



CARACTERIZAÇÃO E AVALIAÇÃO DO POTENCIAL TEÓRICO DE METANIZAÇÃO DOS RESÍDUOS ALIMENTARES DOS RESTAURANTES UNIVERSITÁRIOS DA UFABC

CHARACTERIZATION AND EVALUATION OF THE THEORETICAL METHANIZATION POTENTIAL OF FOOD WASTE FROM UFABC UNIVERSITY RESTAURANTS

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RESUMO

A digestão anaeróbia de resíduos alimentares representa uma alternativa sustentável para o gerenciamento de resíduos e a produção de biogás, contribuindo para a redução de impactos ambientais. Este trabalho teve como objetivo avaliar o potencial de metanização dos resíduos gerados nos Restaurantes Universitários (RUs) da UFABC, considerando tanto os restos de preparo quanto as sobras de pratos, a partir de 61 coletas realizadas. As amostras foram caracterizadas físico-quimicamente por meio das análises de sólidos totais (ST), sólidos voláteis (SV), sólidos fixos (SF), densidade aparente e análise elementar. Os resultados indicaram densidade média de 558,28 kg/m³ para restos de pratos e 340,74 kg/m³ para restos de preparo. Além disso, foram obtidos valores médios de ST de 24,8%, SV de 23,4% e relação SV/ST de 94,2% para os pratos, e ST de 12,5%, SV de 10,9% e relação SV/ST de 87,3% para os preparos e o potencial teórico estimado de produção de metano foi de 542,18 NmL CH₄ gVS⁻¹, confirmando o elevado potencial orgânico dos resíduos.

Palavras-chave: Biogás; Metano; Digestão Anaeróbia; Resíduos Alimentares; Sustentabilidade.

ABSTRACT

Anaerobic digestion of food waste represents a sustainable alternative for waste management and biogas production, contributing to the reduction of environmental impacts. This study aimed to evaluate the methanization potential of waste generated in the University Restaurants (URs) of UFABC, considering both preparation scraps and leftovers from meals, based on 61 samples. The samples were characterized physicochemically through the analysis of total solids (TS), volatile solids (VS), fixed solids (FS), bulk density and ultimate analysis. The results indicated an average density of 558.28 kg/m³ for dish leftovers and 340.74 kg/m³ for food preparation waste. In addition, average values of 24.8% TS, 23.4% VS, and a VS/TS ratio of 94.2% were obtained for dishes, and 12.5% TS, 10.9% VS, and a VS/TS ratio of 87.3% for preparations. The estimated theoretical methane production potential was 542.18 NmL CH₄ gVS⁻¹, confirming the high organic potential of the waste.

Keywords: Biogas; Methane; Anaerobic Digestion; food waste; Sustainability.

1 INTRODUCTION

Proper management of urban solid waste is a central challenge for promoting environmental sustainability and complying with the National Solid Waste Policy (PNRS) in Brazil (BRASIL, 2010). This policy establishes guidelines that prioritize the non-generation, reduction, reuse, recycling, treatment, and proper disposal of waste, based on the principle of shared responsibility for the product life cycle. In this context, higher education institutions play a strategic role in promoting sustainable practices, both as an example to the academic community and as a contribution to society as a whole at large.



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The Federal University of ABC (UFABC), aligned with these principles, established its Sustainable Logistics Management Plan 2016–2022 in 2016 (UFABC, 2016), focusing on sustainability initiatives. However, this plan does not yet include specific technological alternatives for treating organic waste from University Restaurants (RUs). Despite the existence of initiatives such as vermicomposting and the proposed feasibility study for composters, anaerobic digestion was not considered.

Previous studies point to the use of food waste for biogas production as a promising alternative in environmental and energy terms (OLIVEIRA, 2017; FERREIRA, 2015). Thus, this work aimed to characterize the food waste generated in the UFABC RUs by determining the bulk density, total solids, fixed and volatile solids, besides ultimate analysis aiming to evaluate its methane production potential through anaerobic digestion, contributing to the advancement of sustainable practices and the energy recovery from the waste in the university context.

2 METHODOLOGY

Sampling Design

Initially, the number of samples to be collected from the University Restaurants on the Santo André and São Bernardo campus was determined to ensure statistical representativeness. To achieve this the total number of meals served during the observation period was considered ($N = 594$), according to data provided by the Office of the Provost for Community Affairs and Affirmative Action (PROAP) and the company responsible for providing the meals. The sample size calculation was performed using the finite population equation, proposed by Drudi (2019).

$$n = \frac{Nxs^2x(Z\alpha)^2}{(N-1)x\varepsilon^2 + s^2x(Z\alpha)^2} \quad (1)$$

where:

- N is the population size (total number of meals served in the period evaluated);
- S corresponds to the estimated standard deviation;
- $Z\alpha$ is the tabulated value for the adopted confidence level;
- ε represents the tolerated sampling error.

The following parameters were considered: sampling error of 10% ($\varepsilon = 0.10$), 90% confidence level ($Z\alpha = 1.671$), and standard deviation of 50% ($s = 0.5$), according to values usually adopted in the literature. The application of these parameters resulted in an estimated sample size of 62.62 samples.

In practice, 61 samples were collected throughout the study period, representing 97.4% of the calculated value, ensuring the statistical representativeness of the results. The samples were distributed asymmetrically between the two campus, with 39 in Santo André and 22 in São Bernardo, with 36 collected during lunch and 25 during dinner, depending on the student flow in each period.

For analysis purposes, the samples were divided into two distinct types: "kitchen waste," also known as "preparation wastes," and "dish leftovers." The term "kitchen wastes" refers to leftovers from meal preparation that are not served in the dining room and are destined for disposal. Examples of these wastes include vegetable wastes, vegetable and fruit peels, and other food wastes.

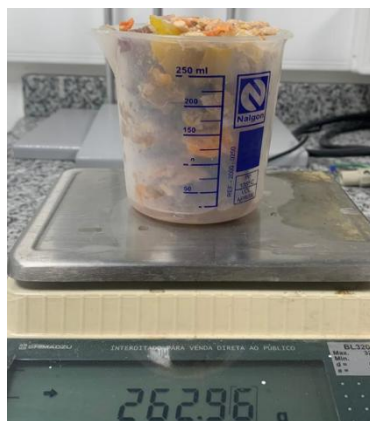
The term "dish leftovers" refers to the waste generated by customers of the University Restaurant (UR) after meals, consisting mainly of rice, beans, fruit peels, leftover salad, protein, among other foods, in addition to napkins and salt sachets.



Determination of Physicochemical characterization

Bulk density is the ratio between the mass and volume of the samples to be analyzed, expressed in kg/m³. This measurement allows us to analyze the reactor volume required to process all the waste generated in the UR by determining its mass.

Figure 1 – Bulk density determination



Source: Personal archive

In Figure 1, we see a beaker of known volume and mass initially filled with the waste from the plates, illustrating the process of determining bulk density. The beaker is filled to its maximum capacity with the sample to be analyzed, thus, from the equation_2 the bulk density can be calculated.

$$\text{Bulk density} = \frac{\text{sample mass (kg)}}{\text{Container volume (m}^3\text{)}} \quad (2)$$

The analysis of total, volatile, and fixed solids was conducted according to the methodology described in the Standard Methods for the Examination of Water and Wastewater (APHA, 2005). To ensure the reliability of the results, the samples were analyzed in duplicate, and each porcelain crucible was previously identified. Before beginning the analyses, the crucibles were calcined in a muffle furnace at 550 °C for two hours, cooled in a desiccator for approximately 30 minutes, and weighed on a semi-analytical balance. Then, approximately 25 g of residue was added to each crucible and subjected to an oven at 105 °C for at least 12 hours. After cooling in the desiccator, the crucibles were weighed again. In the final step, the samples were transferred to the muffle furnace and heated to 550 °C until constant weight was achieved, then cooled in a desiccator and weighed again.

The percentage of total solids in the samples was determined according to equation 3:

$$ST\% = 100 * \frac{(m_{\text{post-oven}} - m_{\text{crucible}})}{(m_{\text{sample in the crucible}} - m_{\text{crucible}})} \quad (3)$$

The percentages of volatile and fixed solids were calculated respectively by equations 4 and 5:

$$SV\% = 100 * \frac{(m_{\text{post-oven}} - m_{\text{muffle powder}})}{(m_{\text{post-oven}} - m_{\text{crucible}})} \quad (4)$$



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$$SF\% = 100 * \frac{(m_{muffle\ powder} - m_{crucible})}{(m_{post-oven} - m_{crucible})} \quad (5)$$

Ultimate analysis aims to determine the mass composition of carbon, nitrogen, hydrogen, sulfur, and oxygen in percentage terms. Ultimate analysis allows estimating the theoretical methane production potential of samples. Analyses were performed on a Thermo Scientific Flash EA 1112 Elemental Analyzer, operated by the CEM (Multi-User Experimental Centers) at UFABC. Each sample, properly dried and ground, was analyzed in duplicate, using a quantity of material ranging from 2 to 3 milligrams.

The data obtained from this analysis are crucial for estimating the theoretical methane production potential, providing essential information for assessing the biodegradability and efficiency of anaerobic digestion processes. Elemental analysis is therefore a crucial tool in studying the theoretical biochemical potential of methane (BMP), in addition to determining the C/N ratio of the samples.

The theoretical calculation of methane production from the elemental composition of the substrate mainly involves the elements carbon (C), hydrogen (H), oxygen (O), nitrogen (N), and sulfur (S). The Boyle equation, derived from the work of Buswell and Hatfield (1936) and also presented by Achinas and Euverink (2019), is widely used to predict biogas production from anaerobic digestion, taking these elements into account.

Boyle's equation can be expressed as:

$$TBMP \text{ (ml CH}_4 \text{ gVS}^{-1}) = \frac{(22,4 \times (\frac{a}{2} + \frac{b}{8} - \frac{c}{4} - \frac{3d}{8} + \frac{e}{4}))}{12,017a + 1,0079b + 15,999c + 14,0067d + 32,065e} \quad (6)$$

Where:

- a: number of Carbon atoms (C);
- b: number of Hydrogen atoms (H);
- c: number of Oxygen atoms (O);
- d: number of Nitrogen atoms (N);
- e: number of Sulfur (S) atoms.

3 RESULTS AND DISCUSSION

Using the sampling plan, it was possible to define the quantity and distribution of samples collected over the months based on information provided by the university's institutional bodies regarding the frequency of use of the University Restaurants (UR). Samples were collected proportionally to the frequency of UR use, as detailed in Table 1.

Table 1 – distribution of sample collection according to frequency of use of UR at both campus

Quantity of Samples	Month	Collected in the UR of Santo André	Collected in the UR of São Bernardo do Campo
2	September 2023	1	1
12	October 2023	8	4
9	November 2023	6	3
5	December 2023	3	2
2	January 2024	2	0
8	February 2024	5	3



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11	March 2024	7	4
8	April 2024	5	3
4	May 2024	2	2

Source: Own authorship

In addition to the temporal distribution over the months, we also proceeded to the distribution based on the number of meals during the days of the week, aiming to ensure the fidelity of the analyses in relation to reality, as if it were implemented on a typical day at the institution, as shown in Table 2.

Table 2 – number of samples collected determined based on the days of the week.

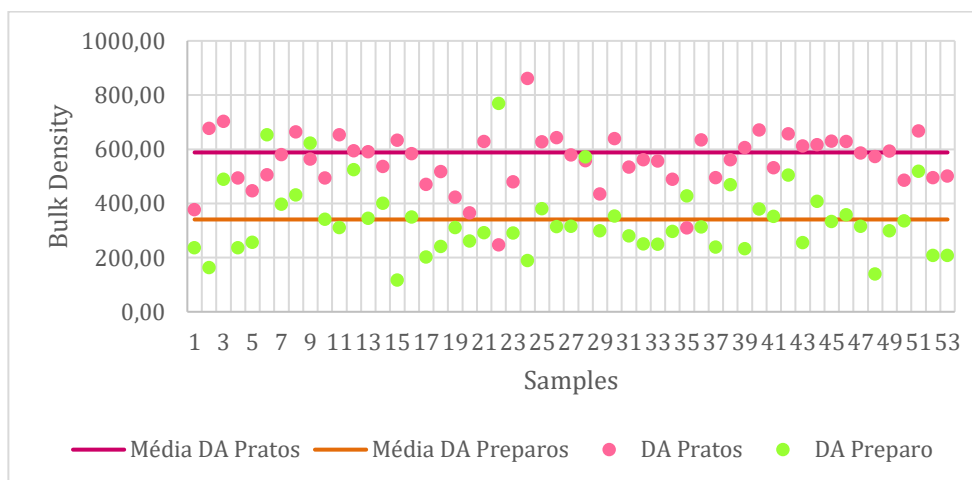
Day of the week	Number of Samples Collected
Second	12
Tuesday	14
Wednesday	12
Thursday	12
Friday	9
Saturday	2

Source: Own authorship

Bulk Density

Fifty-three samples of dish leftovers and 53 samples of kitchen waste were analyzed (the first eight samples were collected without distinguishing between dish and kitchen wastes, so they are not presented here), with results presented in Figure 1. The average bulk density of dishes leftovers was 558.28 kg/m³ (SD = 104.33), while kitchen wastes had an average of 340.75 kg/m³ (SD = 130.44). These values indicate a higher concentration of mass per volume in dishes wastes, while kitchen wastes, composed mainly of peels and stems, presented a lower density and greater variability.

Figure 1 – Comparison of bulk densities of dish and preparation waste



Source: Own authorship



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Total Solids

Total solids (TS) analysis, carried out in the 53 samples of dish and preparation wastes is presented in Table 3. For dishes, the average was 248.53 gTS.kg⁻¹, with values ranging from 21.36 gTS.kg⁻¹ to 449.04 gTS.kg⁻¹, and a coefficient of variation of 35.25%. For prepared foods, the average was 126.26 gTS.kg⁻¹, with a range from 46.86 gTS.kg⁻¹ to 448.04 gTS.kg⁻¹, and a coefficient of variation of 60.04%. These results indicate that dish waste had a higher concentration of total solids and less data dispersion compared to kitchen wastes.

Table 3 – Total Solids from Dish and Preparation Waste

Category	Samples	Average (gTS.kg ⁻¹)	Standard Deviation	Minimum (gTS.kg ⁻¹)	Maximum (gTS.kg ⁻¹)	Coef. of Variation (%)
Total Dishes	Solids 53	248.53	87.60	21.36	449.04	35.25
Total Preparations	Solids 53	126.26	75.80	46.86	448.04	60.04

Source: Own authorship

Volatile Solids

The results of the VS analyses in the same 53 samples of dish and preparation wastes are presented in Table 4. The average volatile solids content was 228.61 gVS.kg⁻¹ in the dishes and 110.24 gVS.kg⁻¹ in the prepared foods. The dishes had a higher average concentration and greater dispersion of values, while the preparation wastes showed a lower concentration but greater relative variability. These results reflect differences in the composition of the evaluated residues.

Table 4 – Volatile Solids from Dish and Preparation Waste

Category	Samples	Average (g/kg)	Standard Deviation	Minimum (g/kg)	Maximum (g/kg)	Coef. of Variation (%)
VS dish wastes	53	228.61	91.78	7.79	438.25	40.15
VS kitchen wastes	53	110.24	60.32	38.56	310.90	54.72

Source: Own authorship

SV/ST ratio

The preparation wastes presented an average SV/ST ratio of 87.3%, a value close to that reported by Rao and Singh (2004) for food waste from markets and residences (89%). In comparison, Ferreira (2015) found 94% in food wastes sent to methanization, and Ferreira et al. (2019) reported 92% for the organic fraction of municipal solid waste. In the dishes, the ratio was 94.2%, agreeing with the findings of Ferreira (2015) and Ferreira et al. (2019) for university restaurants, as well as studies in Korea (Kwon and Lee, 2004; Shin et al., 2004). These results confirm the high organic matter content in both wastes, which favors processes such as anaerobic digestion.



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Ultimate Analysis

Three composite samples of the wastes were analyzed. Each sample was composed of the collections of two different meals and consisted of 50% of dish wastes and 50% of preparation wastes. The samples were homogenized and quartered until a homogeneous sample was obtained. The average values obtained in the elemental analysis of the three composite samples are presented in Table 5. The analyses to determine the levels of C, H, N, and S were performed in triplicate. The oxygen content was estimated by the difference between the C, H, N, S, ash, and moisture contents.

Table 5 - Average elemental composition of the composite food waste samples

Samples	W (%)	H (%)	N (%)	S (%)	Ash (%)	Humidity (%)	The (%)	C/N
Sample 01	46.43	4.92	6.89	0.000	11.99	3.59	26.17%	6.73
Sample 02	44,632	6,502	5,103	0.000	5.69	1,570	36.50	8,746
Sample 03	49,106	7,171	3,278	0.000	5.81	6.63	28.01	14,980
Average	46,722	6,197	5,090	0.000	7.83	3.93	30,226	10,152

Source: Own authorship

The C/N ratio, determined based on the elemental composition, does not fall within the ideal range, which varies between 20 and 30 (ABBASI ET AL,2012). This imbalance can impact methane production, as observed by Abbasi et al. (2012), who highlighted that suboptimal C/N ratios can lead to the release of ammonia, increasing pH and compromising the activity of methanogenic microorganisms.

Carbon, with a content of 46.722%, is the main organic component of the sample and acts as an energy source for the microorganisms responsible for decomposition. This value is considered adequate for the anaerobic digestion process, as it directly contributes to the conversion of organic matter into methane (Deublein and Steinhauser, 2008). The estimated theoretical potential for methane production, based on the elemental composition of the sample, was 542.18 mL CH₄ gVS⁻¹, calculated according to equation 6. This value reflects the maximum capacity for converting carbon into methane under ideal conditions.

4 CONCLUSIONS

The study demonstrated that food waste from UFABC's University Restaurants has potential for energy recovery through anaerobic digestion. The results showed that dish wastes has a higher bulk density and higher total and volatile solids contents compared to preparation wastes, reinforcing its relevance as a substrate for methane production. Volatile solids values close to 90% confirm the high biodegradability of the analyzed waste. Due to the low C/N ratio observed, it is important to consider co-digestion strategies with other substrates available on campus, such as lawn mowing and garden waste, to optimize the anaerobic digestion process.

It is therefore concluded that the energy recovery of UFABC's food waste, combined with awareness and waste reduction policies, can significantly contribute to institutional sustainability and the promotion of the circular economy.



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