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Methanization potential of anaerobic biodigestion of solid food waste

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A B S T R A C T
Anaerobic biodigestion of solid and semi-solid wastes has been widely used for the treatment of these residues and methane production; however, during the process (more specifically in the acidogenic phase), there is a tendency of pH reduction, an unfavorable condition to methanogenic bacteria. Thus, the present work aims to evaluate the methanization potential of an agroindustrial anaerobic granular sludge (AIS) from UASB (Upflow Anaerobic Sludge Blanket) reactor, individually and biodigested with food waste (FW) from the University Restaurant of the Federal University of Pernambuco with buffering agent (AIS + FW + b) and without it (AIS + FW). After the laboratory tests, the AIS + FW + b configuration obtained a cumulative methane production approximately six times greater than that of AIS + FW, and approximately twice that of the inoculum alone (AIS).

Palavras-chave:
biodegradação
metano
pH
inóculo

Potencial de metanização da biodigestão anaeróbia de resíduos sólidos alimentares

R E S U M O
A biodigestão anaeróbia de resíduos sólidos e semissólidos vem sendo bastante utilizada para o tratamento destes resíduos e produção de metano; no entanto, durante o referido processo (mais especificamente na fase acidogênica), existe uma tendência de redução do pH, condição desfavorável às bactérias metanogênicas. Desta forma, o presente trabalho visa avaliar o potencial de metanização isolado de um lodo granular anaeróbio agroindustrial (LAI), proveniente de reator UASB (Upflow Anaerobic Sludge Blanket), bem como biodigerido com resíduo alimentar (RA) oriundo do Restaurante Universitário da Universidade Federal de Pernambuco com agente tamponante (LAI + RA + t) e sem adição do mesmo (LAI + RA). Após a realização de ensaios laboratoriais, a configuração LAI + RA + t obteve uma produção acumulada de metano cerca de seis vezes maior em relação à produção da composição LAI + RA, e de aproximadamente duas vezes maior que a do inóculo isolado (LAI).

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Introduction

Inadequate management of solid and semi-solid organic wastes may result in pollution of surface and subsurface waters, soil and air, due to the high content of biodegradable organic matter. The decomposition of the organic fraction, either natural or accelerated, through biotechnological processes, will generate solid, liquid and gaseous byproducts, and the main gases composing the biogas potentiate the greenhouse effect (GHG).

Thus, the utilization of anaerobic digestion in the treatment of the organic fraction of urban solid wastes (OFUSW) is a technology that has been spread worldwide. In the European Union and India, for instance, the current legislations restrict or prohibit the disposal of organic wastes in landfills (Gomes et al., 2012). It is worth highlighting that, according to the Ministerial order 851/2009 (Diário da República, 2009), used in the entire European Union, OFUSW is classified as: food wastes, garden wastes and other putrescible wastes.

Biomass from rural and agroindustrial areas, according to Avaci et al. (2013), is also an available source of energy, since it encompasses plant residues, animal wastes and agroindustrial effluents.

Therefore, the present study aimed to evaluate the methanization potential of food wastes (FW) inoculated with granular sludge (AIS) through anaerobic biodigestion, at laboratory scale.

Material and Methods

The food waste (FW) used in the study was obtained at the Restaurant of the Federal University of Pernambuco (UFPE), which serves the academic community, providing about 5,000 meals per day in 3 shifts and 5 days a week, during the annual academic period. The generated FW is composed of residues from the kitchen (peels and rotten pieces of fruits and vegetables) and from the refectory (processed food leftovers). The inoculum was an agroindustrial anaerobic granular sludge (AIS) obtained from a UASB (Upflow Anaerobic Sludge Blanket) reactor used for the treatment of raw vinasse, at actual scale of 1000 m^3, which is in operation in the rural area of Vitória de Santo Antão, PE. Both were stored in polyethylene plastic bags and containers after the collections and maintained under refrigeration at temperature of approximately 4 ºC, following the sample preservation technique of CETESB (2011).

In the specific case of FW, quartering sampling was performed according to the NBR 10.007 (ABNT, 2004), subsequently extracting the waste solution using the methodology of Lange et al. (2002), for the determination of the following parameters: hydrogen potential - pH (potentiometric method), bicarbonate alkalinity - BA (methodology of Kapp) and chemical oxygen demand - COD (spectrophotometry). These analyses were also performed in the fresh (liquid) sample of the AIS.

Part of both samples was dried in an oven at temperature of 105 ºC until constant weight, according to WHO (1979), aiming at water content quantification and preparation of samples for tests on dry basis.

Dry FW was ground in knife mill and the AIS clods were broken up using a porcelain mortar. After that, these materials were subjected to the following tests: total volatile solids (TVS), according to NBR13.999 (ABNT, 2003); elemental analysis (carbon and hydrogen) through the method of Pregl-Dumas; and biochemical analysis, following the methods Wendel & Van Soest for carbohydrates and lignin, and Soxhlet for lipids.

The experiment to evaluate methane production potential was conducted at the Laboratory of Solid Wastes Group (8º 3’ 11.38” S, 34º 57’ 15.12” W) using the AMPTS II (Automatic Methane Potential Test System), which is a device equipped with a set of 15 hermetically sealed glass reactors with individual volumes of 500 mL, optional mechanical agitation and temperature control in water bath (37 ± 1 °C). These reactors are connected to containers with 80 mL of a 3 molar sodium hydroxide (NaOH) solution, used to absorb carbon dioxide (CO_2), produced by the biodigestion (CO_2 removal efficiency higher than 98%). The system records the produced methane volume through methane (CH_4) sensors connected to a data acquisition system that automatically builds the curve of cumulative methane production as a function of time.

The reactors of this device were filled with two different configurations of food waste and inoculum, with and without buffering solution, AIS + FW + b and AIS + FW, respectively (Table 1), both with substrate/inoculum proportion of 1.5 (AIS: distilled water + FW and distilled water: FW), as recommended by the device’s manual. The blank of the inoculum (AIS) was made to evaluate the endogenous decay, i.e., the degradation of the inoculum organic matter, which was subtracted from the above-cited configurations to obtain the net methane production rate of the FW. The dose of the sodium bicarbonate buffer considered the proportion of 0.2 g of HCO_3 g^{-1} COD_{waste}, recommended by Döll & Foresti (2010).

FW and AIS were used fresh in the experiment and FW was ground to improve homogenization and reduce particle size in an industrial blender (Spolu, model SPL-052) because, according to Souza (1984), reduction in particle size tends to facilitate anaerobic biodigestion.

All these configurations were conducted in triplicate and under constant agitation of 100 rpm at 37 ºC, for a period that ranged from 21 to 46 days for CH_4 production stabilization, according to the different configurations. The stabilization criterion recommended in the device’s manual and used to determine the end of the test considers that if, after a period of 5 or more days in a row, the consecutive readings show differences lower than 1%, the test can be considered as finished. Eq. 1 presents the formula obtained in this calculation.

$$\text{Stabilization criterion} = \frac{\text{Subsequent reading} - \text{Previous reading}}{\text{Subsequent reading}} \quad (1)$$

Table 1. Filling configuration of the AMPTS II experiment

Configurations	FW	AIS	Distilled water	Sodium bicarbonate
			(g)	
AIS	-	400.0	-	-
AIS + FW	64.0	240.0	96.0	-
AIS + FW + b	62.6	234.8	93.9	8.7

FW - Food waste (substrate); AIS - Agroindustrial sludge (inoculum); b - Sodium bicarbonate (buffering agent)

At the beginning and end of the experiment, the digested biomass was evaluated for moisture, pH, BA, TVS and elemental analysis, following the above-mentioned methodologies.

Results and Discussion

The results of the initial characterization of the FW (substrate) and AIS (inoculum), and of the configurations with and without the addition of buffering agent (AIS + FW + b and AIS + FW, respectively), are presented in Table 2.

The moisture of the substrate, inoculum and configurations did not vary significantly (about 5%), being higher in the treatments with addition of distilled water (AIS + FW and AIS + FW + b). The experiments showed moisture of approximately 90%, which according to Rizzoni et al. (2012) corresponds to the ideal content for anaerobic biodigestion.

The pH of the studied FW was 6.29, slightly below the ideal range, but the addition of inoculum (7.49) contributed to its increment, leading to values between 6.5 and 7.5, a range indicated by Pereira et al. (2009) as optimal for the growth of most microorganisms.

Inoculum addition also contributed to the increase of bicarbonate alkalinity (BA) in the FW, which increased from 120 to 34,945 mg $CaCO_3$ L^{-1} (AIS + FW) and 180,981 mg $CaCO_3$ L^{-1} (AIS + FW + b), leading to values above the minimum range recommended by Souza (1984), who indicate ideal values of bicarbonate alkalinity between 2,500 and 5,000 mg $CaCO_3$ L^{-1}, sufficient to provide a good buffering power to the digestion medium.

For COD, high values occurred for both FW and AIS, typical of organic wastes and anaerobic sludges. TVS content was higher in the FW (93.56%) than in the AIS (63.09%), which may be associated with the fact that AIS has a large inorganic fraction incorporated to it.

Yadvika et al. (2004) indicate that the ideal C/N ratio is between 25:1 and 30:1; however, it can be observed that FW and AIS, individually, and their mixture (AIS + FW), have a C/N ratio lower than the recommended/adequate range, indicating excess of nitrogen and lack of carbon. However, it should be pointed out that the C/N ratio found in the present study (13.20) was very close to that reported by Felizola et al. (2006), who obtained proportion of 12.1, in the characterization of the organic fraction of food wastes.

Cremonez et al. (2013) claimed that methane production is affected by the composition of the substrate and quantity of lignocellulosic fraction. Such difficulty is due to the recalcitrant nature of the lignin that is associated with cellulose and hemicellulose present in the composition of the cell wall of plants and foods. The percentage of carbohydrates and lignin of the FW obtained in the present study was very similar to those reported by Peres et al. (1992), equal to 50.6 and 12.5% for the organic fraction of urban solid wastes.

The relative percentage of lipids of the FW and AIS was higher than that found by Parra-Orobio et al. (2015), but it should be pointed out that these authors characterized municipal solid wastes and sludge from UASB reactor that treated domestic sewage, for later biodigestion. This fact can be justified by the wide variety and natural differences existing in the substrates and inoculum used.

Figure 1 presents the cumulative methane production for the evaluated configurations, showing that AIS + FW had the lowest production in methane volume (mean value of 533.25 NmL) and shortest time of CH_4 production stabilization (21 days) in comparison to the other experiments. The reactors filled only with agroindustrial sludge (AIS) showed the longest time of stabilization (46 days) and produced on average 1793.50 NmL. The configuration AIS + FW + b reached stabilization with 26 days and had a cumulative methane production of 3515.90 NmL, which corresponds to more than six times the production of AIS + FW, and almost twice that of AIS.

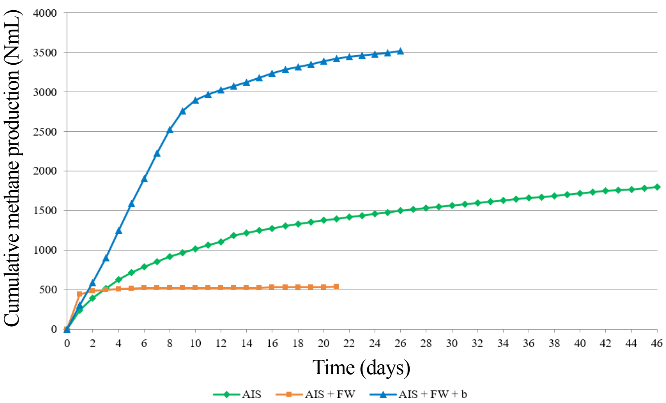
The statistical analysis of the triplicates of the analyzed configurations (Table 3) showed low data dispersion, with more homogeneous values in the configuration AIS + FW, followed by AIS and lastly by AIS + FW + b.

Subtracting the endogenous decay, i.e., the methane production of the inoculum (AIS), the cumulative methane productions for AIS + FW and AIS + FW + b were equal to -304.53 and 2619.20 NmL, respectively (considering only

Table 2. Characterization of the inoculum, the substrate and the configurations of the AMPTS II experiment

Parameters	FW	AIS	AIS + FW	AIS + FW + b
Moisture (%)	85.45	88.24	90.35	90.41
pH	6.29	7.49	7.16	7.14
BA (mg $CaCO_3$ L^{-1})	120	53.676	34.945	180.981
COD (mg L^{-1})	108.937	43.353	-	-
TVS (%)	93.56	63.09	73.08	73.13
C/N	13.2	6.9	6.6	-
Carbohydrates (%)	42.57	49.63	-	-
Lignin (%)	13.47	6.30	-	-
Lipids (%)	7.16	3.37	-	-

FW - Food waste (substrate); AIS - Agroindustrial sludge (inoculum); b - Sodium bicarbonate (buffering agent); pH - hydrogen potential; BA - bicarbonate alkalinity; COD - chemical oxygen demand; TVS - total volatile solids; C/N - carbon/nitrogen ratio



FW - Food waste (substrate); AIS - Agroindustrial sludge (inoculum); b - Sodium bicarbonate (buffering agent)

Figure 1. Mean and cumulative methane production of the analyzed configurations

Table 3. Statistical analyses of the triplicates of the analyzed configurations

Configurations	Mean	Standard deviation	Coefficient of variation
AIS	1793.50	17.06	0.95
AIS + FW	533.25	2.08	0.39
AIS + FW + b	3515.90	79.28	2.25

FW - Food waste (substrate); AIS - Agroindustrial sludge (inoculum); b - Sodium bicarbonate (buffering agent)

240 mL of inoculum added in these configurations). Taking into consideration the FW quantity added to the evaluated configurations and their respective cumulative liquid methane productions, it is possible to determine the relationship between the methane production on dry basis of FW, which was respectively -32.70 and 281.27 N mL CH_4 g^{-1} DM for the configurations AIS + FW and AIS + FW + b.

Thus, the low methane production in the configuration without buffering agent (AIS + FW) and acidification of the medium (final pH of 5.38) can be an indication of methanogenesis inhibition through the hydrolytic and acetogenic step, whose microorganisms exhibit growth rate much higher than that of the methanogenic ones.

Leite et al. (2003) obtained cumulative methane production of about 720 L, during a period of 270 days, from the digestion of solid plant residues (211.52 kg on dry basis) and sludge from sanitary sewage treatment in a batch anaerobic reactor with unit capacity of 2200 L. Considering approximately the same detention time of the configuration AIS + FW + b, i.e., 30 days, the previously cited experiment produced approximately 30 L of methane; however, it is worth highlighting that the added FW dry weight in the present experiment was significantly lower, about 0.0093 kg. Hence, proportionally, the configuration AIS + FW + b showed higher methane production.

After anaerobic biodigestion, the semi-solids of the experiments were characterized and compared with the initial parameters, aiming at the analysis of methane production behavior (Table 4).

It can be observed that the moisture contents of the different configurations were not altered by the anaerobic biodigestion process, because the system is hermetically sealed.

For pH, there was a substantial reduction in the treatment AIS + FW (from 7.16 to 5.38), indicating acidification of the medium and presence of acidogenic microorganisms, resulting in lower methane production and probably higher carbon dioxide production. In the other treatments, pH increased, as in the configuration AIS + FW + b, which was very close to that found by Leite et al. (2009) in a batch anaerobic reactor filled with solid plant resides and sanitary sewage sludge (septic tanks and UASB reactors).

The BA of the configurations AIS and AIS + FW + b increased substantially, due to the alkalinity generated for the equilibrium of the biodigestion, whereas a reduction was observed in the configuration AIS + FW, a behavior that is consistent and inverse to those of the other configurations, since there was acidification of the medium. According to Felizola et al. (2006), high levels of alkalinity in the effluent can be associated with the high concentration of nitrogen, which contributes to the formation of alkalinity by ammonia bicarbonate. This fact can be observed through the association of initial and final nitrogen percentages of the experiments, in which the digested organic nitrogen may have produced ammonia and reacted with the bicarbonate, forming the buffer and increasing the range of alkalinity.

Table 4. Characterization of the biodigested semi-solid after the experiments

Parameters	AIS	AIS + FW	AIS + FW + b
Moisture (%)	88.49	90.51	90.45
pH	7.66	5.38	8.05
BA (mg $CaCO_3$ L^{-1})	103,456	24,350	245,449
TVS (%)	58.87	59.83	52.76
C/N	7.6	7.1	7.3

pH - hydrogen potential; BA - bicarbonate alkalinity; TVS - total volatile solids; C/N - carbon/nitrogen ratio; FW - Food waste (substrate); AIS - Agroindustrial sludge (inoculum); b - Sodium bicarbonate (buffering agent)

Regarding the TVS, the configurations AIS, AIS + FW and AIS + FW + b showed reductions of 6.7, 18.1 and 27.9%, respectively, after biodigestion. Orrico Júnior et al. (2010) obtained mean reduction of 44.05% in TVS contents, in biodigestion using batch reactors filled with poultry litter and dead poultry carcasses, pre-composted for 60 days and biodigested for 98 days.

For the C/N ratio, the treatments AIS and AIS + FW were very similar, respectively, 7.60 and 7.13. Both values are very different from the ratio found by Leite et al. (2009) in batch anaerobic reactor filled with solid plant residues (open markets and supply centers) and sanitary sewage sludge (septic tanks and UASB reactors), which was equal to 13. Such difference can be justified by the composition of the substrates and by the difference of the utilized inoculum percentage, since the above-mentioned authors added only 20% of inoculum, leading to the predominance of characteristics of the substrate.

However, it became evident the importance of using buffering agents in anaerobic biodegradability tests, evaluation of methane potential (BMP) among other similar ones, to guarantee the maintenance of satisfactory environmental conditions of pH and alkalinity and, consequently, the equilibrium and subsistence of various populations of microorganisms present in the anaerobic sludges and responsible for the conversion of complex organic material into methane.

Conclusions

1. Food waste (FW) alone did not show characteristics favorable to anaerobic biodigestion, such as moisture, pH and bicarbonate alkalinity (BA); however, when biodigested with agroindustrial anaerobic granular sludge (AIS), the environmental conditions became more favorable .

2. For the cumulative methane production, the value of the configuration AIS + FW + b was approximately six times higher than that of AIS + FW and twice that of AIS. After digestion, in general, there was an increment in BA and reduction in TVS and C and N contents in the bioreactors, and these alterations were more intense in the configurations that did not acidify, i.e., AIS and AIS + FW + b.

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