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Dimensioning of Artisanal Biodigester for Food Cooking at the Humberto Hernandez Cooperative

Dimensionamiento de biodigestor artesanal para la cocción de alimentos en la Cooperativa Humberto Hernández

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ABSTRACT: This research focused on the design of a homemade biodigester, taking into account the local availability of the required materials and the energy potential of the system once installed at the "Humberto Hernández" Agricultural Production Cooperative, located in the municipality of Güines, Mayabeque province, Cuba. To this end, the existing animal species were identified, as these would provide the organic waste for the biodigester. The number of animals was also determined, considering herd movement, which would allow for the calculation of the daily biomass generated. This information was used to establish the appropriate biodigester size and understand the behavior of the energy parameters. Among the main results obtained, a homemade biodigester (12 m3) suitable for the farm under study was designed, considering the potential number of animals, herd movement based on the farm's layout, and the amount of daily biomass generated. It is demonstrated that the installation of the proposed technology contributes to energy savings and the conservation and preservation of the environment, and that the materials required for the construction of the installation are locally available, an aspect that does not limit the execution of the engineering project.
Keywords: renewable energy, biogas production, anaerobic digestion, energy feasibility, environmental impact.

RESUMEN: Esta investigación se orientó a la proyección de un biodigestor artesanal, teniendo en cuenta la disponibilidad local de los materiales requeridos y el potencial energético a obtener del sistema, una vez instalado en la Cooperativa de Producción Agropecuaria "Humberto Hernández", ubicada en el municipio Güines, provincia Mayabeque, Cuba. Para ello se determinan las especies animales existentes en el escenario, dado que estos aportarán los residuos orgánicos hacia el biodigestor, también se determina la cantidad de animales, considerándose el movimiento de rebaño, lo cual posibilitaría determinar la biomasa generada diariamente con el propósito de establecer el dimensionamiento de la tecnología de biodigestor adecuada y conocer el comportamiento de los parámetros energéticos. Entre los principales resultados obtenidos, se realizó el diseño de un biodigestor artesanal (12 m^3) adecuado para la granja objeto de estudio, considerándose para ello la cantidad potencial de animales a establecer en la misma, así como el movimiento de rebaño concebido por la dirección del área y la cantidad de biomasa diaria generada; se demuestra que con la instalación de la tecnología propuesta se contribuye al ahorro energético y a la conservación y preservación del medioambiente y que los materiales requeridos para la construcción de la instalación se encuentran localmente disponibles, aspecto que no limita la ejecución del proyecto de ingeniería.
Palabras clave: energía renovable, producción de biogás, digestión anaerobia, factibilidad energética, impacto ambiental.

INTRODUCTION

Biodigestion technology is the leading anthropogenic technology in the biotechnological process of anaerobic digestion of biomass to obtain biogas. This technology consists of a sealed reactor with a side inlet for organic matter, an outlet at the top through which the biogas flows, and an outlet for obtaining effluents with biofertilizer properties. Both products contribute to meeting the needs of producers and promoting organic agriculture as an economically viable and ecologically sustainable alternative (Zheng *et al.*, 2012; Cortez & Serrano, 2023).

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Anaerobic digestion is a good alternative for treating waste with high levels of biodegradable organic matter (Flotats, 2001; Sosa, 2017). Therefore, this treatment is suitable for agro-industrial wastewater with a high load of biodegradable organic matter: effluents from sugar, alcohol, meat, paper, canning, and distillery production (Rahayu, *et al.*, 2015; Suárez *et al.*, 2018); agricultural waste, such as slurry and manure Bansal *et al.*, (2017); and municipal solid waste, including both the organic fraction of solid waste Biogas Association (2016) and sewage sludge (Frankiewicz, 2015).

In the current context, one of the most feasible ways to prevent increasing environmental pollution is the search for and development of new energy sources (Guardado, 2006). The only way to ensure a secure energy future is to find an environmentally sustainable way to produce and use energy (Priddle, 1998). It is essential to take advantage of renewable energy sources. This implies better use of local resources and the application of appropriate technologies that contribute to saving conventional fuel, returning nutrients to the soil, and preserving the environment (Santos *et al.*, 2011).

To these aspects, we must add the high prices of fuels and the high local electricity rates, factors to consider for the introduction of biodigesters or biogas plants that produce energy from agricultural waste (Parra *et al.*, 2019).

The functioning of biodigestion technology will depend largely on the type and quality of the biomass, a term that refers to all organic matter generated from photosynthesis or produced by the food chain. And as raw material for recycling processes: it originates from freshly expelled feces and urine (animal excrement), which are made up of the leftover digested food not used by the organism, plus waste such as bedding, food scraps, or other added material (Grundey, 1982).

Based on the criteria described above, the "Humberto Hernández" Agricultural Production Cooperative (APC), located in Güines, Mayabeque Province, Cuba, required the design of a homemade biodigester to produce biogas for cooking and to obtain biofertilizers. Therefore, the objective of this research was to determine the dimensions and energy potential of using this technology in that production system.

MATERIALS AND METHODS

Scenario Characterization

The "Humberto Hernández" Agricultural Production Cooperative (APC) is located in the municipality of Güines, Mayabeque province, Cuba, and has a total area of 1,030 hectares. These lands are dedicated to sugarcane production, various crops (grains, root vegetables, greens, and fruit), and include grazing areas and other areas designated for forage production. This cooperative also develops livestock production: pigs, cattle, sheep and goats, poultry, and rabbits.

This APC, situated on a plain with unique morphological and morphometric characteristics, has a gentle slope and karst influence, with an elevation ranging from 5 to 31 meters above sea level.

The predominant soils in this APC are Brown soils with carbonates (41.5%), Red Rendzinas (25.1%), and, to a lesser extent, Vertisols and Alluvial soils. The first two occupy 66.6% of the cultivated sugarcane soils in the cooperative, being present in the highest areas with slopes reaching 2 to 3% and the most extensive plains of the entity. (According to the soil map (1/25000).

Vertisols are located to the south and east of the APC. The existing subtypes are typical and therefore soils with poor drainage, occupying a total of 18.37%. Alluvial soils occupy the smallest area (15.03%), and their subtypes are typical and differentiated. They are located to the west of the APC and on the banks of the straightened Mayabeque River, which borders the APC from north to south, and to a lesser extent on the banks of waterways that feed into or branch off from the Mayabeque, such as the Agua Emulos River and the Zanja Amarilla (Hernández *et al.*, 2019).

For the design of the biodigestion technology to process the workers' food and obtain effluent from the system for agricultural work, a study was conducted of the materials and resources available at the APC itself, as well as the demand for Biogas for the intended purpose: Based on these elements, a biogas technology proposal was developed that would be most feasible according to the entity's conditions and budget.

Methodology for Biodigester Sizing

To calculate the design parameters of a homemade biodigester, it is necessary to know the input data and the parameters that must be determined (Table 1).

The daily amount of material (Bmd) is directly related to the amount of biomass generated, whether domestic, agricultural, or animal waste. In addition, the maximum yield and production increase plans must be taken into account.

The amount of daily biomass generated (Bmd) is determined through the following expression:

$$Bm_d = Ca \times Ce \times Rp \quad \times Rt, \quad kg. \quad dia^{-1} \qquad (1)$$

here: Ca- Number of animals; Ce- Amount of excreta per animal, kg/day; Rp- Ratio between the average live weight of the animal population and the tabulated equivalent live weight; Rt- Fraction between the time of stabling with respect to the duration of the day, h/day.

$$Bm_d = Ca \times Ce \times \left(\frac{PVp}{PVe}\right) \times \left(\frac{Te}{24h}\right), \quad kg.dia^{-1} \qquad (2)$$

Where: PVp-Average live weight of the animal population, kg; PVe- Tabulated live weight equivalent; Te-Hours of the day that the animal remains stabled, h/day

Table 1. Input and output data required for the design of a homemade anaerobic biodigester

Parameters	Unit
Input data	
Daily biomass generation (Bmd)	kg day^{-1}
Excreta-water ratio (N)	L kg^{-1}
Biogas yield (Y)	m^3 kg^{-1}
Hydraulic retention time (HRT)	día
Output data	
Daily volume of material (manure and water mixture) (Vdm)	kg day^{-1}
Volume of the biodigester, (Vbiodig)	m^3
Volume of the fermentation chamber, (Vcf)	m^3
Volume of the cylinder, (V1)	m^3
Volume of the biogas containment (V_2)	m^3
Volume of the compensation tank (Vtc)	m^3

The daily volume of material (manure and water mixture) (Vdm), is nothing more than the sum of the residual and the dilution of the biomass (residual and water).

$$\mathrm{Vdm} = (1+N)\cdot Bmd, \quad m^3 . dia^{-1} \tag{3}$$

Where: N: Excreta-water ratio, L/kg. It is required to know that the density of water is 1000 kg/m³.

Meanwhile, the biodigester volume (Vbiodig) is calculated taking into account the volume of material (manure and water mixture) Vdm entering the biodigester and the retention time (TRH).

$$V_{biodig} = \mathrm{Vdm}\cdot TRH, m^3 \tag{4}$$

Once the biodigester volume is predetermined, the design volume is calculated, with two possible scenarios:

- Treating all the waste and obtaining the resulting byproducts.
- Treating only the portion of the waste that guarantees the required energy.

The fundamental expressions used for sizing a homemade biodigester (characterized by its three main parts: anaerobic fermentation chamber, biogas containment chamber, and compensation chamber (effluent outlet)) are presented below.

The steps to follow for their use are:

- The total volume of the biodigester (V_biodig) is calculated based on the volume of the water-manure mixture and the retention time, as shown in equation 4.
- Subsequently, the daily volume of biogas (G) produced is calculated:

$$G = Y \times B_{md}, m^3 . \quad dia^{-1} \tag{5}$$

where: Y - Biogas yield, m3. kg^{-1}

The biogas yield (Y) is determined by the expression:

$$Y = \frac{X}{C_e}, m^3 . \quad kg^{-1} \tag{6}$$

Where: X - energy conversion coefficient of the excreta produced daily, i.e., the daily biogas production based on the type of organic waste, m³/day.

For all types of biodigesters, the volume of the compensation tank (Vtc) is equivalent to the volume of gas produced, i.e., it ranges between 25% and 30% of the biodigester volume.

RESULTS AND DISCUSSION

Biodigester Sizing

For the correct sizing of the homemade biodigester, the following parameters must be determined:

- Daily biomass generation (Bmd);
- Daily volume of material (manure and water mixture) (Vdm);
- Biodigester volume (Vbiodig);
- Fermentation chamber volume (Vcf);
- Biogas containment volume (Vcg);
- Compensation tank volume (Vtc).

The results obtained for each of these parameters are shown in Table 2, considering that the APC's own warehouse has 2 m³ PVC tanks available, which could be used for the fermentation chamber. Therefore, considering that available capacity, the other parameters and the number of animals (bovines) required for the production of excreta for the operation of the proposed biodigestion system were determined.

Potential Energy Contribution

To determine the potential energy contribution based on the number of animals available, the following parameters must be determined:

- Biogas productivity (Y);
- Daily biogas volume (G).

Table 3 shows that for every 350 kg of live weight of cattle, 10 kg of wet manure are obtained per day, generating 0.36 m³ of biogas/day. Considering a manure-to-water ratio of 1:1 and a retention time of 40 days, the biodigester dimensions were determined (Table 2) and the energy contribution of the animal population (Table 3).

As shown in Table 3, the biogas yield for each species is 0.036 m³/kg, and for that number of animals housed, a total daily gas production volume of 4.5 m³/day is possible. Based on the values shown in Table 4, the installation of a 12 m³ homemade biodigester is proposed (Guardado, 2007).

As shown in Table 4, the installation of biodigesters in agricultural production units is an energy-efficient option, in addition to contributing to environmental conservation and protection.

To estimate the cost of the construction and installation of the proposed biodigestion system (excluding labor). Table 5 lists the materials required for its construction and installation.

Table 2. Sizing of the proposed artisanal biodigester

Source of raw material	Animal/day	Average Mass,kg	Bmd, kg/day	Vdm, m³/día	V_{biodig}, m³	V_{cg}, m³	V_{cf}, m³	V_{tc}, m³
Bovine manure	50	350	125	0,25	12	4	12	4

Table 3. Energy contribution of the animal population

Source of raw materials	Animal per day	Average Mass (kg)	Bmd, kg/day	Y, m³/kg	G, m³/day
Cows	50	350	125	0.036	4.5

Table 4. Energy contribution of the biogas to be obtained with the installation of the proposed technology

Sizing parameters	Proposed Biodigester
V_{biodig}, m³	12
V_{cf}, m³	12
$V_{tc,}$ m³	4.0
$V_{cg,}$ m³	4.0
Energy parameters	**Proposed Biodigester**
Y, m³/kg	0.036
G, m³/day	4.5
Potential Energy Savings	**Proposed Biodigester**
Electricity, kWh	8.4
Natural Gas, m³	2.7
Charcoal, kg	1.35
Wood, kg	12.15
Gasoline, L	3.6
Fuel Alcohol, L	5.4
Fuel Oil, L	3.15

Table 5. List of materials for the construction and installation of the proposed 12 m³ biodigester

Materials	MU	Quantity
P-350 Cement	Bags	24
Sand	m³	5
Gravel (38 mm)	m³	5
15 cm Block	u	100
110 mm (4 in) Pipe	m	100
14 mm (1/2 in) Pipe	m	120
PVC Tank (2 m³)	u	6
Polyethylene Bag (5 m³)	u	1
Shut-off Valves	u	8
Excavation	m³	24
Accessories: Connectors, elbows, PVC cleaner and glue, plastic cable ties		

It should be noted that the correct sizing of this type of technology promotes the maximum use of waste obtained in production scenarios.

CONCLUSIONS

- A small-scale biodigester was designed for the workers' dining hall at the "Humberto Hernandez" Agricultural Production Cooperative (APC), determining the required number of cattle based on the fermentation chamber volume.
- It is evident that the installation of the proposed technology contributes to energy savings and environmental conservation and preservation.
- It is evident that the materials required for the construction of the installation are locally available, which does not limit the execution of the engineering project.

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