

## CO-DIGESTÃO ANAERÓBIA DA FRAÇÃO ORGÂNICA DE RESÍDUOS SÓLIDOS URBANOS E DEJETOS DE BOVINO LEITEIRO: OBTENÇÃO E PROJEÇÃO DOS RESULTADOS EM UM ESTUDO DE CASO NO MUNICÍPIO DE PENÁPOLIS-SP

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**RESUMO:** O trabalho objetivou analisar o potencial de produção de biogás e biofertilizante do processo de co-digestão anaeróbia do substrato composto pela fração orgânica dos resíduos sólidos urbanos (FORSU) e dejetos de gado bovino leiteiro (DGBL) utilizando biodigestores semicontínuos com capacidade de 60 L. Para análise dos dados considerou-se um delineamento inteiramente casualizado, utilizando-se o programa SAS® ao nível de significância de 5%. Foram analisadas a produção, o potencial de produção de biogás, a redução dos sólidos totais (ST), a redução de sólidos voláteis (SV) e os teores dos nutrientes Nitrogênio, Fósforo e Potássio (NPK) do biofertilizante. Os resultados foram aplicados em um estudo de caso tendo como base os dados de coleta de resíduos sólidos urbanos da cidade de Penápolis-SP co-digerido com estrume de 40 vacas. O experimento foi composto de 2 tratamentos, sendo um composto por 90% de FORSU, 10% DGBL e de água e outro tratamento de controle somente com DGBL e água, com 5 repetições para cada tratamento. Concluiu-se o biodigestor semicontínuo com uma proporção FORSU e DGBL de 90% -10%, produz 1 m<sup>3</sup> de biogás com 36,23 kg de FORSU com um potencial de produção de biogás de 0,117 m<sup>3</sup>/kg de SV ad.

**Palavras-chave:** biogás, biofertilizante, energia renovável.

## ANAEROBIC CO-DIGESTION OF THE ORGANIC FRACTION OF URBAN SOLID WASTE AND MILK CATTLE WASTE: OBTAINING AND PROJECTING RESULTS IN A CASE STUDY IN THE CITY OF PENÁPOLIS-SP

**ABSTRACT:** The objective of this study was to analyze the biogas and biofertilizer production potential of the anaerobic co-digestion process of the organic solid waste (FORSU) and dairy cattle manure substrate (DGBL) using semicontinuous biodigesters with capacity of 60 L. For data analysis we considered a completely randomized design, using the SAS® program at a significance level of 5%. The production, the biogas production potential, the reduction of total solids (TS), the reduction of volatile solids (VS) and the nutrient content Nitrogen, Phosphorus and Potassium (NPK) of the biofertilizer were analyzed. The results were applied in a case study based on data from the collection of urban solid waste from the city of Penápolis-SP co-digested with 40 cows manure. The experiment consisted of 2 treatments, one consisting of 90% FORSU, 10% DGBL and water and another control treatment with DGBL and water alone, with 5 replications for each treatment. The semicontinuous biodigester with a FORSU and DGBL ratio of 90% -10% was completed, producing 1 m<sup>3</sup> of biogas with 36.23 kg of FORSU with a biogas production potential of 0.117 m<sup>3</sup>/kg of VS ad.

**Keywords:** biogas, biofertilizer, renewable energy

## 1 INTRODUCTION

Proper solid waste management and the need to restructure the energy matrix with clean energy generation are two major challenges for public managers in order to carry out administration based on sustainable development. The increase in methane and carbon dioxide emissions has been one of the causes of the increase in the greenhouse effect, which involves landfills and dumps as one of its sources, contributing to air pollution and aggravating this effect. According to the Panorama of Solid Waste in Brazil, carried out by the Brazilian Association of Public Cleaning and Special Waste Companies - ABRELPE, in 2018, each Brazilian produced an average of 1.04 kilograms of waste per day. In China, 199,311 tons of solid waste are collected daily. Of this total, 40.5% had an inadequate destination, as they went to the dumps or controlled landfills that Brazil still has, totaling 80,821 tons per day (ABRELPE, 2019).

Considering the scenario in the city of Penápolis-SP, the numbers reported by the Autonomous Department of Water and Sewage of Penápolis – DAEP (2019) show that 100% of the MSW collected in the city has proper disposal, and in 2015, there was a decrease of approximately 3.9% in MSW collection, resulting in a reduction from 0.730 kg of MSW per inhabitant per day in 2014 to 0.702 kg per inhabitant per day in 2015.

Kroeger *et al.* (1998) reported that 30% of urban waste and a large proportion of industrial waste can be biologically treated by composting and anaerobic digestion. Anaerobic digestion is an efficient waste treatment method that uses organic waste, treating it in either its solid or liquid form, thus avoiding the disposal of waste in dumps and landfills. This form of waste treatment produces biogas, which is composed mainly of methane (CH<sub>4</sub>) and carbon dioxide (CO<sub>2</sub>), which are greenhouse gases (GHGs) and can be used to generate electrical, thermal, or mechanical energy.

The biodegradation percentage of FORMS was reported by Forster-Carneiro *et al.* (2008), who reported a potential reduction in VS of 79.5% in an experiment that investigated the influence of different fractions of municipal

solid waste in an anaerobic treatment under thermophilic conditions (55°C).

Anaerobic biodigestion allows for energy recovery through the production of biogas, which can be used as an energy source directly in burners or generator engines, reducing the pollution potential of the effluent and allowing its reuse as a biofertilizer, which can be used as fertilizer for vegetable crops (Amaral *et al.*, 2004; Xavier; Lucas Junior, 2010).

One way to increase biogas production in the anaerobic biodigestion process is codigestion, which combines the treatment of different residues rich in carbohydrates or microorganisms, such as sugarcane juice, vinasse, and bovine and chicken manure. Codigestion is a term used to describe the combined treatment of residues with various complementary characteristics, characterizing one of the main advantages of anaerobic technology (Fernández, A; Sánchez, A.; Font, X, 2005).

According to Orrico *et al.* (2016), dairy cattle manure, when combined with other residues with an accelerated degradation rate, can increase its biogas production potential. Hartmann and Ahring (2005) analyzed the influence of codigestion using manure and investigated the anaerobic biodigestion of FORMS with manure at a 1:1 ratio in a semicontinuous biodigester with a capacity of 3 L. The production potential after 83 days was 0.63 m<sup>3</sup>/kg of biogas and a 74% reduction in VS.

El-Mashad and Zhang (2010), using 100 ml of inoculum (bacterial seed culture), evaluated the biogas production potential of two mixtures with DGBL and FORSU at ratios of 68:32 and 52:48, respectively, on the basis of volatile solids. The experiments revealed 0.455 and 0.531 m<sup>3</sup>/kg VS, respectively when batch biodigesters with a capacity of 1 liter were used under mesophilic conditions (35°C).

A study of anaerobic codigestion carried out by Ponsá, Gea and Sánchez (2011) analyzed the methane production of FORMS codigested reactors with pure organic substrates using reactors with a mixture of vegetable oil, animal fat, cellulose and protein. The experiment revealed that the four cosubstrates used led to

improvements, but vegetable oil was the most suitable cosubstrate to be digested anaerobically, having achieved a production of 450 L CH<sub>4</sub> kg<sup>-1</sup> VS in 21 days, representing a yield 25% higher than that presented by the control reactor.

## 2 MATERIALS AND METHODS

The experiment was conducted at the Biomass and Anaerobic Biodigestion Laboratory of the Rural Engineering Department of the Faculty of Agricultural and Veterinary Sciences of São Paulo State University (FCAV), UNESP – Jaboticabal Campus, located at the geographic coordinates: 21°14' 05" S; 48° 17'0 9" W and an average altitude of 613.68 m. The region's climate, according to the Köppen classification, is Aw transitioning to Cwa. In Jaboticabal, the climate is characterized as humid tropical, dry in winter and rainy in summer, with an annual precipitation of 1,426.6 mm, an average annual temperature of 22.2°C and an average annual relative humidity of 70.8%. Dairy cattle manure was obtained from the feedlot of the Cattle Farming Sector of the Department of Animal Science of FCAV/UNESP – Jaboticabal Campus. The organic fraction of solid waste was collected from a restaurant in the city of Jaboticabal.

The experiments in semicontinuous biodigesters analyzed the values of biogas production potential and electricity generation, the percentage reductions in volatile and total solids, and the NPK content of the effluent, which were determined on the basis of the percentage of MSW (municipal solid waste) collected in the city of Penápolis. The semicontinuous biodigester trial lasted 82 days, and after the biodigester stabilized, the final 45 days were used for analysis. For loading, 4 kg of dairy cattle manure and 25 kg of food scraps, composed of meat, vegetables, greens, and fruits, were collected weekly and transported to the Rural Engineering Department. Benchtop tubular semicontinuous biodigesters with a capacity of 60 liters were used, which were

constructed with PVC pipes with a diameter of 300 mm and a length of 1 m, and their ends were sealed with a fiberglass cap. A 60 mm pipe was coupled at one end for influent intake and at the opposite end of a 60 mm pipe with a 75 mm valve for the effluent outlet.

The gases generated in the biodigesters were stored in gasometers 250 mm in diameter and 60 cm in length and connected to the biodigesters by means of plastic hoses for biogas conduction. The experiment consisted of 2 treatments with 5 repetitions each, totaling 10 semicontinuous biodigesters with a storage capacity of 60 L and a daily substrate load of 2 L with an HRT of 30 days. The FORMS (forestry, solid waste) was collected weekly, where residues were transported to the laboratory and subjected to a process of grinding and dilution with water in the proportion defined for treatment T1 for the five repetitions, totaling 2 liters of substrate for daily loading. The added DGBL (digesterone-based liquid) for both treatments was homogenized manually with the aid of shovels in buckets to provide better fermentation conditions.

To define the daily proportions of each of the residues that made up the treatments for supplying the biodigesters, laboratory-scale values were simulated on the basis of the organic fraction of municipal solid waste from the city of Penápolis and the manure from a herd of 40 dairy cows, with a production of 1200 l/day. The organic fraction of municipal solid waste (FORSU) was calculated at 30% of the waste collected daily, and for dry matter (DGBL), an average daily generation of 30 kg/cow was adopted, resulting in a DGBL/FORSU ratio of 11.11%. For dilution, 3 parts water and 1 part FORSU+DGBL residue were used. On the basis of the Penápolis residue values and considering a daily load of 2 L, treatment T1 consisted of 0.450 kg of FORSU, 0.050 kg of DGBL, and 1.5 kg of water, with 5 repetitions. T0 was the DGBL control biodigester, which was composed of 0.450 kg of DGBL and 1.550 kg of water. Table 1 presents the loading values for the semicontinuous biodigesters.

**Table 1.** Composition of the samples subjected to semicontinuous biodigesters

Treatments	FORSU (kg)	DGBL (kg)	WATER (kg)
T	0	0.450	1,550
T1	0.450	0.050	1,500

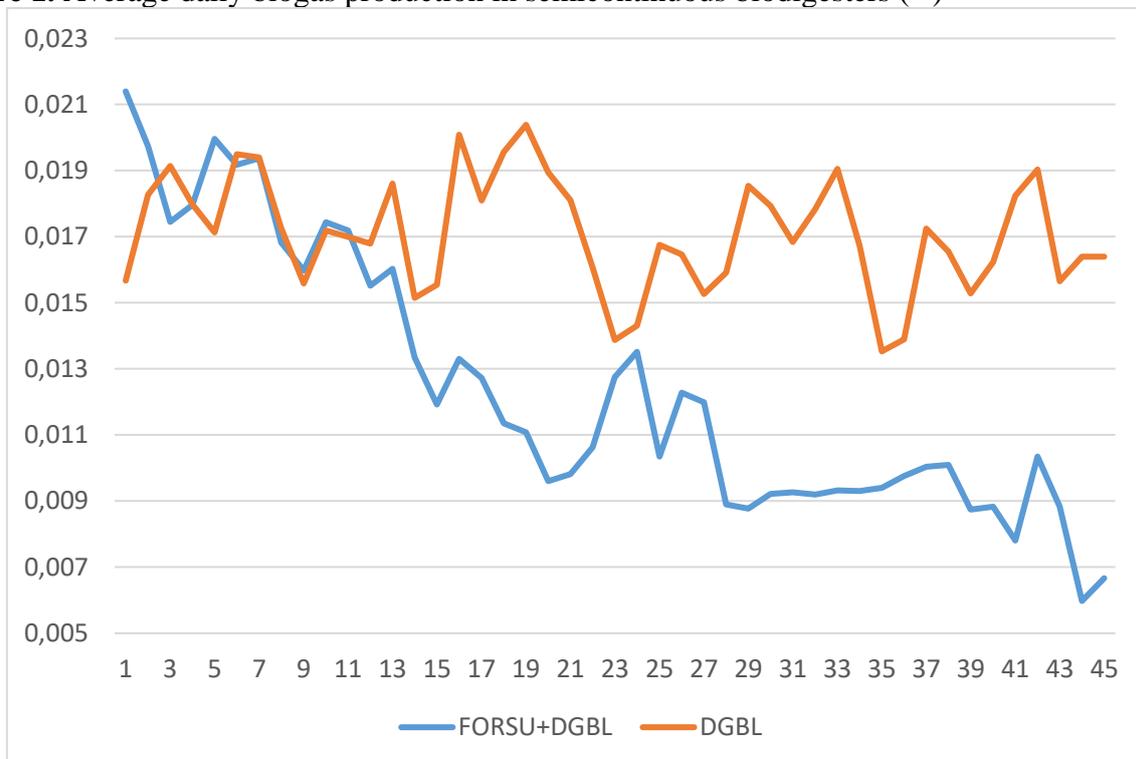
Source: Survey Data

(2017)

### 3 RESULTS AND DISCUSSION

Figure 1 shows the average daily biogas production rates over the 45 days of data analysis. At the beginning of the process, the treatment with FORSU+DGBL codigestion

performed better than the control, demonstrating that the addition of FORSU facilitates the start of the degradation process, as its composition includes residues that are more easily degraded than the manure is.

**Figure 1.** Average daily biogas production in semicontinuous biodigesters (m<sup>3</sup>)

Source: Survey Data (2017)

Compared with DGBL alone, the initial degradation of FORSU causes a decrease in biogas production over time in the FORSU+DGBL treatment. Although the FORSU+DGBL treatment resulted in a lower yield than the control biodigester did, the performance was considered satisfactory, considering that the objective of the experiment was to increase biogas production from FORSU when DGBL was used as inoculum. The

biodigester with the codigested substrate presented a total yield of 0.559 m<sup>3</sup> of biogas at the end of the period, which represents approximately 72% of the production presented by the DGBL control biodigester, with a yield of 0.769 m<sup>3</sup> of biogas. The biogas potential per kg of added VS, per kg of added ST, per kg of FORSU, and per kg of DGBL are presented in Table 2.

**Table 2.** Measurements of biogas production potential in semicontinuous biodigesters

Treatment	m <sup>3</sup> /kg of ST ad	m <sup>3</sup> /kg of SV ad	m <sup>3</sup> /kg of FORSU	m <sup>3</sup> /kg of DGBL
FORSU+DGBL	0.106 b	0.117 b	0.027	0.248 a
DGBL	0.238 a	0.283 a	0.0	0.038 b
F	160.46	185.43	354.5	251.58
p value	<0.0001	<0.0001	<0.0001	<0.0001
CV%	9.55	9.56	16.79	14.64

Source: Survey Data (2017)

Hartmann and Ahring (2005) analyzed the influence of codigestion using manure and FORMS with manure at a 50:50 ratio in a semicontinuous biodigester with a capacity of 3 L under thermophilic conditions and recirculated process liquid. The production potential presented after 83 days was 0.63 m<sup>3</sup>/kg of VS of biogas and a 74% reduction in VS. The production potential results of 0.117 m<sup>3</sup>/kg of VS presented in this study are lower; however, it should be considered that the FORMS+DGBL ratio used was 90:10 without

the use of recirculation and heating technologies.

Table 3 shows that FORSU+ DGBL is a material that contains a greater amount of organic matter in its composition than DGBL does, as it presents a higher percentage of VS. The FORSU+DGBL treatment results in a greater percentage reduction in VS than the DGBL treatment does, demonstrating that the anaerobic biodigestion system is efficient for the treatment of FORSU+DGBL, decreasing the concentration of organic load by approximately 85.57%.

**Table 3.** Percentage reduction in SV

Treatment	%Tributar y	%Effluent	kg Effluent	kg Effluent	% Reduction
FORSU+DGBL	5.27	0.76 b	0.105 a	0.015 b	85.57 a
DGBL	3.02 b	1.86 a	0.060 b	0.037 a	38.28 b
F	0	166.94	0	168.09	343.98
p value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
CV%	0	10.29	0	10.26	6.51

Source: Survey Data (2017)

Table 4 presents the percentages of total solids in the influent and effluent and the percentage reduction in total solids in the FORSU+DGBL and DGBL treatments in semicontinuous biodigesters. The percentage

reduction in total solids of 81.89% reaffirmed the degradation efficiency of the anaerobic biodigestion system for the FORSU+DGBL treatment.

**Table 4.** Percentage of total solids reduction in semicontinuous biodigesters

Treatment	%Tributary	%Effluent	kg Effluent	kg Effluent	%Reduction
FORSU+DGBL	5.84 a	1.05 b	0.117 a	0.021 b	81.89 a
DGBL	3.59 b	2.28 a	0.071 b	0.045 a	36.36 b
F	0	149.20	0	149.34	300.62
p value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
CV%	0	9.53	0	9.49	7.02

Source: Survey Data (2017)

This case study applies the results obtained in the semicontinuous experiment to a real-world production scale on the basis of data from the municipality of Penápolis. The results presented include data on biogas production potential and energy generation potential. For the calculation of FORSU (foreign solid waste), the results of Kroeger *et al.* (1998) reported that 30% of urban waste can be biologically treated by composting and anaerobic biodigestion. Considering that waste collection in the city of Penápolis in 2014 and 2015 reached an average of approximately 13,000 t/year, it is possible to estimate that 10,700 kg of FORSU/DAY were produced. For the calculation of DGBL (digestible biomass), the volume of manure generated daily by 40 cows was considered, which, according to Santos and Nogueira (2012), is approximately 7% of the animal's live weight. Therefore, considering that the average weight of the animals used in this experiment was approximately 430 kg, it is possible to estimate that 1,190 kg of DGBL/DAY are produced. To calculate the volume of water for a 6% TS dilution, this study used a FORSU+DGBL/water ratio of 1:3, where the total daily load volume of the biodigester was estimated at 47,560 kg.

Considering the values determined in the anaerobic biodigestion test of 0.105 kg of VS in the daily influent and the potential biogas production per kg of added volatile solids of 0.117 m<sup>3</sup>/kg, the daily biogas production value

based on the potential biogas production per kg of added volatile solids is estimated to be 584.27 m<sup>3</sup>.

The electricity generation from biogas is achieved through combustion, and according to the ER-BR gas generator set manual (ER-BR, 2017), the generator set required to meet the biogas demand produced by the biodigester is the 120 kVA biogas motor generator set, model GMWM120, with a biogas consumption of 47 m<sup>3</sup>/h (65% CH<sub>4</sub>) and a generation potential of 77 kWh. Therefore, with a generator operating for 12 and a half hours, it is possible to estimate a daily electricity generation potential of 962.50 kWh.

To estimate the fertilization value of the effluent from the FORSU+DGBL anaerobic biodigestion process, the volume of biofertilizer generated and the concentrations of the nutrients N, P, and K were considered as a basis. Urea (45% N) was the mineral fertilizer used as the nitrogen source, single superphosphate (18% P<sub>2</sub>O<sub>5</sub>) was used as the phosphorus source, and potassium chloride (58% K<sub>2</sub>O) was used as the potassium source. On the basis of the value found in the semicontinuous experiment for the total solids of the effluent, the biofertilizer from the FORSU anaerobic biodigestion process in Penápol presented 500 kg of dry matter. Table 5 shows the equivalence of the NPK concentration in the effluent with the fertilizer source.

**Table 5.** NPK equivalence in effluent with fertilizers

N(%)	Urea (kg)	P(%)	Single superphosphate (kg)	K(%)	Potassium Chloride (kg)
2.02	22.44	2.29	145.67	2.8	28.96

Source: Survey Data (2017)

## 4 CONCLUSIONS

The experiment in semicontinuous biodigesters with a FORSU and DGBL ratio of 90%-10% revealed a biogas production potential of 0.117 m<sup>3</sup>/kg of VS ad and a value of 36.23 kg of FORSU for the production of 1 m<sup>3</sup> of biogas. A case study based on data from the city of Penápol reported the production of 500 kg of biofertilizer daily and the potential for generating 1.63 kWh of electricity per m<sup>3</sup> of biogas. Anaerobic biodigestion is a process that presents itself as an alternative to the treatment of organic waste, reducing greenhouse gas emissions by landfills and dumpsites and generating clean energy, in addition to increasing the lifespan of the landfill. sanitary, since the percentage of organic waste collected but not sent to landfills is directly proportional to the increase in the period of its use.

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