and analyze the results" (AMPTS II light manual). Based on these measurements, normalized gas production was calculated (0 °C, 1 atm and dry gas).

2.7 Biomethane production and Biochemical Methane Potential (BMP) test

As mentioned above, the experiments of anaerobic digestion were carried out in an automated system, AMPTS II Light (BPC or Bioprocess Control AB, Lund, Sweden) considering the conditions for 4 experiments. Inoculum for A and B was I1 and for C and D I2, both inocula were from the same abattoir wastewater treatment plant but sampled at different times; substrate for A and C was vinasse and for B and D $V_{73\%}$-$F_{27\%}$; I/S = 1; T 37 °C for A and B, 52.5 °C for C and D; operational volume 1 L; agitation 20 s per minute at 40 rpm; initial pH 7.

Results of the experiments are expressed as NmL, in this case, accumulative biomethane. Another expression is NmL CH_4 g^{-1} VS, known as Biochemical Methane Potential (BMP).

2.8 Preparation of bioreactors

Equations 1 and 2 were used in order to determine the amount of substrate and inoculum to be added, maintaining the I/S ratio constant. The term m_{tot} is the total amount in the bioreactor (corresponding to 1000 g); m_{ss} is the amount of substrate (g); m_{IS} is the amount of inoculum (g); α is the I/S ratio; VS_s are the volatile solids of the substrate on a wet basis and VS_I are the volatile solids of the inoculum on a wet basis.

$$m_{SS} + m_{IS} = m_{tot} \tag{1}$$

$$\frac{m_{IS}VS_I}{m_{SS}VS_S} = \alpha \tag{2}$$

Solving *mss* from Eq. 1 and replacing it in Eq. 2 gives Eq 3. Simplifying Eq. 3, the amount of inoculum to be supplied to the bioreactor is shown in Eq 4. Having calculated m_{IS}, the amount of substrate is obtained from Eq.1.

$$\frac{m_{IS}VS_I}{(m_{tot}-m_{IS})VS_S} = \alpha \tag{3}$$

$$m_{IS} = \frac{\alpha VS_S m_{tot}}{VS_I+\alpha VS_S} \tag{4}$$

It should be noted, in the case where the mixture is of two components like substrate (V_{73}-F_{21}), that for the calculation of *VSs*, Eq. 5 is used, where VS_{SV} are vinasse volatile solids on a wet basis, VS_{SF} are filter cake volatile solids on a wet basis, β is the filter cake fraction in the substrate and γ, the fraction of vinasse in the substrate.

$VS_S = \beta V_{SF} + \gamma V_{SV}$
(51)

2.9 Kinetic study. Sigmoidal models

As biomethane is a product of bacterial metabolism involved in anaerobic digestion, sigmoidal functions (Zwietering, et al., 1990) can describe the kinetics of cumulative biomethane production. In Table 1 the equations and the kinetic parameters of the ten models that were estimated using the Solver function in MS-Excel for these kinetic studies are shown.

Table 1. Kinetic models

Model	***Equation***	***Citation***
First order	$Y(t) = Y_{max}(e^{-kt} - 1)$ (6)	Caillet et al., 2019
Hill equation	$Y(t) = Y_{max}\dfrac{t^b}{Km^b + t^b}$ (7)	López et al., 2017
Modified Gompertz	$Y(t) = Y_{max}\, e^{-e^{\left[\left(\mu_{max} * \frac{e}{Y_{max}} * (\lambda - t)\right) + 1\right]}}$ (8)	Zwietering et al., 1990
Modified Richards	$Y(t) = \dfrac{Y_{max}}{\left\{1 + ve^{1+v} * e^{\left[\frac{\mu_{max}}{Y_{max}}(1+v)\left(1+\frac{1}{v}\right)(\lambda - t)\right]}\right\}^{\frac{1}{v}}}$ (9)	Zwietering et al., 1990
Modified Schnute	$Y(t) = \left(\mu_{max}\dfrac{1-b}{a}\right)\left[\dfrac{1 - be^{(a\lambda + 1 - b - at)}}{1-b}\right]^{\frac{1}{b}}$ $a = \dfrac{\mu_{max} e}{Y_{max}}$ (10)	Zwietering et al., 1990
Modified Logistic	$Y(t) = \dfrac{Y_{max}}{1 + e^{\left\{\left[\frac{4\mu_{max}}{Y_{max}}(\lambda - t)\right] + 2\right\}}}$ (4) (11)	Pererva et al., 2020
Cone	$Y(t) = \dfrac{Y_{max}}{1 + kt^{-v}}$ (12)	Zahan et al., 2018
Transfer function	$Y(t) = Y_{max}\left\{1 - e^{\left[\frac{\mu_{max}(\lambda - t)}{Y_{max}}\right]}\right\}$ (13)	Zahan et al., 2018
Avrami	$Y(t) = Y_{max}\left(1 - e^{-kt^n}\right)$ (14)	Shirzad & Viney, 2023
Modified Avrami	$Y(t) = Y_{max}\left(1 - e^{-kt^{\left[e^{\frac{1}{\frac{1-n}{n}}}\left(\frac{\mu_{max}\lambda}{Y_{max}} + 1\right)\right]}}\right)$ (15)	Calculation based on Zwietering et al., 1990

Where, *Y(t)* is the Biochemical Methane Potential (NmL CH_4 g^{-1} VS), Y_{max} is the maximum Biochemical Methane Potential (NmL CH_4 g^{-1} VS), μ_{max} is the maximum Biochemical Methane Potential rate (NmL CH_4 g^{-1} VS d^{-1}), λ the lag phase (d), e exp (1), t incubation time (days), *k* kinetic constant (d^{-1}), Km is the time constant at half of Y_{max} (d), v shape coefficient, a and b are model coefficients.

The kinetics were evaluated by assessing how close the predicted data were to experimental data through two statistical indicators or parameters: the root mean square error (RMSE) and the coefficient of determination (R^2) (Kambezidis, 2012).

3. RESULTS AND DISCUSSION

3.1 Substrate and Inoculum characterization

Having applied the corresponding gravimetric methods (APHA, 2005), the characterization of substrates and inocula was obtained. The analytical results are shown in Table 2.

Table 2. Analytical characterization of substrates and inocula

Sample	*Filter cake*	*Vinasse*	*Inoculum 1*	*Inoculum 2*
% TS	21.26	14.05	31.29	5.14
% VS_{DW}	42.53	69.08	29.11	59.07
% VS_{ww}	9.04	9.71	9.12	3.04
% Moisture	78.74	85.95	68.71	94.86
% Ash	57.47	30.92	70.89	40.93

3.2 Kinetic study

The results of the anaerobic digestion in terms of maximum accumulative biomethane in each bioreactor are shown in Table 3. Vinasse showed the highest accumulative biomethane with Inoculum 1 and 2. A different result was observed from the mixture of vinasse and filter cake in Inoculum 1 and 2, Inoculum 1 showing the best results.

Table 3. Maximum accumulative biomethane according to conditions used

Experiment	*T (°C)*	*Inoculum*	*Substrate*	*Maximum accumulative biomethane (NmL)*
A	37	I1	V	1 466.7
B			$V_{73\%}$ - $F_{27\%}$	832.8
C	52.5	I2	V	473.6
D			$V_{73\%}$-$F_{27\%}$	77.1

Inoculum I1 and I2 are from the same abattoir wastewater treatment plant but sampled at different times

Results of the daily biomethane production can be observed in figure 2. A general comparison of experiments A and B with C and D demonstrates a faster activity of thermophilic microorganisms compared to the mesophilic ones, as the maximum daily biomethane production in the former occurred on day 1, and in the latter case (mesophilic range) this started between days 1 and 2.

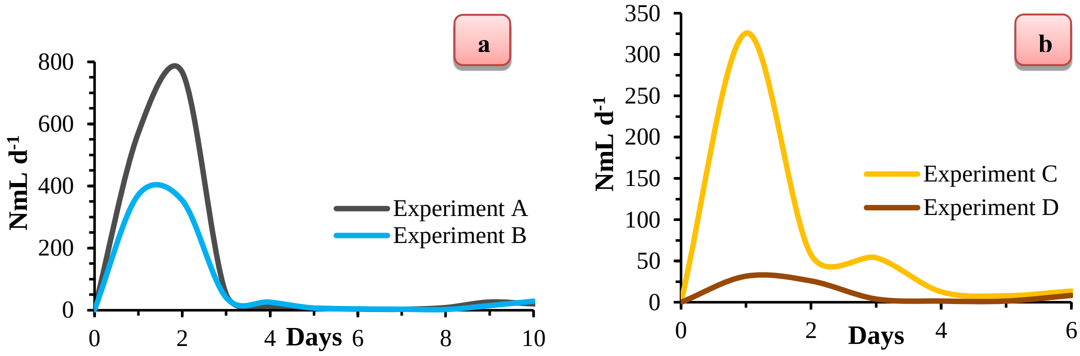

Figure 2. Daily production of biomethane: **(a)**Mesophilic range and **(b)** Thermophilic range

The 12 h difference in daily biomethane production in the thermophilic range suggests that by raising the temperature, the favoring of hydrolysis is linked to increased bacterial growth (Campos & Flotats, 2004). Nevertheless, the sudden decrease in the biomethane production indicates a clear inhibition in the methanogenesis stage.

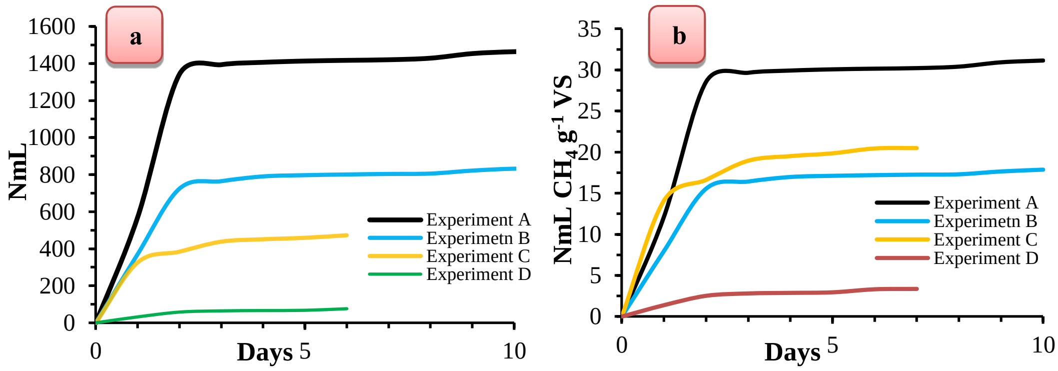

Figure 3. (a)Accumulative biomethane registered. (b) Biochemical Methane Potential (BMP)

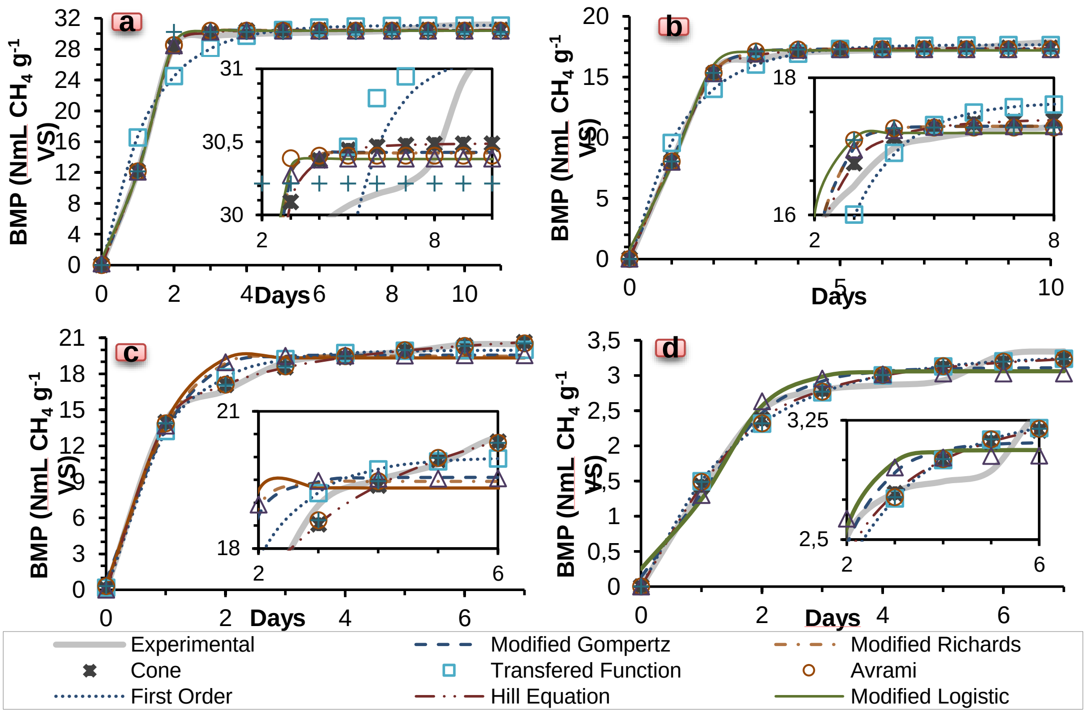

Figure 4. Comparison of kinetics and fitted mathematical models versus the observed values: (a) Experiment A, (b) Experiment B, (c) Experiment C and (d) Experiment D

The high bacterial growth rate accelerates the decomposition of the organic matter, in which ammonia is obtained as a byproduct (acidogenesis). The increase in its concentration leads to the alkalinization of the medium, a phenomenon reported by Pandey & Soupir (2012), if the pH reaches 7.6 at a NH_3-N concentration between 560 and 568 mg/L, biomethanogenesis is reduced by 50% (Gebreeyessus & Jenicek, 2016).

The daily biomethane production, from highest to lowest, was achieved in Experiment A (766.65 NmL d^{-1}), followed by Experiment B (371.25 NmL d^{-1}), then Experiment C (325.95 NmL d^{-1}) and finally Experiment D with the lowest daily production of 31.75 NmL d^{-1}.

However, the results in figure 3a indicate that in terms of accumulated biomethane, a higher production was obtained in Experiments A and B, both under mesophilic conditions. Furthermore, in the case of the substrate, vinasse exhibits a higher biomethane production compared to vinasse filter cake mixture (table 2). This behavior is related to substrate composition (López et al., 2017); with vinasse, there is no presence of lignocellulosic material, which implies a lower requirement of hydrolytic bacteria (first stage of anaerobic digestion). The opposite is found with filter cake.

Figure 3b shows the Biochemical Methane Potential (BMP) or the potential biomethane produced per gram of organic matter (volatile solid), expressed as NmL CH_4 g^{-1} VS. These results are congruent with the accumulative biomethane and daily biomethane figures. The highest amount of BMP, at the start of the asymptotic behavior observed in figure 4, was produced on day 3 for all the experiments. On that day, the BMPs were 24.64 NmL CH_4 g^{-1} VS (Experiment A), 16.43 NmL CH_4 g^{-1} VS (Experiment B), 18.94 NmL CH_4 g^{-1} VS (Experiment C) and finally 2.73 NmL CH_4 g^{-1} VS for Experiment D.

The adjustment behavior of the mathematical models, whose parameters were obtained using SOLVER in MS-Excel, is presented in figure 4. The purpose is to find those models that are closest to experimental data. In order to make it easier to observe the differences between results, in table 4 kinetic fitting constants and statistical parameters are included.

In general, in the graphs of figure 4, two types of behavior are observed in the 4 case studies: higher production (Experiment A and B) and lower production for Experiments C and D. In the case of the higher production scenario, the equations that presented a Coefficient of Determination $\geq$0.9971 were Hill, Modified Gompertz, Modified Richards and Modified Schnute, of which the first two listed stand out for presenting the lowest average distance from the experimental data with an average RMSE of 0.3042 and 0.3611, respectively.

Table 4. Comparison of parameters of the different mathematical models

Eq.	*Units*	*Experiments*			
		A	***B***	***C***	***D***
Hill Equation	Y_{max}	30.4890	17.4140	22.9170	3.4040
	Km	1.1000	1.0530	0.6090	1.2140
	B	4.3030	3.0880	0.9040	1.6750
	R^2	0.9982	0.9983	0.9986	0.9894
	RMSE	0.3955	0.2228	0.2427	0.1103
Modified Gompertz	Y_{max}	30.4290	17.2920	19.5520	3.1120
	Λ	0.5840	0.3330	0.0840	0.1130
	μ_{max}	29.1810	11.9890	15.4690	1.4890
	R^2	0.9979	0.9971	0.9787	0.9795
	RMSE	0.4317	0.2905	0.9660	0.1564
Modified Logistic	Y_{max}	30.3830	17.1950	19.3200	3.0610
	Λ	0.5270	0.3640	0.3860	0.2020
	μ_{max}	25.2830	12.0860	23.3710	1.5530
	R^2	0.9975	0.9943	0.9698	0.9687
	RMSE	0.4938	0.4395	1.1315	0.1969
Modified Richards	Y_{max}	30.4230	17.2930	19.4655	3.1340
	Λ	0.5670	0.3270	0.1800	0.0010
	μ_{max}	8.1860	0.4230	0.1259	0.0170
	V	0.1280	0.0130	0.0026	0.0040
	R^2	0.9979	0.9971	0.9767	0.9805
	RMSE	0.4328	0.2914	0.9902	0.1608
Cone	Y_{max}	30.4890	17.4140	22.8490	3.4040
	K	4.3030	3.0880	0.9140	1.6750
	Λ	0.9090	0.9490	1.6420	0.8240
	R^2	0.9938	0.9930	0.9860	0.9632
	RMSE	0.3955	0.2228	0.2438	0.1103

Eq.	*Units*	*Experiments*			
		A	***B***	***C***	***D***
Modified Schnute	Y_{max}	24.6000	18.5150	22.4000	3.4320
	b	-0.4860	0.1310	0.2500	0.2300
	λ	0.5330	0.3440	0.2560	0.3980
	μ_{max}	25.9560	12.2670	20.2030	2.1660
	R^2	0.9978	0.9971	0.9767	0.9729
	RMSE	0.4415	0.2864	0.9894	0.1772
Transfer function	Y_{max}	31.0720	17.6390	20.0010	3.2840
	λ	0.0420	0.0260	-0.0070	0.0090
	μ_{max}	24.6800	14.1090	21.5200	2.0110
	R^2	0.9611	0.9822	0.9925	0.9856
	RMSE	1.8464	0.7130	0.5620	0.1286
Avrami	Y_{max}	30.4040	17.2710	21.0440	3.2670
	K	0.5090	0.6250	1.0770	0.6060
	R^2	0.9977	0.9965	0.9987	0.9856
	RMSE	0.4491	0.3170	0.2503	0.1286
Modified Avrami	Y_{max}	30.2140	17.2710	21.0440	3.2670
	K	0.5130	0.6250	1.0770	0.6060
	λ	2.0290	0.5590	0.8050	0.4260
	μ_{max}	30.0120	10.4200	16.1080	1.3220
	R^2	0.9947	0.9965	0.9987	0.9856
	RMSE	0.6798	0.3170	0.2503	0.1286
First Order	Y_{max}	31.0900	17.6480	19.9940	3.2870
	K	0.7740	0.7860	1.0840	0.6080
	R^2	0.9609	0.9822	0.9925	0.9856
	RMSE	1.8726	0.7218	0.5645	0.1287

With respect to the lowest production, 3 of the 4 models previously listed (Modified Gompertz, Modified Richards and Modified Schnute) present the "worst" fits with an R^2 ≤0.9805, except for Hill which together with Avrami, Modified Avrami and Transfer Function, are the ones that best describe the observed behavior of BMP in the range of R^2 ≥0.9925 in Experiment C and R^2 ≥0.9858 for Experiment D. The Hill equation presented the lowest average RMSE of 0.1764, followed by Modified Avrami with an average value of 0.1895.

Table 5 presents values reported in the literature. The study reveals that the Y_{max} values obtained are relatively low, even though the μ_{max} values fall within range. The inhibition in biomethane production is due to the use of fast degrading substrates, resulting in high concentrations of ammonia and the accumulation of intermediaries of volatile fatty acids (VFAs) that result in a change of the optimal pH for methanogenesis (Marin et al., 2016; Yono et al., 2014). Therefore, its control and adjustment during anaerobic digestion is recommended.

Table 5. Comparison of parameters obtained with Modified Gompertz equation in the literature.

Reference	***Inoculum***	***Substrate***	Y_{max} $NmL\ CH_4\ g^{-1}\ VS$	μ_{max} $NmL\ CH_4\ g^{-1}\ VS\ d^{-1}$	***Days of production***
Experiment A	Digested sludge	Vinasse	30.4290	29.1810	3
Zahan et al., 2018	Wastewater	Chicken litter	108.5	2.29	50
		Yoghurt whey	354.8	13.86	
Caillet et al., 2019	Activated sludges	Vinasse	216.18	28.07	30

4. CONCLUSIONS

The variation in biomethane production of mesophilic and thermophilic organisms was studied, with two different substrates, with an I/S ratio of 1. Thermophilic organisms exhibit a higher growth rate than their mesophilic counterparts, however the rapid accumulation of byproducts from substrate degradation inhibits their biomethane production by 79.52% on average. In the case of substrates, a higher BMP was obtained in the experiments containing only vinasse as a substrate in relation to the filter cake vinasse. Filter cake needs to be pretreated in order to break the lignin layer to enhance the hydrolysis step. Production time was 3 days, which would reduce production costs of converting raw materials to biomethane. Information was generated as a resource to contribute to the elimination of the pollution impact from vinasse and filter cake, as well as the bioenergetic potential through their biomethane transformation.

From the equations used, it can be established that Gompertz Modified and Hill presented the best approaches; the first one is the most widely used in the literature due to the calculation of three kinetic parameters instead of one. The use of more complex equations than the ones listed above would not be recommended because the R^2 values vary at the third decimal place. Their use would be justified if the purpose was to search for a specific constant.

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CONFLICT OF INTEREST

The authors declare no conflict of interest concerning the publication of this manuscript.

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- B BCh E. Carlos Loyo-Inclán. Research, writing – revision and editing.
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