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Article

Qualitative Aspects of Biogas Production in a Small-Scale Biodigester by Anaerobic Digestion of Food Waste from University Environment

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ABSTRACT

Organic waste are materials that, in balanced natural environments, spontaneously degrade and recycle nutrients in nature's processes. The adoption of appropriate methods for the management of organic waste is essential for urban, peri-urban and rural development. The use of Small-scale biodigestion systems in urban areas and mainly in rural areas is a real alternative. Biogas is a renewable source of energy used as a substitute for natural gas and liquefied petroleum gas. From the anaerobic decomposition of different types of biomass and substrates, we have the metabolic product called biogas, a mixture of methane, carbon dioxide and small amounts of other gases such as hydrogen sulfide. The quality of the biogas generated has a direct effect on its use as an energy source, requiring a minimum fraction of CH_4 for its combustion and for other processes such as the transformation of the biogas generated into biofuel, its purification to remove the portions of other gases present its necessary. This work evaluated the quality of the biogas generated in a small-scale biodigester, based on the decomposition of food waste from the university environment. A mobile laboratory analyzed the composition of the biogas generated. The results showed that this substrate and its heterogeneity has enormous potential for generating biogas with excellent amounts of methane CH_4 composition minimum value was 58.46%, the maximum reached 68.41% and the average was 65.44%. Regarding the presence of CO_2 within the biogas evaluated, the minimum value of CO_2 was 38.02%; the maximum value was 44.39% and the average stayed in 38.55%. Hydrogen in the composition minimum value was 7.41 ppm, 13.42 ppm maximum and average of 9.63 ppm. H_2S minimum value obtained was 0.0 ppm, reaching the maximum value of 249.76 ppm, with average of 138.75 ppm.

Keywords: biogas; small-scale bioreactors; sustainability; domestic urban waste, renewable energy.

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RESUMO
Resíduos orgânicos são materiais que, em ambientes naturais equilibrados, degradam e reciclam nutrientes espontaneamente nos processos da natureza. A adoção de métodos adequados de gestão dos resíduos orgânicos é essencial para o desenvolvimento urbano, periurbano e rural. O uso de sistemas de biodigestão de pequena escala em áreas urbanas e principalmente em áreas rurais é uma alternativa real. O biogás é uma fonte renovável de energia usada como substituto do gás natural e do gás liquefeito de petróleo. Da decomposição anaeróbia de diferentes tipos de biomassa e substratos, temos o produto metabólico chamado biogás, uma mistura de metano, dióxido de carbono e pequenas quantidades de outros gases como o sulfeto de hidrogênio. A qualidade do biogás gerado tem efeito direto na sua utilização como fonte de energia, exigindo uma fração mínima de CH_4 para sua combustão e para outros processos como a transformação do biogás gerado em biocombustível, sua purificação para retirar as porções de outras gases é necessário. Este trabalho avaliou a qualidade do biogás gerado em um biodigestor de pequena escala, a partir da decomposição de resíduos orgânicos do ambiente universitário. Um laboratório móvel analisou a composição do biogás gerado. Os resultados mostraram que este substrato e sua heterogeneidade tem enorme potencial para geração de biogás, com excelentes quantidades de metano CH_4, o valor mínimo da composição foi 58,46%, o máximo atingiu 68,41% e a média foi de 65,44%. Em relação à presença de CO2 no biogás avaliado, o valor mínimo de CO2 foi de 38,02%; o valor máximo foi de 44,39% e a média ficou em 38,55%. O valor mínimo de hidrogênio na composição foi de 7,41 ppm, máximo de 13,42 ppm e média de 9,63 ppm. (Farhat et al. 2018). O valor mínimo de H2S obtido foi de 0,0 ppm, atingindo o valor máximo de 249,76 ppm, com média de 138,75 ppm.
Palavras-chave: biogás; biorreatores de pequena escala; sustentabilidade; resíduos sólidos domésticos; energia renovável.

Introduction

The great technological evolution has emerged with innumerable solutions to our society's problems, but at the same time, it has generated others, and for these, the sought of alternatives. We live in greater comfort, which demands more energy sources and ends up creating problems as the vast majority of the main sources of energy are not renewable and have a negative impact on the environment (C. L. . Silva et al. 2009)

From the anaerobic decomposition of different types of biomass and substrates, we have the metabolic product called biogas, a mixture of methane, carbon dioxide and small amounts of other gases such as hydrogen sulphide. Biogas is a renewable source of energy used as a substitute for natural gas and liquefied petroleum gas (Rajendran, Aslanzadeh, and Taherzadeh 2012)

As part of the natural and cyclical flow of nature's processes, biomass is a renewable resource, with the obtaining of solar energy through the process of photosynthesis that takes place inside the organelles called chloroplasts, present in plants, this energy accumulated in biomass around the world. Combustion is released as heat. In addition, the release of carbon dioxide occurs, which is again absorbed by plants, closing the carbon cycle (Odorico; Konrad et al. 2016).

It is possible to compare the energy level contained in the different forms of energy, either by boiling water test, controlled cooking test or performance test in the kitchen (VITA 1985). The energy contained in 1.0 m³ of purified biogas is equal to 1.1 L of gasoline, 1.7 L of bioethanol, or 0.97 m³ of natural gas (Martins das Neves, L.C.; Converti, A.; Vessoni Penna 2009)

The technological options for converting the energy contained in biomass are many and can occur with the release of energy directly in the form of heat or electricity, or done in another way such as liquid biofuel or biogas. Depending on the type of biomass, one or more technologies applied, according to the scheme presented in the Biomass Atlas of Rio Grande do Sul for the production of biogas and bio methane adapted from a 2005 publication by ANEEL (Odorico; Konrad et al. 2016).

The use of small-scale biodigestion systems applied in urban areas and mainly in rural areas, it is possible, economically viable and efficient. They can be the answer to the problems and needs of our society, as they improve the availability of energy and simultaneously generate protection for the soil, water, air and the environment, in addition to other benefits (Rajendran, Aslanzadeh, and Taherzadeh 2012).

The production of biogas in rural areas and the use of waste from urban areas is a global reality. One of the challenges for scientists and engineers is the construction of a model of biodigester that has a considerable useful life, using accessible and low-cost materials taking into account the economy of each location. We can have biogas production in 100mL reactors inside a laboratory, (Alves 2008), (C. D. O. Silva et al. 2020),(Wang et al. 2017),(Ali and Al-Sa'ed 2018) and 10,000m³ reactors as in many cities in Europe (Rajendran, Aslanzadeh, and Taherzadeh 2012), (Scarlat, Dallemand, and Fahl 2018), (Demaziere 2020).

The term biogas commonly used to refer to a gas produced from the biological breakdown of organic matter in the absence of oxygen. It is one of the products formed during anaerobic decomposition and consists of the vast majority of Methane (CH_4; 50-60%), carbon dioxide (CO_2; 50-40%), hydrogen sulphide (H_2S; <1%), hydrogen (H_2), water (H_2O) and small traces of other substances depending on the composition of the substrate (Ramatsa et al. 2014).

In order to produce biogas, organic matter ferments in the biodigester with the help of bacterial communities. Four fermentation stages occur simultaneously, move the organic material from its initial composition to the state of biogas

- The first stage of the digestion process is the hydrolysis stage. In the hydrolysis stage, insoluble organic polymers (such as carbohydrates) are broken down, making them accessible to the next stage of bacteria called acidogenic bacteria.
- Acidogenic bacteria convert sugars and amino acids into carbon dioxide, hydrogen, ammonia and organic acids.
- In the third stage, acetogenic bacteria convert organic acids into acetic acid, hydrogen, ammonia and carbon dioxide, allowing for the final stage - methanogenic.
- Methanogens convert these final components into methane and carbon dioxide - which can be used as renewable, flammable energy

The fundamental issue is that small-scale reactors help to transform waste on site, reducing costs of transporting waste to the landfill, waste segregation and biodigestion processes take place at the generating source and the entire chain benefits. Organic waste consists of animal or vegetable remains discarded from human activities. Its origin can be domestic or urban (food scraps and pruning), agricultural or industrial (residues from agribusiness, wood industry, slaughterhouses, food processing, etc.), basic sanitation (human waste or sludge from sewage treatment plants), among others. In the case of organic food waste, generated in the waste of all stages of handling food products, from production, through marketing, to consumption in restaurants and households (Roubík and Mazancová 2019).

This study expected to demonstrate the efficiency of an anaerobic biodigestion system in transforming organic waste from restaurants at the University of Vale do Taquari into biogas and evaluate its quality in order to reinforce the importance of decentralized waste treatment systems.

MATERIAL AND METHODS

The research started with the installation of the biodigester system, chosen as a prototype. Used bovine manure to activate the reactor, the supply and operation of the system based on the protocol provided by the company that developed the biodigester. Organic wastes are still under explored substrates, but with a high potential for biogas generation (Lansing et al. 2010).

The first step was the biodigester installation. Instead of developing a new model of reactor, the objective of this study was to evaluate the performance of a commercial worldwide used bioreactor. After some research the Homebiogas (small-scale biodigester) system was selected because its facility to be set up, easy management and operation. (Figure 1). After the system placed on a flat surface and the digestion chamber filled with water. Plastic parts were fixed in the biodigester with the aid of petroleum jelly, metal clamps and a screwdriver. With a hose, the digestion chamber filled with water until its support capacity. After the digestion chamber was installed the organic waste inlet structure and the biogas and liquid effluent outlet structure, the biogas reservoir was installed on the set.

The use of bovine manure to activate the reactor is recommended because it is a traditional substrate for the production of biogas, is already digested and has rates above 50% of methane (Xavier and Nand 1990). To activate the system, 100 liters of fresh bovine manure was used, mixed with water in buckets to create a consistent paste. With the digester tank almost complete with water, the waste inlet plunger removed for filling the equipment.

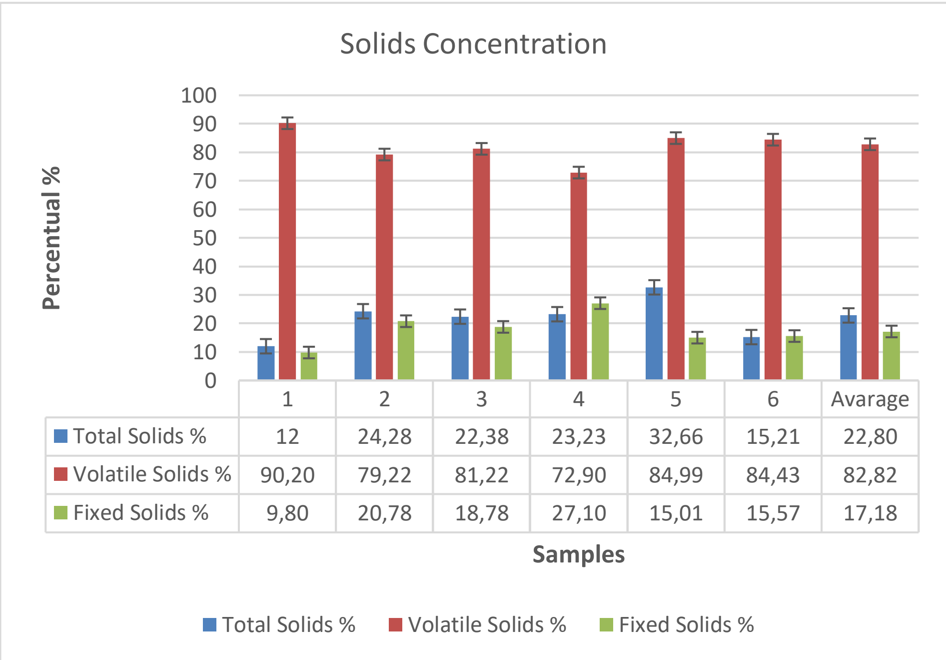
After the initial activation with animal manure, the system was not fed with leftover food to avoid an imbalance inside the reactor, where the bacteria present in the cattle manure are reproducing and fixing. Gas production can occur within 1 to 4 weeks. This time of activation and initial production of biogas varies according to the temperature, quality of the manure used. For first use, the gas valve on the stove is opened to allow air in the pipes to escape before igniting the gas.

When the first flame occurred, the system fed with organic waste started. From the biogas collections generated, the evaluations and analyzes were made at the Research Center for Sustainable Energy and Technologies (CPETS / TECNOVATES) - University of Vale do Taquari - For reading CH_4, CO_2, H_2, O_2, N_2 and H_2S, data collected in a mobile laboratory, which was received by CPETS from a German company called Awite, capable of measuring data in real time.

Organic waste from Univates restaurants (Figure 2) was weighed and characterized, for the 6 samples analyzed of Total Solids (ST), volatile solids (SV) and fixed solids (SF). During the period of 27 days, the system received 44 kilograms of food waste, the total amount of 4 kilos per day, respecting the days of Monday, Wednesday and Friday, in the total of eleven day of alimentation.

RESULTS AND DISCUSSION

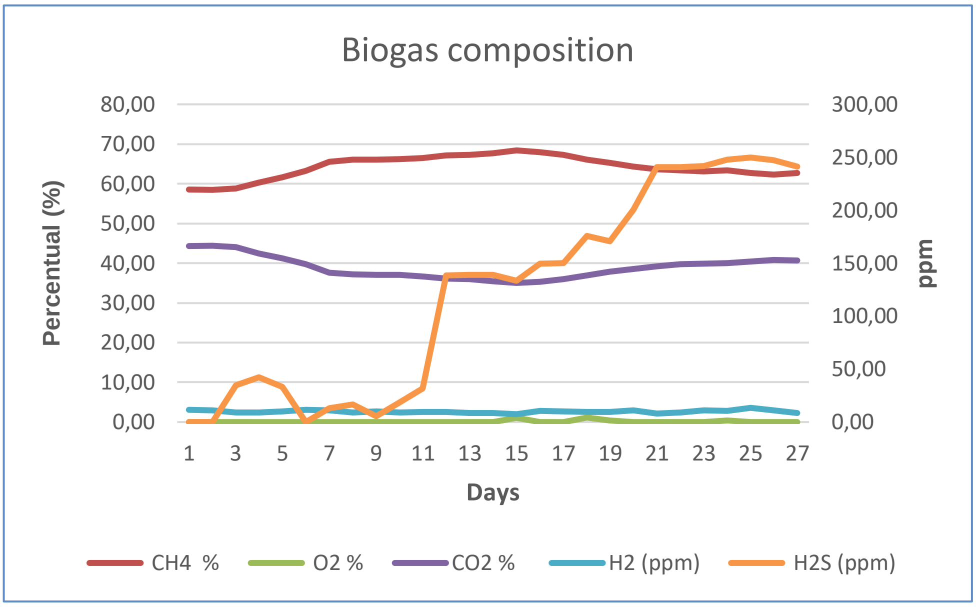
The analysis of concentration of total solids, volatile solids and fixed solids are very important for the estimation of the biogas production of the evaluated substrates. Knowing the mass of volatile solids of the substrate placed in the system, it is possible to estimate the volume of biogas that should be produced by this mass inside the biodigester. According to the graphic 1, the average total solids was 22.81%, the average concentration of volatile solids in organic waste was 82.82%, and fixed solids was in the range of 17.17%. The maximum measured value of volatile solids reached 90.19% in sample 1. This high biodegradable potential is due to the high volatile organic fraction. This high biodegradable potential is due to the high volatile organic fraction (De Oliveira and Negro 2019)



Graphic 1 - Solids concentration

It should be noted that the composition of biogas is not exclusively methane, a gas with high combustion and flammability; it is composed of other gases such as hydrogen sulfide (H_2S), which has characteristics of corrosivity and toxicity, ammonia (NH_3), hydrogen (H_2) and carbon dioxide (CO_2) (Kunz 2019).

The evaluation took place over 27 days, and the data obtained from the evaluations of the mobile laboratory are shown in Graphic 2. The concentrations of CH_4 (%), CO_2 (%), O_2 (%), H_2 (ppm) and H_2S (ppm) varied during the 11-day feeding period with 4 kilograms of organic waste from the university environment.



Graphic 2 - Biogas composition

The methane CH_4 composition minimum value was 58.46%, the maximum reached 68.41% and the average was 65.44%. Regarding the presence of CO_2 within the biogas evaluated, which is inversely proportional of the presence of CH_4 (Odorico Konrad et al. 2016). The minimum value of CO_2 was 38.02%; the maximum value was 44.39% and the average stayed in 38.55%. Hydrogen in the composition minimum value was 7.41 ppm, 13.42 ppm maximum and average of 9.63 ppm. Hydrogen can be measured in ppm or percentage, in a study that evaluated anaerobic co-digestion and used the raw material composed of fruit and vegetable residues, activated sludge, olive mill wastewater, and cattle manure obtained 8% H_2, 28.5% CO_2 and 63.5% CH_4 (Farhat et al. 2018). H_2S minimum value obtained was 0.0 ppm, reaching the maximum value of 249.76 ppm, with average of 138.75 ppm.

An important detail with the data measurements by the mobile laboratory was the finding of an increase in the amounts of H_2S in the composition of the biogas generated, reaching 249 ppm. The system uses an activated carbon filter for the removal of hydrogen sulfide (H_2S), which is characterized by removal by the adsorption process, and which is usually extremely efficient in reducing H_2S (<5 ppm). But when saturation and loss of adsorption efficiency is reached, it is necessary to change the activated carbon (Kunz 2019)

The focus issue when it comes to the quality of biogas is related to the amount of methane (CH_4) present in its composition. The use of small-scale systems for anaerobic biodigestion, for the transformation of organic waste and generation of biogas for domestic use, for certain families in different locations around the world. They stop burning wood or coal as they primary source of energy, especially for cooking food, reducing exposure to harmful gases such as carbon dioxide is very beneficial (Roubík and Mazancová 2019).

(Odorico Konrad et al. 2016) made the characterization of CH_4, CO_2, H_2S and O_2 in two reactors, R1 and R2, for a period of three months, with the anaerobic digestion of the mixture of liquid waste coming from different industrial processes and poultry manure. The results showed an average of H_2S concentration of 156.01 for R1, and of 91.64 ppm for R2, and the CH_4: CO_2 inverse relationship of 3.15 for R1 and 2.98 for R2, respectively during the monitoring period. The percentage of CH_4 and CO_2 in R1 was of 75.76 and 24%; in R2 this percentage was of 74.64 and 25.07%, numbers that shows how much more CH_4 content is in the biogas composition, the less CO_2 we will have. In addition, if we have high percentage of CO_2 we will have less CH_4 with this inverse relationship applied.

Studies such as the one made by (C. D. O. Silva et al. 2020) obtained values of production of Biogas and Methane from the anaerobic decomposition of domestic organic solid waste, that corroborated the ease of this material and its easy assimilation by the microorganisms involved in the process of anaerobic digestion, because they have a high energy potential. The efficiency of methane generation in the study by Silva et al. 2009, was similar to this study (CH_4 average of 65,44%), reaching an average of 60% methane with a maximum percentage of 75%, this value shows that the domestic organic solid waste has a satisfactory energy potential for energy use.

CONCLUSION

Small-scale systems for anaerobic biodigestion are an excellent tool and alternative for biological treatment of organic waste. The present study can evaluate in practice the efficiency of a biodigester in the transformation of organic matter into biogas.

Organic waste is an excellent substrate for the generation of biogas, and precisely because it is most of the waste generated daily by people, companies, industries, society in general, it must have a better destination than landfills, generating value and transformed into clean and renewable energy.

The quality aspects of the methane concentration shown to be reliable and efficient for different uses by biodegrading organic waste, in present study reach the medium value of 65.44%. About the H_2S was possible to corroborate the importance of the gas filtration for elimination of this particular amount, and the need to change activated carbon or the entire filter between six months and one year of system operation.

In addition, some other substrates can be tried in co-digestion with organic waste for upgrading the biogas production. One possible example is used cooking oil, which is a substrate with high volatile solids and great potential anaerobic digestion. Some other possible substrate to de used are farinaceous and other carbohydrates.

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Figure 1. Homebiogas, small- scale biodigester.

Figure 2. Organic waste from the University restaurant.