Biogas resource evaluation: analysis of temperature and pH factors to ensure efficient biogas production using pineapple waste

Oswaldo Doblado Sierra, Mechatronic Engineer[1], Jorge Santos Ramirez, Energy Engineer[2], Alicia Reyes Duke, Master's degree in engineering[3]
[1, 2, 3] Universidad Tecnológica Centroamericana, UNITEC, Honduras, fabriciosierra@unitec.edu, *santos1109@unitec.edu*, alicia.reyes@unitec.edu.hn

Abstract– **According to the Intergovernmental Panel on Climate Change, human influence on climate change is evident. The evidence comes from the unprecedented levels ("in at least the last 800,000 years") of GHG concentration in the atmosphere. These levels in 2011, 391 ppm (parts per million) for CO2, 1,803 ppb (parts per billion) for CH_4, and 324 ppb for N_2O, exceeded levels recorded before industry by approximately 40%, 150%, and 20%. [1] The influence of electricity generation by means of fossil fuels has been increasingly noticeable in terms of the effects they generate on climate change, so that over the years the generation of energy by means of renewable energies has been a great alternative. Within the Honduran energy sector, it is projected that in the coming years renewable energy generation will have an 80% share in the energy matrix of the Honduran country and only 20% of fossil energy [2], being biogas an alternative that has gained strength in recent years due to the environmental impact, through biodigesters using organic waste capable of generating clean energy. It is important to know how temperature affects pH measurements. Therefore, a comparison of two types of biodigesters, one subway and one above ground, was carried out in order to determine the most suitable for pH and temperature control. In this document the generation of biogas from pineapple waste is projected in two biodigesters, one underground and the other exposed to the open air, in addition, the behavior of the internal temperature of the biodigesters is shown, which presents a difference of +/- 3 (°C), based on the temperature registered in the biodigesters, a pH behavior is denoted, According to these behaviors previously mentioned, it is shown that the pH beyond its composition also influences its behavior based on the temperature that it is exposed to. The biogas generation was simulated in Aspen in order to project the biogas generation capacity in a larger scale biodigester, which reached a production of 20% of the gas demand of an atypical house in the rural sector, which is the sector that is sought to help with the elaboration of the prototype.**

Keywords—, Biodigester, Biogas, Pineapple Waste, pH, Temperature.

I. INTRODUCTION

Due to the importance of proposing a solution to the demand that electric energy presents, different solutions are sought with the aim of generating said service or reducing its use, along with supporting the environment, a renewable option is the generation of biogas by means of biomass production using pineapple waste.

Digital Object Identifier (DOI):
http://dx.doi.org/10.18687/LACCEI2022.1.1.82
ISBN: 978-628-95207-0-5 **ISSN:** 2414-6390

Generating biogas using this waste could be considered as a viable option, since it is one of the most harvested fruits in our country, especially in the entire Atlantic coast, where there is the highest demand for energy services, since in These areas are home to the majority of industrial and production companies in Honduras. In addition to being an alternative for reducing electricity consumption associated with the increasing increase in the electricity rate.

In Honduras one of the most prominent items is agriculture according to the Central Bank of Honduras (BCH), producing large crops of fruits and vegetables throughout the year, of which pineapple is one of the most harvested fruits and presents a series of problems with the control of the waste that is produced each end of harvest. This occurs because the harvests of this fruit generate tons of waste that complicates the process for future harvests, there are different processes to control this waste, to which producers go, but most are harmful to the environment. In the development of this research, a comparison analysis of two types of biodigesters will be carried out based on environmental factors, pH and temperature; choosing the most appropriate to be implemented the generation of biogas for direct use in a home, using pineapple waste as a primary resource.

II. CONTEXT

Since ancient times biogas has been mentioned as a gas that comes from the decomposition of organic matter, the first anaerobic digestion unit for obtaining biogas was implemented from the use of sewage, built in India in 1859, in the leper asylum-hospital of Matunga, near Mumbai in India. This plant was responsible for purifying the hospital's wastewater and provided light and power to the hospital in case of emergencies when the electrical circuit failed; but there is also a record of a digester construction in the city of Otago in New Zealand, almost twenty years earlier, around 1840. [3].

A. Microenvironmental Analysis

The microenvironment analysis takes into account the situation of gas production from biomass in the country, as well as illustrating the installed capacity in MW in the different Latin American countries.

Figure 1 shows the statistics of the 7 major biogas producing countries in Latin America, in 2020.

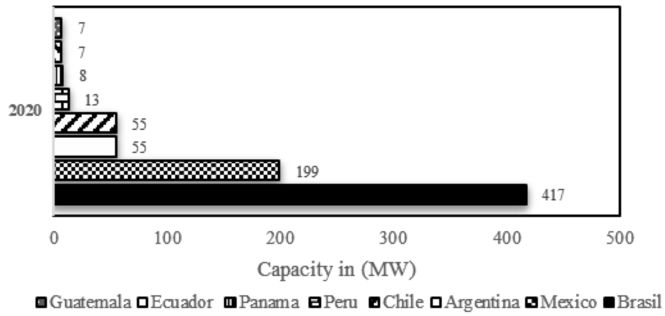

Fig. 1 Methodology in stages.

B. Internal analisis

The internal analysis will show different plants in Honduras where biogas is produced:

Honduran Green Power Corporation

The company Honduran Green Power Corporation, S.A. de C.V., is located in the municipality of Choloma, inaugurated in 2016, the 43 MW electric power plant which operates based on the combustion of biomass. The energy is destined for the company's own consumption and the surplus is sold to the National Electricity Company (ENEE). The primary resources used as a source of generation are: King grass, pine infected with weevil, rachis from African palm and bagasse from sugar cane. The plant was an initiative by the Honduras 2020 Program with the vision of being able to create sustainable areas through the generation of renewable energy.

Biogas and Energy SA

Biogás y Energía SA is a company located in the community of Los Leones, Trujillo, Colón. The plant has an installed capacity of 1.17 MW, with a gross generation of 3877.38 MWh [4]. The energy generated is destined for the company's own consumption and the surplus is sold to ENEE, and biogas is also used for the gas burners used in the company. The primary resource used as a source of generation is agroindustrial waste derived from the extraction of African palm oil.

III. METHODOLOGY

The approach that was selected for the investigation is of a mixed, quantitative and qualitative type. Likewise, the quantitative approach in the research was based on the collection of data and information, managing to obtain a numerical and statistical analysis to guarantee to capture the objectives set and to be able to verify the established hypotheses. On the other hand, the qualitative approach was carried out by inspecting the natural behavior of the events put to the test, where through data collection it was possible to discover and refine the research questions and hypotheses. In the course of the investigation, the interaction of both approaches will be observed.

A. Variables

The dependent variable is the one that is not manipulated, they are all those characteristics in which the process is affected by the independent variable. For this research, biogas production was taken as a dependent variable, where biogas is mainly composed of methane (CH_4) and carbon dioxide (CO_2), in variable proportions depending on the composition of the organic matter from which it has been produced.

The independent variables are all those factors that will be tested and can be manipulated to condition the dependent variable. For the present research, different factors were taken as independent variables, as part of the dependent variable, biogas is taken, because it is the one that has the greatest.

B. Hypothesis

Research hypothesis (H_i): Better control of environmental factors (temperature and pH) required for biogas production is maintained through an underground biodigester.

Null hypothesis (H_o): Better control of environmental factors (temperature and pH) required for biogas production is maintained through a biodigester outdoors.

C. Techniques and Instruments

1) Observation: By means of the observation of the experimental containers, a series of data was collected and recorded to later be analyzed.
2) Literature review: A broad search for information was carried out to support the research topic and develop a detailed theoretical framework.
3) Data collection: A collection of data obtained from each of the tests that was carried out on the experimental containers was elaborated, then these data were used to analyze and conclude whether or not it meets the objectives.
4) Design: Two designs were developed for the prototype of the biodigester so that it can be adapted for automatic or manual use, as well as the box for storing the components of the control system.
5) Arduino: The Arduino platform was used to carry out the programming of the sensors and indications necessary for the proper handling of the control system.
6) Aspen Plus: Through the program, the simulation of the fermentation process of pineapple waste in the biodigester was carried out.
7) AutoCAD: A sketch of the biodigester was made, which shows and classifies the parts in which the biodigester design is composed, as well as the installation of the biogas flow to be used in a home.
8) Fritzing: The design of the connections of the control system components was carried out.
9) Microsoft Excel: It was used in order to collect the data of the samples made to the experimental biodigesters, to control the temperature and order of the amounts of pineapple waste and water that were introduced.

10) Minitab: Graphs were made of the data obtained from the analysis of the comparison of the biodigesters.
11) Proteus: This program was used to simulate the Arduino programming of the sensors and devices necessary to simulate the control system where it includes the pH, temperature and agitation factors of the biodigester.
12) SolidWorks: The design of the appropriate biodigester was made with the requirements that are necessary for the anaerobic process, where pressure tests were carried out on the digester to ensure its operation.
12) Tinkercad: The system circuit was created, where the pH and temperature sensors were simulated to guarantee with more certainty the proper functioning of the control system.

D. Materials

Materials for construction of the biodigester:

- Tank 250 L. of high-density polyethylene
- Stainless steel pipe.
- PVC Pipe.
- Flexible PVC hose.
- Smooth sheet of stainless steel.
- PVC valve.
- Copper stopcock.
- High density polymer pipe seals.

Materials for the elaboration of the control system:

- Arduino Mega micro controller.
- Type k thermocouple sensor.
- MQ4 gas sensor.
- pH sensor.
- DC motor
- 16 x 2 LCD
- Jumpers and cables
- Breadboard
- Buttons
- Relay

E. Research methodology

The methodology proposed in this research project consists of 6 stages, the purpose of which is to design a biodigester for the production of biogas.

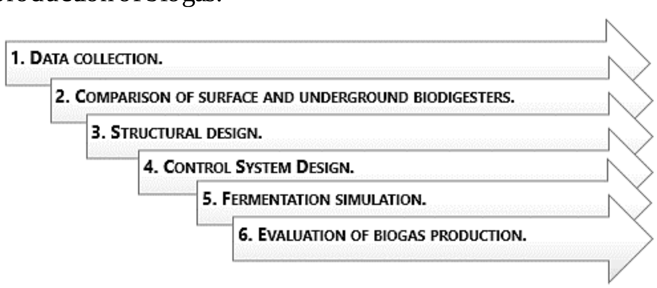

Fig. 2 Methodology in stages.

Stage 1: Data collection.

The project was carried out in San Pedro Sula, being the project used under the meteorological conditions that occur in the region, as it was presented within the research variables is the temperature, which presents a degree of incidence within the biodigester, for gas generation, and therefore there are other meteorological variables that influence the efficiency of the biodigester.

Stage 2: Comparison of biodigesters, surface and underground.

Two experimental biodigesters will be carried out located in two different environments, one surface and the other underground, to then carry out a comparative analysis of the temperature and pH factors, managing to determine the average difference of both biodigesters and thus determine which is the most efficient to maintain a better control of these factors, guaranteeing a more stable biogas production.

Stage 3. Structural Design.

A sketch design will be made of how the biodigester will be constituted using AutoCAD, and the 3D design in SolidWorks, where then a series of tests will be carried out to guarantee its implementation.

Stage 4. Design of the control system.

The design and programming of a control system will be carried out in an automatic and semi-automatic way, to manage a better control of 3 important factors that influence the production of biogas, which are the temperature, pH and agitation of the substrate. System that will be adapted to be implemented in the biodigester.

Stage 5. Fermentation.

Through the use of ASPEN PLUS, a model will be made to simulate the fermentation process of pineapple waste in the biodigester, in order to determine the data that will be obtained through the biodigester model.

Stage 6. Evaluation of biogas production.

A data collection will be carried out to verify the biogas pressure that was generated in the experimental biodigesters and thus be able to determine the range of the carbon / nitrogen ratio in which they are found.

IV. RESULTS AND ANALYSIS

This chapter will detail the results obtained from the data collection with the biodigesters carried out, as well as the complementary simulations to the prototype proposed in this research.

A. Comparative analysis of pH and Temperature.

The analysis of pH and temperature during the project was carried out on a daily basis, since these two factors must be taken care of to avoid affecting the methanogenic bacteria. A comparative analysis of two types of biodigesters was carried out to determine which is the most suitable to maintain stable pH and temperature parameters.

The pH status was recorded once a day and the temperature 3 times a day, since a stable control of these factors, which are very important for biogas production, must be maintained.

These analyses were recorded during a period of 5 weeks with one day, making a total of 36 days. The results of the temperature and pH behaviors are shown graphically in Figures 4-11, which were plotted in Minitab for better understanding.

Table I shows the comparison of the average temperature of the two types of biodigesters, underground and surface, where it can be observed that the underground has more stable ranges.

TABLE I
Average temperature comparison of the biodigesters.

Item	Average temperature		
No. Week	Subway	Superficial	Difference
Week 1	29.32 (°C)	30.36 (°C)	-1.04
Week 2	28.09 (°C)	29.91 (°C)	-1.82
Week 3	26.30 (°C)	25.26 (°C)	1.04
Week 4	26.64 (°C)	25.57 (°C)	1.07
Week 5	27.70 (°C)	26.46 (°C)	1.24
Week 6	27.70 (°C)	28.88 (°C)	-1.18
Total	27.62 (°C)	27.72 (°C)	

Figure 3 shows in detail the behavior that the temperature presented during the evaluation period of the underground biodigester prototype, where a trend of stable values was obtained, giving a minimum temperature of 24.8 °C and a maximum of 29.8 °C.

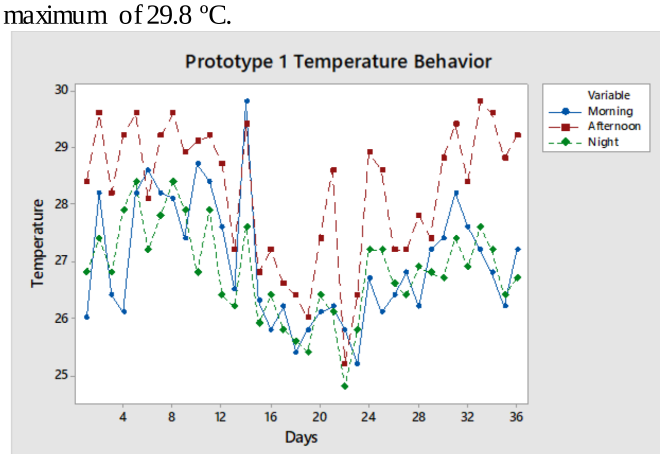

Fig. 3 Temperature behavior of the underground prototype.

Figure 4 shows in detail the behavior of the temperature during the evaluation period of the surface biodigester prototype, where a variable trend was obtained as a result, giving a minimum temperature of 19.2 °C and a maximum of 33.2 °C.

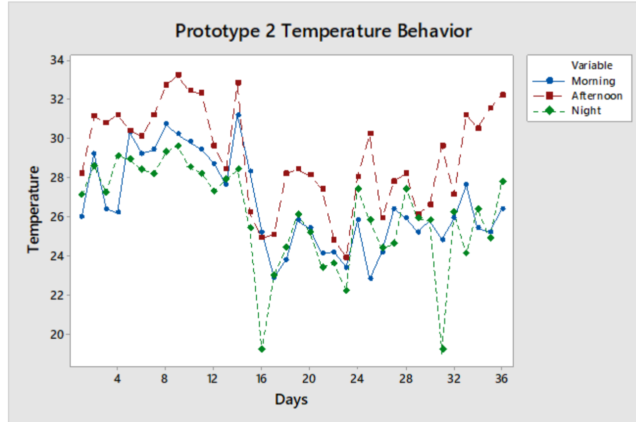

Fig. 4 Temperature behavior of the surface prototype.

Table II shows the comparison of the average pH of the two types of biodigesters, underground and surface, where it can be observed that the underground has more optimal ranges.

TABLE II
Average pH comparison of the biodigesters.

Item	pH promedio		
No. Week	Subway	Superficial	Difference
Week 1	6.66	6.45	0.21
Week 2	7.07	6.92	0.15
Week 3	7.13	6.45	0.68
Week 4	7.17	6.92	0.25
Week 5	7.21	6.88	0.33
Week 6	7.23	7.28	-0.05
Total	7.05	6.88	

Figure 5 shows the specified behavior of the pH during the evaluation period of the underground biodigester prototype, where a stable trend of values was obtained as a result, giving a minimum pH of 6.3 and a maximum of 7.32.

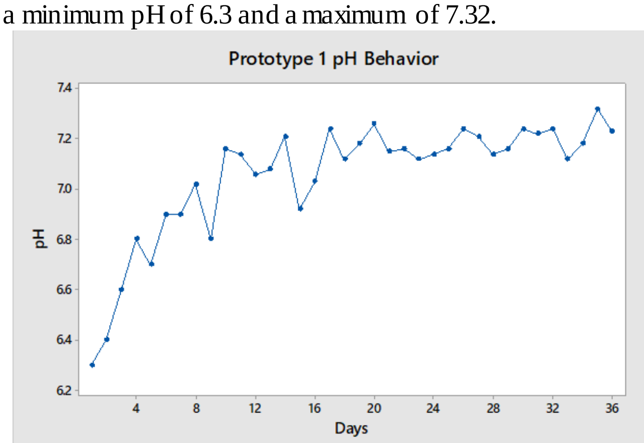

Fig 5. pH behavior of the underground prototype.

Figure 6 shows the detailed behavior of the pH during the evaluation and data collection period of the surface biodigester prototype, resulting in a variable trend, giving a minimum pH of 5.82 and a maximum of 7.48.

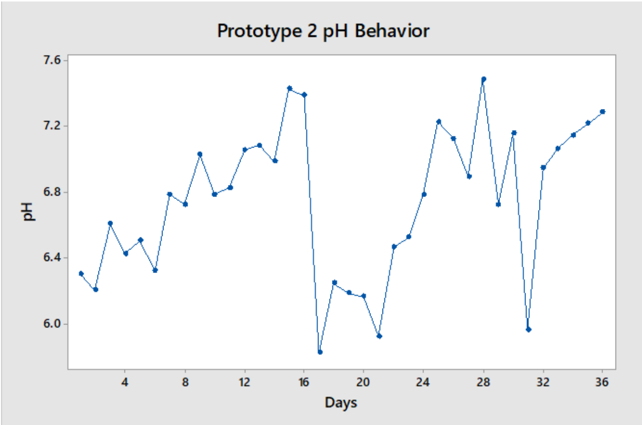

Fig. 6- pH behavior of the surface prototype.

A. Biodigester design

The biodigester used is of the semi-continuous type with an ascending flow, which has a vertical cylindrical geometric shape in the lower part of the body where the bioreactor is, allowing the generation of biogas to be ascending until it reaches the upper part, where it is located. A free space in the shape of a bell that allows the production of biogas to accumulate and then pass to the storage balloon or for direct use.

The design of the digester tank and its components for the biodigestion process were carried out in SolidWorks, in units of measurements in millimeters, it has two options for the agitation process implemented in the model, one automatically and manually.

Figure 7 shows the automatic agitation system, for which the use of a 12 V DC motor was implemented.

Fig. 7- Prototype with automated stirring process.

Figure 8 shows the manual stirring system, for which a T-type knob was designed, adapted with the base tube, which by means of it the propeller can be rotated and the stirring process carried out manually.

Fig. 8- Prototype with manual stirring process.

Table 3 shows the dimensions of each of the parts of the biodigester are directly related to economic and environmental factors, which is constituted as follows.

TABLE III
Average pH comparison of the biodigesters.

No.	Unit	Technical Specifications	Dimensions
1	Digester tank	Capacity for 180 L. of substrate; High density polyethylene.	Cover: 550 mm
2	Storage tank	Capacity for 32 liters; Concrete.	Height: 880 mm
3	Breather	2" PVC pipe.	Diameter: 695 mm
4	Effluent outlet	3" PVC pipe.	-

B. Technological contributions.

The application of a control system for monitoring the factors of pH, temperature and production of methane gas produced from biogas was implemented; as well as an agitation system to maintain a stable temperature and avoid the accumulation of mud on the upper part of the substrate.

Control system

An automated system was carried out in order to take data from the substrate inside the digester without having to take samples for analysis. The design of this system is based on taking data on the temperature and pH of the substrate, as well as measuring the percentage of methane that is produced from the biogas that is generated. The programming of the necessary elements of the system was carried out in Arduino and different simulations were carried out to verify their validity.

Figure 9 shows the incorporation of the elements necessary to make the control system, for which a thermocouple type K MAX6675 sensor, pH sensor, MQ sensor and DC motor with their respective complements and the LCD where they are reflected was implemented.

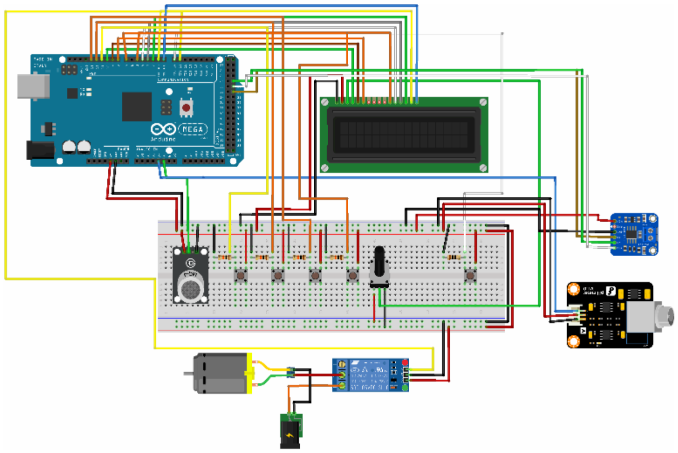

Fig. 9- Elements of the control system.

Automated stirring system

For the agitation process it is necessary to carry out movements at low speed since the substrate must be agitated under shear to guarantee favorable conditions for methanogenic bacteria, which are responsible for producing methane gas. For which the use of a 50 RPM DC motor was implemented.

The motor selected for the process is a model PN01007-38 geared motor, with 6 N-m (4.4 ft-lb) straight torque. The motor shaft is 9.5mm in diameter and 30mm long; it is easy to adapt screws and to be placed in the propeller tube of the biodigester.

C. Fermentation

It has been experimentally demonstrated that a load in semi-continuous digesters should not have more than 8% to 12% total solids to ensure good process performance, as opposed to batch digesters, which have between 40 to 60% total solids [5].

The main component of pineapple is water, which constitutes approximately 85 % of its weight. The edible part, together with the peel has a water content of 81 to 86%, leaving the remaining 14 to 19% as total solids [6] and the pineapple stubble, bagasse and crown contains 12.3% total solids [7]. Using a mixture of both components we obtain an average of 14.4% total solids.

In order to know how much water to mix according to the amount of pineapple, it is necessary to apply the formula of % T.S. (diluted load).

$$0.08 = \frac{1\,kg\ organic\ matter + \%\,S.T\ fresh\ organic\ matter}{1kg\ fresh\ organic\ matter + added\ water}$$

(1)

$\%\,S.T.(diluted\ load) = 8\%$

$\%\,S.T.\,fresh\ organic\ matter: 14.4\%$

$$0.08 = \frac{1\ kg\ pineapple\ waste * 0.144}{1kg\ fresh\ pineapple\ waste + added\ water} \quad \textbf{(2)}$$

We solve for added water:

$$added\ water = 2.8\frac{L}{kg}fresh\ organic\ matter \quad (3)$$

D. Biogas production

The biogas production for research purposes was estimated by means of a simulation through Aspen Plus, which assumed the components of the table below.

TABLE IV
Component estimation

Component	Simulated composition
CH_4	57.20%
CO_2	32.93%
H_2S	0.87%
NH_3	0.44%
H_2	0.20%

Based on the previously estimated components, the following biodigester was elaborated in Aspen to obtain an estimate of methane gas, with a boiling point of 125 °C, and a specific gravity of 747. 7 kg/m3, the capacity of the biodigester is 180 liters, the biodigester is subjected to 1 atm of pressure, Figure 10 shows the design of the biodigester, and the process of separation of the substrates to obtain the different gases, for this document will focus on obtaining methane gas.

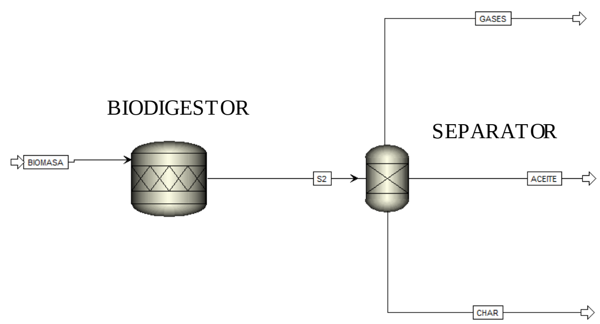

Fig. 10- Control system elements.

Table V shows the data obtained from the composites with a temperature of 30 °C, which is the average temperature that occurs in the place where the prototype was located, 3-stage isentropic compression model, which is reflected in the design of the Aspen simulation, the data obtained from this simulation are shown.

TABLE V
Data obtained from the bioreactor simulated at Aspen.

	Units	Gases
Temperature	K	398.15
Pressure	atm	1
Vapor mass fraction		1
Liquid mass fraction		0
Solid mass fraction		0
Enthalpy of mass	cal/gm	-1985.99
Mass Density	gm/cc	0.0006639
Enthalpy flux	cal/sec	-221.0832
Mass fluxes	kg/hr	0.4007571

	Units	Gases
BIOMASS	kg/hr	0
CO	kg/hr	0.1107421
CO_2	kg/hr	0.1019262
CH_4	kg/hr	0.0452384
H_2	kg/hr	0.0034429
NH_3	kg/hr	6.62E-05
H_2S	kg/hr	0.0009925
N_2	kg/hr	0.0016159
OIL	kg/hr	0
H_2O	kg/hr	0.1367329

E. Analysis of biogas production.

Next, an analysis of the results on the biogas production obtained from the two types of biodigesters will be carried out; where a comparison will also be made of the carbon / nitrogen ratio of pineapple waste.

Carbon / Nitrogen Relation

There are a great variety of different criteria on what is the optimal relationship that should exist between the organic matter to be degraded (carbon) and the amount of the main macronutrients that occurs in an anaerobic process, depending on the type of substances of which this compound is produced. The microorganisms that work in the anaerobic process always consume these elements (carbon, nitrogen), for proper functioning there must be an adequate relationship between nutrients to be able to develop the bacterial flora correctly. The C / N ratio should be between a range of 15/1 - 45/1, with recommended values of 20-30 / 1 **[8]**.

Table VI shows the theoretical classification of compounds that make up the pineapple plant, where it can be seen that the substrate is within the recommended C / N ratio.

TABLE VI
Carbon/Nitrogen ratio of pineapple.

Substrate	Carbon content by weight (%)	Contenido de nitrógeno por peso (%)	Carbon to nitrogen ratio (C/N)
Rastrojo de piña (Tallo, corona, raíz)	40.6	1.36	29.9:1

Record of biogas produced

With the biodigesters running from week one, it took about five weeks for one of the storage globes to be fully filled. The volume of biogas produced from the biodigesters was measured with the help of the biogas flow meter located at UNITEC.

Table VII shows the comparison of the measurement of biogas produced, the temperature of the gas and the time it took to measure all the biogas of the types of biodigester proposed.

TABLE VII
Values of biogas obtained.

Sample	Measurement (m^3)	Instantaneous Measurement [m^3/h]	Temperature (°C)	Time m:s
Initial Value	30.500	0	28.7	0
Prototype 1	30.740 (0.240)	1.284	29.8	07:13
Prototype 2	30.967 (0.227)	1.271	30.1	06:13
Difference	0.013	0.017	0.3	1 min

With the measurement taken it is possible to determine how much biogas can be used in a given period of time. With the amount of gas produced, a gas stove, as well as a gas lamp, could be lit for a short period of time.

F. Analysis of the implementation of direct use of biogas.

To make use of biogas, it is necessary to have certain equipment for its distribution, storage, purification and treatment of the biogas produced from the biodigester, in order to be able to distribute the biogas in the different points for its consumption and to be able to remove contaminants that may arrive.

Table VIII shows the main equipment that is necessary for the implementation of direct use of biogas for direct use.

TABLE VIII
Equipment necessary for the implementation of direct use of biogas

Equipment	Description
Biogas distribution equipment	Couplings, gaskets, flexible hose and valve.
Desulfurizing filter	Removes hydrogen sulfide, which is a natural component of biogas. H2S is corrosive, therefore, its removal is important to ensure a longer life of domestic biogas equipment.
Filter drier	It allows the extraction of water vapor which is a natural component of biogas.
Flowmeter	To have an easy and quick measurement of the level of biogas production.

Figure 11 shows an exemplified sketch of the laying of the gas distribution network in different equipment of a house, in which direct use is made of the biogas produced from the proposed biodigester.

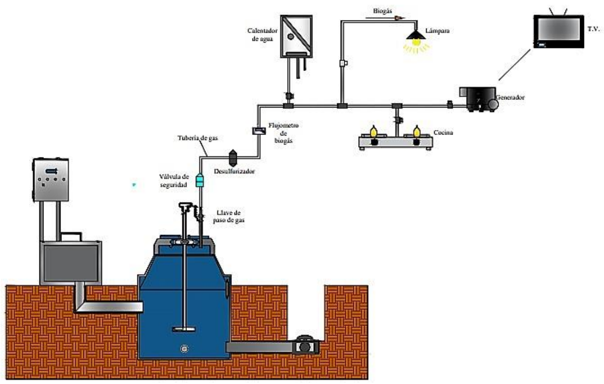

Fig. 11 Laying of the biogas distribution network.

In order to compare the energy and economic savings that will be obtained through the direct use of the biogas produced in a home, a comparison in kWh of the biogas production and the average consumption of a stove is presented, which is one of the electrical appliances that more consumes energy, which can be seen in table IX.

TABLE IX
Comparison of energy and cost savings.

Equipment	Average monthly consumption (kWh)	Monthly energy generation (kWh) biogas	Percentage of monthly savings	Economic savings
Stove	90	18.825	20.95%	L. 90.17.00

G. Budget for the construction of the biodigester system.

This section will present the costs involved for the construction of a biodigester in a home, for which **Table X** shows the total investment, classified in materials and equipment to be used, as well as the labor for the installation and system adaptation.

TABLE X
Total, investment.

Name	Price USD	Price in Lempiras
Materials and equipment	$ 818.47	L 19,991.04
Labor	$ 122.83	L 3,000.00
Total	$ 941.30	L 22,991.04

CONCLUSIONS.

The research presented has managed to meet the general objective of determining what type of biodigester is the most suitable for the implementation of biogas production for direct use in a home. Which the results obtained from the investigation allow to obtain the following conclusions:

1. The null hypothesis (Ho) is rejected, since the underground biodigester maintains better control of environmental factors, pH and temperature, guaranteeing a biogas production greater than 5%.
2. It was possible to observe through the analysis of the behavior of the biodigesters how the temperature influences the pH factor, as the temperature increased, the pH decreased, a situation caused by molecular vibrations, since these increase when the temperature rises; in the same way when the temperature decreased.
3. The prototype of underground biodigester reached a lower temperature, therefore, it is denoted that there is a temperature differential at certain depths that oscillates between 3 - 4 degrees below the outdoor temperature, which is why in the present location it presents a better scenario to work on land.
4. The carbon / nitrogen ratio of the use of pineapple waste for biogas production was analyzed, where it was obtained that it has a ratio of 29.9: 1, a value that is within the recommended values for the correct gathering of microorganisms.
5. Regarding the simulations carried out based on the design carried out, a production of 20% of the total demand that would be presented by an electric stove for conventional use in a rural sector is presented, so it can present significant savings in said households.

References

[1] Villatoro Flores, H. F. (2016). Assessment of the Macroeconomic Impacts of First-Generation Biofuels from a Life-Cycle Perspective in the Japanese Transportation Sector. Tohoku University, Tokyo, Japan. doi:https://ci.nii.ac.jp/naid/500001052166/

[2] J. L. O. Fernandez, J. L. O. Avila and R. A. Ordoñez, "Potential effect on the energetic matrix of Honduras with the installation of residential photovoltaic generators for self-consumption," 2019 IEEE 39th Central America and Panama Convention (CONCAPAN XXXIX), 2019, pp. 1-6, doi: 10.1109/CONCAPANXXXIX47272.2019.8976994.

[3] ORTEGA, S. P. (2013). BIOGAS ENERGY: AN OPTION. XALAPA: UNIVERSIDAD VERACRUZANA.

[4] IRENA. (2020). Renewable Energy Capacity Statistics 2021. Abu Dhabi: International Renewable Energy Agency.

[5] DIRECTORATE GENERAL OF ELECTRICITY AND MARKETS (DGEM). (2019). ANNUAL STATISTICAL REPORT OF THE ELECTRIC SUBSECTOR. Tegucigalpa: Secretaría de Estado en el Despacho de Energía. Retrieved from https://portalunico.iaip.gob.hn/portal/ver_documento.php?uid=NTY2NTIxODkzNDc2MzQ4NzEyNDYxOTg3MjM0Mg==

[6] Moreno, M. V. (2011). Biogas Manual. Santiago de Chile: Project CHI/00/G32.

[7] SÁNCHEZ-HERNÁNDEZ, M. Á.-M.-G. (2015). Production of Pineapple Cayenne Lisa and MD2 (Ananas comosus L.) under conditions of Loma Bonita, Oaxaca. Loma Bonita Oaxaca: Universidad del Papaloapan. Campus Loma Bonita

[8] RODRIGUEZ, J. A. (2020). Biomass management of pineapple crop. ENGORMIX.

[9] Arciniega, I. L. (2017). Biogas production through co-digestion of solid and semi-solid waste: towards a centralized biogas plant for energy generation. Santiago de Queretaro: CIDETEQ.