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ENERGY GENERATION BY ANAEROBIC DIGESTION: CHARACTERIZATION OF SEWAGE SLUDGE AND BOVINE DEGETES ANDBIOGAS PRODUCTION - PART I

GERAÇÃO DE ENERGIA POR DIGESTÃO ANAERÓBIA: CARACTERIZAÇÃO DO LODO DE ESGOTO E DEJETO BOVINO E PRODUÇÃO DE BIOGÁS - PARTE I

GENERACIÓN DE ENERGÍA POR DIGESTIÓN ANAEROBIA: CARACTERIZACIÓN DE LODOS DEPURADORES Y DEGETES BOVINOS Y PRODUCCIÓN DE BIOGÁS - PARTE I

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ABSTRACT

Accelerated population growth has led to an increase in the production of agricultural, industrial and agro- industrial waste, with the aggravating factor being incorrect disposal, causing a public health problem. In this sense, the objective was to evaluate the anaerobic digestion (AD) between bovine manure (BM), sewage sludge (SS) and water (W) in the proportions of 100:0 BM:SS, 0:100 BM:SS, 50:50 BM:SS and 50:50 BM:A to propose a solution to these environmental liabilities. The substrate was characterized for its physicochemical properties. The biogas generated due to the AD of substrates under MoAD and CoAD was analyzed for its weekly and cumulative production potential. In general, the mean values of the substrate characterization parameters were in the ideal range for biogas production. However, it was verified that with the CoAD between BM and SS, average values of the physical-chemical parameters were obtained, which favored a higher production of biogas with a shorter start-up time. Thus, it is concluded that the sewage sludge used as a codigestant of bovine manure stabilizes the organic matter and provides a liquid medium and microbial load for greater biogas production, in addition to being an excellent substitute for water.

Keywords: anaerobic codigestion, anaerobic monodigestion, water

RESUMO

O acelerado crescimento populacional levou ao aumento da produção de resíduos agrícolas, industriais e agroindustriais, tendo como agravante seu despejo incorreto causando problema de saúde pública. Neste sentido, objetivou-se avaliar a digestão anaeróbia (DA) entre dejetos de bovino (DB), lodo de esgoto (LE) e água mineral (A) nas proporções de 100:0 DB:LE, 0:100 DB:LE, 50:50 DB:LE e 50:50 DB:A para propor uma solução a esses passivos ambientais. O substrato foi caracterizado quanto suas propriedades físico-química. O biogás gerado devido à DA dos substratos sob MoDA e CoDA foi analisado quanto seu potencial de produção semanal e acumulada. No geral, os valores médios dos parâmetros de caracterização do substrato encontraram-se na faixa ideal para produção de biogas. No entanto, verificou-se que com a CoDA entre DB e LE obteve-se valores médios dos parâmetros físico-quimico que favoreram a maior produção de biogas com menor tempo de partida. Dessa forma conclui-se que o lodo de esgoto utilizado como codigestante do dejeto bovino estabiliza a matéria orgânica e fornece meio líquido e carga microbiana para que haja maior produção de biogás, além de ser um excelente substituto da água.

Palavras-chave: *Codigestão anaeróbia, monodigestão anaeróbia, água*

RESUMEN

El rápido crecimiento poblacional ha llevado a un aumento en la producción de residuos agrícolas, industriales y agroindustriales, teniendo como agravante la incorrecta disposición, provocando un problema de salud pública. En este sentido, el objetivo fue evaluar la digestión anaeróbica (DA) entre estiércol bovino (EB), lodos de depuradora (LD) y agua (A) en las proporciones de 100:0 EB:LD, 0:100 EB:LD, 50 :50 EB:LD y 50:50 EB:A para proponer una solución a estos pasivos ambientales. El sustrato se caracterizó por sus propiedades fisicoquímicas. El biogás generado debido a la DA de sustratos bajo MoDA y CoDA fue analizado por su potencial de producción semanal y acumulativo. En general, los valores medios de los parámetros de caracterización del sustrato estuvieron en el rango ideal para la producción de biogás. Sin embargo, se verificó que con el CoDA entre EB y LD se obtuvieron valores promedio de los parámetros físico-químicos, lo que favoreció una mayor producción de biogás con un menor tiempo de arranque. Así, se concluye que los lodos de depuradora utilizados como codigestores de estiércol bovino estabilizan la materia orgánica y brindan un medio líquido y carga microbiana para una mayor producción de biogás, además de ser un excelente sustituto del agua.

Descriptores: *codigestión anaeróbica, mono digestión anaeróbica, agua*

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INTRODUCTION

Accelerated population growth has led to an increase in energy demand and the production of agricultural, industrial, and agro-industrial waste. Brazil is a country that still faces serious public health problems due to the lack of adequate and sufficient environmental sanitation to serve the entire population. The improper disposal of sewage (including human and animal waste), industrial and agro-industrial waste leads to the contamination of water resources (SILVA et al., 2020; FERREIRA, 2017). In addition, it leads to an increase in the proliferation of diseases, increasing public spending on treating the sick population that could be applied in other areas, such as environmental.

According to the 2022 Sanitation Ranking conducted by the Instituto Trata Brasil, 35 million Brazilians do not have access to treated water, 100 million do not have sewage collection, and only 50% of sewage is treated in Brazil, resulting in preventable diseases that can lead to death. In Brazil, 50% of the volume of treated sewage equals more than 5.3 thousand Olympic swimming pools of raw sewage being dumped into nature every day (ITB, 2022). Therefore, it is essential to develop public policies based on scientific methodologies that meet the requirements of environmental and public health agencies, aiming at the final disposal, recycling of waste, and socio-environmental awareness of the population.

Anaerobic biodigesters, considered a clean energy technology, have high financial and environmental viability. The use of anaerobic biodigesters can solve the problem of energy supply and costs, as well as contribute to the reduction of the consumption of polluting sources of energy. This means of generating clean energy mitigates the environmental and health problems caused by environmental contamination (SZYBA and MIKULIK, 2022; FREITAS et al., 2019).

The principle of operation of anaerobic biodigesters consists of Anaerobic Digestion (AD) through Anaerobic Mono-digestion (MoAD) and Anaerobic Co-digestion (CoAD), where the transformation of organic matter into biogas and organic fertilizer occurs. With this process, biogas is recovered to convert it into thermal and electrical energy, reintegrating the waste product into the production cycle. The conversion of biogas into electrical and/or thermal energy is presented as a solution to the lack of electricity and reduction of the burning of natural resources, which affects millions of Brazilians. Studies have shown that the use of biogas as an energy source is a viable solution from an economic and environmental point of view (SZYBA and MIKULIK, 2022; VILLARROEL-SCHNEIDER et al., 2020; BANJA et al., 2019; GOVENDER et al., 2019).

Biogas, considered a renewable energy source, can be produced on-site from waste generation, being used in lighting, heating, cooling, cooking, and even in the feeding of engines, in order to replace fossil fuels used in these processes and that have a high environmental impact.

The replacement of traditional fuels with alternative sources can lead to improvements in the environment, population health, increase the lifespan of landfills, and generate revenue through waste reuse. The objective of this work was to evaluate the anaerobic digestion of cattle waste and sewage sludge in anaerobic biodigesters through substrate characterization and biogas production potential.

MATERIALS AND METHODS

The experiment was conducted at the Multi-User Research Laboratory of the Rural Renewable and Alternative Energy Group (LabGERAR) of the Rural Federal University of Rio de Janeiro (UFRRJ), located in Seropédica - RJ, Brazil, with geographical coordinates of 22º 45' 33" S and 43º 41' 51" W. The climate of the region is classified as Aw according to the Köppen classification system, with an average annual temperature of 24.5 ºC.

The sewage sludge was obtained from the Palatinato Sewage Treatment Plant (ETE), belonging to Águas do Imperados of the Águas do Brasil Group, located in Morino municipality of Petrópolis in the state of Rio de Janeiro, and the bovine manure was collected from the Dairy Cattle Farm at UFRRJ.

For the experiment, the MoAD ratios of 100:0 and 0:100 bovine manure:sewage sludge (BM:SS), and 50:50 bovine manure:mineral water (BM:MW) were established, and for CoAD, 50:50 BM:SS, with trials performed in triplicate.

The physico-chemical characterization of the substrate was carried out regarding the potential of hydrogen ion concentration (pH), total alkalinity (TA), volatile acidity (VA), moisture content (M), total solids (TS), volatile total solids (VTS), chemical oxygen demand (COD), and nitrogen (N), as recommended by CONAMA 375/06 Legislation for agricultural use of sewage sludge generated in sewage treatment stations and their derivative products (BRAZIL, 2006). The methodology described by APHA (2005) was used to determine pH, TA, VA, M, TS, VTS, COD, and N. The analyses were performed in triplicate for each anaerobic biodigester.

The anaerobic biodigester used in the experiment was based on the Indian model, consisting of a water-seal containment chamber, fermentation chamber, gasometer, and U-tube manometer with water manometric liquid, according to Matos et al. (2017).

The volume of biogas generated due to AD of substrates under MoAD and CoAD was calculated by the product of the vertical displacement of the gasometer by its internal cross-sectional area during the hydraulic retention time. The correction of the biogas volume for the conditions of 1 atm (101.32 kPa) and 20 °C was carried out based on the work done by Matos et al. (2017).

Using the biogas volume, the weekly (WPP) and accumulated (APP) production potentials were calculated, with values expressed in L of biogas per kg of added substrate. The APP was calculated by summing the WPP for the current and previous collection times.

The burn test was performed using a Bunsen burner, whose hose was attached to the biogas outlet, to detect the presence of methane in the biogas. If the flame continued to burn after lighting the Bunsen burner, the burn was confirmed (SILVA et al., 2021).

For the evaluation of the results regarding the anaerobic digestion assay of the substrate of the 100:0, 0:100, and 50:50 BM:SS and 50:50 BM:MW, analysis of variance followed by the Tukey test at a 5% probability level was performed using the SISVAR statistical program.

RESULTS AND DISCUSSION

Physical-chemical evaluation of the substrate

The environmental parameters pH, alkalinity, and acidity are closely related to each other, being indicators of the success of the organic matter biodegradation process aiming at biogas production (SAFAR et al., 2018).

For the proportions with sewage sludge (0:100 and 50:50 BM:SS), it was possible to verify a reduction in pH, meaning that the medium became more acidic compared to the samples with only bovine manure or with the addition of water (Table 1).

Table 1 - Average values of hydrogen potential (pH), total alkalinity (TA), volatile acids (VA) of the substrates

Parameters	100:0 BM:SS	0:100 BM:SS	50:50 BM:SS	50:50 BM:MW	CV (%)	p-value
pH	7.40A	6.73B	6.96B	7.41A	1.74	0.00
TA ($g\ L^{-1}$)	6.13A	1.20D	4.40B	3.60C	3.98	0.00
VA ($g\ L^{-1}$)	6.48A	2.48B	5.12A	2.00B	18.88	0.00

*Means followed by different uppercase letters on the same line differ statistically from each other in the comparison between substrates by Tukey's test at 5% error probability. CV - Coefficient of variation.

Although the medium became more acidic with the addition of sewage sludge, it still remained in the ideal range for biogas production, which varies from 6.5 to 8.0 (GONÇALVES and RAMALHO, 2021; ANDRADE et al., 2022).

The acidity of the medium represented by the reduction in pH was also observed in the work developed by Ribeiro (2018) when characterizing sewage sludge for use as biomass. According to these authors, the acidity of the medium occurs due to nitrification reactions of ammoniacal nitrogen and degradation of sewage sludge by microorganisms producing organic acids in the process.

Total alkalinity estimates the buffering power, i.e., the medium's capacity to neutralize acids during anaerobic digestion. In the anaerobic medium, alkalinity is associated with the formation of carbon dioxide and volatile acids, making the medium more balanced, avoiding a sharp drop in pH. Volatile acidity measures the acid radicals of the medium and their resistance to pH increase when a base is added, besides being related to the size of the population of methanogenic bacteria (ASSUNÇÃO, 2020).

It was observed in Table 1 that both the average values of TA and VA decreased significantly with the addition of a liquid medium to the bovine manure (Table 2), with water causing greater reduction. The same behavior was reported by Assunção (2020). By analyzing the effects of alkalinity and volatile acidity on anaerobic digestion, it can be verified that the medium became stable and balanced due to not obtaining significant changes in pH.

However, according to the VA/TA ratio, only 50:50 BM:MW presented results within the ideal range. For proportions 100:0 BM:SS, 100:0 BM:MW, and 50:50 BM:SS, values ranging from 1.05 to 2.06 were found, indicating instability in the system. According to Feiden (2001), values in the range of 0.1 to 0.5 indicate whether AD is occurring satisfactorily. Values higher than this range indicate the occurrence of some disturbance or overload in the medium (FEIDEN, 2001).

Significant differences were observed in the parameters of moisture content, total solids, volatile solids, biodegradability, chemical oxygen demand, and nitrogen among the proportions of bovine manure, sewage sludge, and water in the substrates, as shown in Table 2.

Table 2 - Average values of moisture content (M), total solids (TS), volatile solids (VTS), biodegradability (BD), chemical oxygen demand (COD), and nitrogen (N) of the substrates

Parameters	100:0 BM:SS	0:100 BM:SS	50:50 BM:SS	50:50 BM:MW	CV (%)	p-Value
M (%)	84.77D	93.96A	88.41C	91.94B	0.19	0.00
TS (%)	15.23A	6.04D	11.59B	8.06C	1.71	0.00
VTS (%)	12.24A	2.90D	8.26B	6.49C	2.22	0.00
BD	0.80A	0.48C	0.72B	0.81A	1.09	0.00
COD (g L^{-1})	17.08A	7.14C	11.15B	11.24B	6.54	0.00
N (mg L^{-1})	4.00A	6.00A	3.00C	3.10C	0.00	0.00

* Means followed by different uppercase letters on the same line differ statistically from each other in the comparison between substrates by Tukey's test at 5% error probability. CV - Coefficient of variation.

The importance of moisture content lies in the need of microorganisms for water to survive, transport, and distribute in the substrate, facilitating the biodegradation of organic matter and the dilution of compounds. The moisture content of the proportions studied (84.77 to 93.96%) is within the suitable range for biogas production, as reported in the literature (ANDRADE et al., 2022; ANDRIAMANOHIARISOAMANANA et al., 2016).

The average values of TS and VTS obtained from the substrates ranged from 6.04 to 15.23% and 2.90 to 12.24%, respectively. The literature recommends total solids values around 8% for maximum biogas production, since higher values can hinder the process flow, leading to the creation of crusts in the substrate and possible obstruction of bioreactor inlets and outlets, as well as low substrate dilution values (CREMONEZ et al., 2013; DEGANUTTI et al., 2002). However, authors who worked with values higher than 10% or lower than 8% with biogas production can also be found in the literature. Andrade et al. (2022) adopted 15% of TS when working with food waste and bovine manure, and Pagani et al. (2019) operated with TS ranging from 3.98% to 15.98% in the MoAD of bovine manure at different dilutions.

In the MoAD, it was observed that the lower average moisture content and, consequently, higher TS and VTS values for the proportion containing bovine manure may be due to the high organic matter load in this substrate. The opposite was also observed for the MoAD of only sewage sludge (Table 1). In this last case, the reduced values of TS or VTS are due to the large amount of liquid in the sample, as evidenced by the moisture content (Table 1). According to Meyer et al. (2017), the substrate can be classified according to its TS content as solid

(16% or more of TS), semi-solid (12 to 16% of TS), and liquid (12% or less of TS). Thus, the proportion 100:0 BM:SS is classified as semi-solid, and the others are liquid.

The average VS values of 50:50 BM:MW and BM:SS were similar to those found by Amorim et al. (2004) and Orrico Júnior et al. (2010). These results reflect on the BD values, where the presence of bovine manure favors the high content of organic matter and, consequently, the production of biogas. The proportions studied presented BD values within the ideal range for biogas production, with the exception of the MoAD of SS 0.48 (ANDRIAMANOHIARISOAMANANA et al., 2016).

Chemical oxygen demand refers to the measurement of oxygen needed to oxidize degradable organic matter, fibrous materials, also indicating contamination in the sample under analysis (SORIA et al., 2001).

As reported for M, TS, and VTS, the proportion containing only BM showed higher values, and SS lower values of COD, confirming the results obtained regarding the biodegradability of organic matter for biogas production. However, both sewage sludge, and water served as dilution media for bovine manure, reducing the COD value, without showing significant differences between them (Table 2).

In all proportions analyzed, COD values similar to those reported by Assunção (2020) were observed, with the exception of 100:0 BM:SS. According to these authors, methane production in biogas decreased with different substrate dilutions, due to its direct influence on the initial concentration of COD and VTS.

Nitrogen is one of the nutrients that stand out because it provides energy to microorganisms. In sanitary sewage, nitrogen comes from protein and urea (LOPES, 2015). For all proportions studied, low total nitrogen content was observed, with the highest value obtained for MoAD 0:100 BM:SS (6.0 mg L-1). Monitoring nitrogen content is necessary because high values can be detrimental to AD. The formation of free ammonia (toxic > 150 mg L-1) was observed, presenting ease in penetrating the cell membrane of microorganisms, resulting in proton imbalance and potassium deficit, increasing intracellular pH and inhibiting enzymatic reactions (Lopes, 2015; Chernicharo, 2007). The presence of ideal quantities of nutrients, such as nitrogen, in anaerobic digestion systems is essential for the development of microorganisms (ASSUNÇÃO, 2020; CHERNICHARO, 2007).

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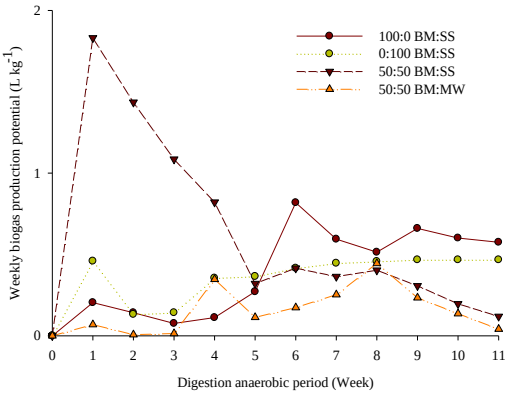
Weekly and accumulated biogas production potential

Analyzing Figure 1, it was observed, through the burning test, that in all proportions, gas production only occurred in the first weeks of anaerobic digestion. In the first week of anaerobic digestion, there was a peak in gas production, followed by a decrease for all proportions studied. The 50:50 BM:SS proportion presented the highest peak in biogas production, followed by an abrupt decrease until the 5th week (Figure 1).

Figure 1 - Weekly biogas production potential



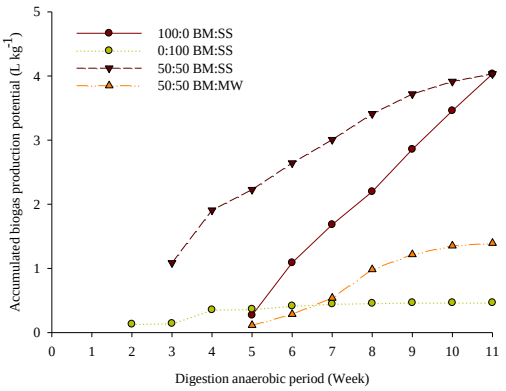
Silva et al. (2021) reported initial gas production when evaluating anaerobic codigestion between fish farming sludge and bovine manure, with methane production detected from the 3rd week for all ratios studied, except for the fish farming sludge MoAD. According to these authors, this behavior may occur because in the first few weeks there is a significant amount of oxygen facilitating the action of aerobic and facultative bacteria at the expense of methanogenic bacteria.

Checking whether there is actually only biogas production at the beginning of anaerobic digestion is extremely important in order to avoid erroneous results regarding the ratio with the greatest potential for biogas production.

Thus, the start-up time, i.e., the beginning of biogas production, varied according to the ratio under study. A longer start-up time (5th week of anaerobic digestion) was obtained with the proportion containing only bovine manure and diluted in

water. With sewage sludge as a substrate, biogas production was advanced by 3 weeks. The CoAD between bovine manure and sewage sludge (50:50 BM:SS) anticipated biogas production by 2 weeks of AD (Figure 2).

Figure 2 - Accumulated biogas production potential



Regarding the potential for biogas production, it was found that 100% sewage sludge (SS) was inferior to the other proportions despite the shorter start-up time (2 weeks of anaerobic digestion). The opposite was observed for the MoAD of bovine manure, in which, although the start of biogas production was delayed, the potential was high (Figure 2).

When comparing the effect of dilution, sewage sludge favored AD in terms of shorter start-up time and higher potential for biogas production by providing an additional load of organic and microbial matter. This behavior was verified in the results obtained for U, TS, VS, BD, and COD (Table 2).

Overall, it was found that substrates with higher organic matter contents, represented by high average values of TS, VTS, BD, and COD in the reactors' feed, i.e., the beginning of anaerobic digestion, were responsible for the best results in biogas production. On the other hand, dilution with water tended to decrease the potential for biogas production and increase the start-up time due to the reduction in the substrate's quality available to the system. Finally, it should be noted that replacing sewage sludge with potable water results in a sustainable activity that aligns with the circular economy principles. The same result was reported by Silva et al. (2021).

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CONCLUSION

Overall, it can be observed that the addition of sewage sludge and water made the substrate containing only bovine manure a more diluted system, altering its physicochemical properties. However, as sewage sludge, even though it is a very liquid substrate like water, contains a certain amount of stabilized organic matter and microbiological load, it has a higher potential for biogas production. Additionally, the use of sewage sludge in anaerobic digesters offers environmentally appropriate purposes compared to disposal in nature.

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