Development of a Biodigestor Prototype for the Treatment of Organic Waste and Biogas Production

Tays Amaral Costa[#1], Zarur Oliveira Silvano[#2], Ricardo Guimarães Andrade[#3]
[#1] *Industrial Engineering Student, Faculdades Integradas de Cataguases - FIC/UNIS, Cataguases/MG, Brazil.*
[#2] *Professor, Faculdades Integradas de Cataguases - FIC/UNIS, Cataguases/MG, Brazil.*
[#3] *Researcher, Empresa Brasileira de Pesquisa Agropecuária - EMBRAPA, Juiz de Fora/MG, Brazil.*

Abstract

Currently, sustainable waste management is fundamental in terms of efforts to reduce greenhouse gas emissions and, consequently, to mitigate global climate change. Proper treatment and disposal of organic waste and the production of biogas may be viable through an anaerobic biodigestion process. The present study aimed at the development of a low cost biodigestor prototype and, on an experimental basis, to demonstrate biogas production using organic residues inoculated with swine manure. The biodigestor system was structured according to the specifications described in the methodology. The production of biogas occurred, however, due to the short experimental period, it was not possible to quantify it. The pressure gauge was not sensitive enough to detect low pressure variations. In general, it is concluded that the biodigester has the potential to be used both as a sustainable alternative in the treatment of organic residues produced daily in Brazilian households and in the production of biogas and, thus, contribute to soften the generation of environmental liabilities.

Key words*:* *Biodigester, organic waste, biogas.*

I. INTRODUCTION

The increase in demand for fossil fuels coupled with the energy crisis triggered a search for new energy alternatives to replace or supplement the energy sources generated through non-renewable resources. This factor together with the aggravating of the increasing volumes of solid waste generated daily in the various human activities contributes to the development of alternative and viable technical solutions for the disposal and treatment of solid waste such as the use of biodigesters.

Organic wastes (food waste and other materials that degrade rapidly in nature) account for half of the solid urban waste generated in Brazil, in which case the treatment and correct disposal of these wastes is essential in order to minimize possible impacts on the environment [1]. The biodigester is the place where the organic matter decomposes, in the absence of oxygen, with biogas being one of the possible products. During the reduction of the organic load present in a waste, there is the minimization of the polluting power and sanitary risks of these wastes and at the same time, the biogas is a byproduct, which can be converted into thermal or electrical energy [2]. In addition, there is also the production of biofertilizer that can be used as fertilizer.

In view of the above, the present study aimed at the development of a low cost biodigestor prototype for organic waste treatment and biogas production.

II. LITERATURE REVISION

A. Waste

The intensification of human activities in recent decades has led to an accelerated increase in waste production, becoming a problem for public management in the sustainability process related to waste management actions and their correct final disposition [3].

This concern has led to laws that seek the orderly management of these wastes, such as Federal Law No. 12305/2010, which stipulates the National Policy on Solid Waste [4], which aims at the disposal and disposal of the environmentally appropriate waste. The National Policy on Solid Waste, in its art. 3, item XVI defines solid waste as being: “Material, substance, object or well-disposed resultant from human activities in society, whose final destination is proceeding, is proposed to proceed or is obliged to proceed in the solid or semisolid states, as well as gases contained in containers and liquids whose peculiarities make the its launch in the public sewage system or in water bodies, or require technically or economically unviable solutions in the face of the best available technology [5]”.

According to recent research [6], the generation of urban solid waste in Brazil reached 78.3 million tons. Of this amount, 58.4% were sent to landfills. Meanwhile, 41.6% were sent to dumps or controlled landfills, which do not have the necessary set of systems and measures against damage and degradation to the environment.

Organic waste accounts for half of the urban solid waste generated in Brazil. In this case, the correct treatment and disposal can be made possible with the use of biodigesters, where the organic residues undergo an anaerobic biodigestion process inside the biodigester.

B. Anaerobic Digestion

Anaerobic digestion is the treatment process that occurs in the absence of oxygen and in multiple stages, in which the microorganisms degrade the organic material and produce biogas, composed in its greater proportion by methane ($CH4$) and carbon dioxide ($CO2$) [7].

Anaerobic digestion is composed of the acidic and methanogenic phases. The acid anaerobic phase can be subdivided, in terms of microbial activity, into hydrolysis, acidogenesis and acetogenesis. Bacteria are not able to assimilate particulate organic matter, and then hydrolysis of complex particulates (polymers) occurs in materials of smaller molecules that can pass through the cell walls of bacteria [8].

In the following phase (acidogenesis) the soluble products generated by the hydrolysis are metabolized inside the fermentative bacteria cells and transformed into simpler compounds: volatile fatty acids, alcohols, lactic acid, carbonic gas, hydrogen, ammonia and hydrogen sulfide [7]. The acetogenic bacteria are responsible for the oxidation of the products generated in the acidogenic phase in a suitable substrate for the methanogenic bacteria.

The products generated by the acetogenic bacteria are hydrogen, carbon dioxide and acetic acid [8]. Of all the products metabolized by acidogenic bacteria, only hydrogen and acetate can be used directly by the methanogenic bacteria [7]. The final step in the anaerobic degradation process is methanogenic, where bacteria use a limited number of substrates [8]. The organic compounds are ultimately degraded into methane and carbon dioxide. However, the process of anaerobic digestion, suffers interference from environmental factors [9]. In this way, it is necessary to control them so that the microorganisms involved in this process are not harmed, ensuring a smooth operation of the system.

Among the factors that influence anaerobic digestion, the following stand out: temperature, hydrogenation potential (ph), particle size, nutrients, hydrodynamics and type of substrate [10]. The ideal range for the production of biogas is between 35 and 45 ° C, and it may also be possible to produce in a range of 50 to 60 ° C [11]. Most importantly, there is no sudden change in temperature for bacteria to survive. Another important point to be observed concerns the pH range that would be ideal for the good performance of anaerobic digestion processes, in this case, ideal pH around 7 is recommended [12].

The process of anaerobic biodigestion of organic solid waste can be optimized and accelerated through the use of methods that contribute to a rapid and balanced initiation of the process, such as the use of appropriate inocula [13].

Biodigestion with inoculum substantially improves the profitability of biogas production [14]. The inoculum used in this work was pig manure, which according to the same author, are rich in anaerobic microorganisms capable of accelerating biofertilization time.

C. Biodigesters

An anaerobic biodigestor is defined as the medium where the process of degradation, transformation or decomposition of organic matter occurs in the absence of oxygen, having as biogas product [7]. For this to occur it is necessary the joint action of several microorganisms, which may require high detention times, so that the added matter is decomposed.

In addition to the production of biogas, the decomposition of organic matter produces biofertilizer [15]. It should be noted that the calorific value of biogas, with a percentage of about 70% of methane, is approximately 23,380 kJ/m³, or 6.5 kW/m³, while for comparative purposes natural gas has a calorimeter of 37,300 kJ/m³, or 10.4 kW/m³ [16].

The use of the biodigestor promotes a valorization of energy sources that are ecologically correct or less impacting to the environment, because it uses the existing biomass as a way to replace the liquefied petroleum gas by the biogas [17].

The biodigestor is composed of a reservoir that stores the biomass for a period, and a chamber (gasometer) that stores the biogas produced [15]. The biogas is retained in the free part of the biodigester and in sequence can be piped for use in various applications, such as heating, cooling, or the generation of electric energy.

In the continuous biodigester, the container receives refills of organic matter during the biogas production, simultaneously with the withdrawal of the biofertilizer. On the other hand, the discontinuous or batch biodigestor is a simple system with a low operational requirement [17]. It is loaded at one time, and kept closed for a suitable time interval, where the organic matter is fermented and subsequently discharged [18]. In the case of the present study, the model used was the "discontinuous biodigestor".

III. METHODOLOGY

Regarding the approach, the present work fits as quantitative research; as to its nature, is characterized as applied research. As for the objectives, the work can be classified as explanatory research. In relation to the procedures, it is included as a bibliographical and experimental research [19].

The methodology used initially consisted in the collection and reading of bibliographic material published in the study area, such as chapters of books, theses and papers. These are available on search engines such as Google Scholar and other digital databases such as Scielo (http://www.scielo.org/php/index.php).

The elaboration of the study was conducted in an explanatory manner and based on the elements necessary to understand the processes related to anaerobic biodigestion and consequent biogas production.

On June 9, 2018, experimental implementation was started with the assembly, construction and operation plan of the biodigestor prototype. For the assembly of the system, materials of easy acquisition and low cost were used. Measurements and quantities are shown in Table 1.

It is also worth noting that a SALCAS manometer, model EN 837-1, was installed in the system for possible internal pressure reading, which would indicate the production of biogas generated, evidencing quantitative research.

A. Materials

A prototype can be defined as a model constructed from specifications created to simulate the appearance and functionality of a product or service being developed [20]. Table 1 lists the materials used to assemble the prototype and their respective prices.

Table 1 – Materials used in the construction of the biodigestor prototype

Materials	Amount	US Dollar ($)
50 liter capacity plastic drum	1	Recycled
Weldable adapter with flange (50 mm diameter)	2	6,60
Weldable adapter (50 mm diameter)	1	1,02
Weldable PVC pipe (50 mm diameter)	4x (50; 10; 5; 5 cm)	Recycled
Weldable PVC Cap (50mm diameter)	1	1,79
Ball Valve (50 mm diameter)	1	2,79
*Weldable adapter with flange (*½ inches diameter)	1	2,17
*Weldable PVC pipe (*½ inches diameter)	2x (3; 2 cm)	Recycled
*Ball Valve (*½ inches diameter)	1	1,66
*PVC Pipes Elbow (*½ inches diameter)	1	0,12
PVC Pipes Elbow (50 mm diameter)	2	0,25
Weldable threaded sleeve (50mm diameter)	1	0,26
Pressure gauge	1	Recycled
Adhesive for pipes and PVC connections	1	1,18
Matte black spray paint (Tek Bond brand)	1	3,45
*PVC spigot (*½ inches diameter)	1	2,53
*Straight hose connector (*½ inches diameter)	4	2,05
*Gas Hose (*¼ inches diameter)	1x 4 m	2,00
Glass container with a capacity of 3 liters	1	Recycled
PVC welded pipe fitted with 2 plugs (50mm diameter)	1x 30 cm	Recycled
Truck Tire Tube	1	Recycled
PVC Spigot Tee	1	1,76
Acetic Silicone Sealant (Tek Bond brand)	1	4,32
Adhesive gutter seal (Tek Bond brand)	1	4,35
	Total cost ($) =	38,30

B. Methods

For the construction of the prototype of the biodigester, a 50 liter plastic drum was used as a storage container for the reagents and anaerobic fermentation products. The first step in the assembly process was to drill a 50 mm diameter hole in the drum cover with the aid of a drill with a coupled saw, this would be the point for feeding the system with organic waste.

In this hole were coupled: a PVC tube 50 mm in diameter and 50 cm in length, a 50 mm diameter plug, a 50 mm diameter flange, a weldable PVC adapter, a PVC tube with 50 mm diameter and 70 cm in length. All tubes were glued at both ends and then applied Tek Bond transparent acetic silicone to prevent possible gas leaks at the junction of the hole with the tube.

The second stage was based on the assembly of the biogas extraction system. A 20 mm diameter hole was made in the drum cover. In this hole were coupled: a flange ½ inch in diameter, a PVC pipe ½ inch in diameter and 3 cm in length, a ball valve with ½ inch diameter, a PVC pipe with 2 cm length, a 90 degree elbow and ½ inch diameter. In this elbow were adapted a weldable mitt and a PVC spigot with ½ inch in diameter; a conduction hose for ¼-inch diameter biogas and 4 m long. This hose was divided into four parts with 1 m length each. A part (1 m) of this hose drove the biogas to a filter constructed of 10 cm PVC pipe, where the ends were sealed with two buffers (one on each side) of 50 mm in diameter. For connection of the hose in this tube, a hole was made at each end where a straight hose connector was fitted (one on each side). Inside this tube contained three steel sponges used as one of the steps of filtering of the gas produced. Subsequently, through a hose the biogas was led to a glass container with a capacity of 3 liters. A hole was made in the lid of the glass container and a straight hose connector was adapted so that the hose would lead the biogas to the bottom of the container and thus ensure that the gas was filtered in water solution with caustic soda. The solution for gas filtration consisted of two tablespoons of caustic soda in 800 ml of water. After filtration, another straight hose connector was adapted to conduct the filtered biogas to be stored or consumed. The filters are responsible for retaining part of the hydrogen sulphide (H_2S) present in the biogas, removing the unpleasant odor [21]. The third part of the hose (1 m) led the filtered biogas to be stored in a truck tire tube passing from a tee spigot to a hose. The fourth part of the hose (1 m) was responsible for the passage of the biogas to the end point where a flame lighter was installed to attempt to burn the biogas.

The third step consisted in drilling a 50 mm diameter hole in the lower side of the drum for the purpose of installing the materials needed to extract the biofertilizer. In this hole were coupled: a flange with 50 mm diameter, a PVC tube with 50 mm in diameter and 5 cm in length, a ball valve with 50 mm in diameter, a PVC tube with 10 cm in length. In this tube, a 90 degree elbow with 50 mm diameter was adapted, followed by a weldable PVC tube 10 cm long and 50 mm in diameter and another elbow with the same measurements as the previous one. This process was necessary to ensure that the gases produced remained trapped in the upper part of the drum during the process of draining or withdrawing part of the biofertilizer produced.

The fourth step consisted of a hole where a pressure gauge was installed to measure the pressure of the gas generated in the system. The drum where the anaerobic biodigestion occurred was painted externally with matte black spray paint to aid in the increase of internal temperature and facilitate the fermentation process by the bacteria.

The drum of the biodigester system was loaded with the mixture of food waste, swine manure and water, with a ratio of eleven liters of water, three kilograms of manure and sixteen liters of food waste. The biodigester was properly sealed and the organic residues remained inside the drum for a period of forty-seven days. The experiment was conducted in the district of Ribeiro Junqueira, belonging to the municipality of Leopoldina, State of Minas Gerais, Brazil. According to the climatic classification of Köppen, the region has warm tropical rainy climate, with average air temperature records of the coldest month above 18 ºC. The average annual air temperature is 22.6 °C and the annual average precipitation is 1226.3 mm, with the months of July and December, respectively, being those with the lowest (13.8 mm) and higher (272.2 mm) rainfall indices [22].

IV. RESULTS AND DISCUSSION

Figure 1 shows the entire biodigester prototype system that was developed. It is noted that the treated organic waste is extracted from the 50 mm diameter barrel installed in the lower part of the drum. On the other hand, the gas that is produced is stored in the upper part of the drum and can follow the path to be extracted when passing through two filtration points, the first in the container with steel sponge and the second with water and soda solution caustic After filtration, it can be stored (truck tire air chamber) or proceed directly to firing.

The feeding of the system with the organic residue was begun in August 2018, according to the description of the mixture of organic residues presented in the methodology. Generally, biogas production can only be observed after at least 20 to 30 days of anaerobic fermentation [23]. However, even after this period there was no biogas production, that is, the valve was opened and the air chamber was not filled with gas. In this case, some of the justifications could be related to some leakage of biogas in the system or related to the non-generation of biogas due to problems in the mixing of organic residues stored in the drum. These issues were assessed and it was identified that there were leaks in the drum lid, more precisely at the junction of the hole in the lid with the barrel that is responsible for extracting the biogas from inside the drum. In addition, it was observed that the lid of the glass container containing caustic soda solution and water was not well sealed and was also repaired with the use "adhesive gutter seal" product.

After the leakage containment repairs, in the third week of September 2018, a new waste load was added to the biodigestion system. For the new waste load, the bovine wastes (feces) were replaced by swine manure. This replacement is mainly due to the identification, according to literature, of greater biogas production capacity. However, the proportions of eleven liters of water, three kilograms of manure and sixteen liters of food waste were maintained.

Figure 1 – Built prototype

To calculate the daily production of biogas, it is assumed that 1 kg of waste would be able to generate 0.1 m³ of biogas [13]. Therefore, for 16 kg of organic waste added, 1.6 m³ of biogas per day would be produced. Considering that, in order to boost the biodigestion process, 3 kg of pig manure were added, according to Colatto and Langer [13], for each 1 kg of dry swine manure, 0.35 m³ of biogas would be generated. Thus, for 3 kg of pig slurry added, theoretically, 1.05 m^3 per day would be generated.

According to information provided by the company "BGS equipamentos para biogás", a double burner biogas stove has a consumption rate of 0.45 m^3/h of biogas per burner. With the estimated theoretical volume of 2.65 m^3 of biogas produced daily, it would be possible to keep the flame of a burner burning for 6 hours per day.

One cubic meter of biogas is energetically equivalent to 0.396 liters of Liquefied Petroleum Gas - LPG [25]. As the theoretical capacity of daily biogas production is 2.65 m^3, the equivalent of 1.05 liters of LPG can be generated.

Due to the short experimental period, internal pressure was not sufficient for reading in the manometer, however, it was verified that the anaerobic fermentation process was established, because when opening the valve of the part of the system related to the extraction of the biogas, it was possible to notice the presence or biogas generation by means of a flame test (Figure 2).

Figure 2 – Flame test

V. CONCLUSION

From what was exposed and discussed in the course of this work, one can conclude that biogas production occurred, but it was not possible to quantify it. The pressure gauge was not sensitive enough to detect low pressure variations. From the proposed objectives, success was achieved in the system construction, biogas formation and biofertilizer production stages.

The processing of organic solid wastes through anaerobic digestion in biodigestors is a viable alternative for the disposal of organic residues produced daily in Brazilian households. The citizen, when choosing to carry out the treatment of the residues, can produce renewable energy for own consumption and contribute with the environment by mitigating the generation of environmental liabilities. In addition, the ease and the low cost of construction of the biodigestor are emphasized.

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