Optimization of the cocoa shell, inoculum, and water mixture for biogas production with 40-70% methane concentrations

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Abstract. Biomass has been a valuable source of energy over the years and its application includes many areas, whether for cooking, heating, or electricity generation. In Honduras, especially in the rural sector, biomass, mainly firewood, became the main source of energy, which has led to a high consumption of firewood and, consequently, to an increase in the rate of deforestation. In this study, we proposed to use a more specific biomass, cocoa husk, as feedstock for biogas generation. It is important to note that biogas does not only consist of methane; it also contains carbon dioxide (CO_2), nitrogen (N_2), hydrogen sulfide (H_2S) and oxygen (O_2). However, to be considered of quality, the concentration of methane in the biogas must range between 40% and 70%. The main objective of this research has been to optimize the mixture of raw materials, including cocoa husk, water and inoculum, with the purpose of obtaining a methane (CH_4) concentration in the biogas produced, located in the range of 40%-70%. To achieve biogas production, several tests were carried out in four biodigesters, each with different proportions of water, inoculum, cocoa husk and grinding level. This made it possible to obtain varying amounts of biogas and to measure the methane gas concentration in each test. During the operation of the biodigesters, the temperature and pH of the mixture were constantly monitored. This was possible because methanogenic bacteria, responsible for methane generation, thrive at temperatures between 30 and 40 degrees Celsius and in a pH range of 6 to 8. The results obtained have the potential to demonstrate that cocoa shells can be a viable feedstock for biogas generation in Honduras. Furthermore, these findings could serve as a basis for future research in other cities around the world, thus contributing to the search for energy generation solutions.

1 Introduction

The search for renewable and sustainable energy sources is a global priority due to the growing demand for energy, the depletion of fossil resources and concerns about climate change.

Approximately 80% of the world's energy consumption comes from fossil fuels, whose reserves are depleting [1]. In 2016, around 1.6 billion people, mostly in rural areas, lacked

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access to electricity, while 2.5 billion still relied on traditional fuels such as wood and dried dung for cooking and heating, with negative consequences for the environment and health, as well as limiting economic opportunities to combat poverty [2]. Even though greenhouse gas emissions typically come from burning fossil fuels, in Honduras 47% of the population, equivalent to 1,127,000 households, relies on firewood and other organic waste for cooking [3]. According to the 2019 Multipurpose Household Survey, 87% of the rural population and 26% of the urban population used firewood for cooking, often in conjunction with electricity or liquefied petroleum gas (LPG). In 2011, 66% of urban households purchased firewood, in contrast to 49% in rural areas, since in this area, the majority collect it directly [4].

Studies have been conducted on the production of biogas from cocoa shells. Acosta [5] evaluated its viability to generate renewable energy through anaerobic digestion, achieving 60% methane in two reactions, one dry anaerobic and the other with distilled water. Carreño Vesga [5] analysed the pre- preparation of cocoa lignocellulosic biomass using a specific methanogenic activity (SMA) test and found that a cow inoculum ratio of 1:3 resulted in higher methane production due to volatile solids content. These studies highlight the potential of cocoa as a renewable energy source[6]. In this research, biogas production from organic wastes is explored, focusing on the use of cocoa shells as feedstock. Four biodigesters will be used to perform anaerobic reactions with various mixtures of cocoa husk, inoculum, and water. Cocoa, which comes from Theobroma cacao trees, is economically important in various industries such as food, pharmaceuticals, and cosmetics. However, cocoa shells, which are rich in organic matter, are often discarded without efficient utilization[7]. This thesis focuses on analysing the critical factors affecting biogas production from cocoa shells, inoculum, and water. This includes determining the optimum ratio between these components and the conditions for anaerobic digestion[8]. It also seeks to achieve methane concentrations in the biogas that range between 40% and 70%, a key indicator of its quality and usefulness as a fuel. This study has important implications for waste management, as it can offer a solution for the management of cocoa shells while generating a renewable energy source. The thesis aims to promote future research on the generation of biogas from biomass as a main source of energy and to serve as a model for studies in various cities around the world.

2 Context

Today, renewable energy has become more prominent as a source of energy for many countries. Asshown in Fig. 1.

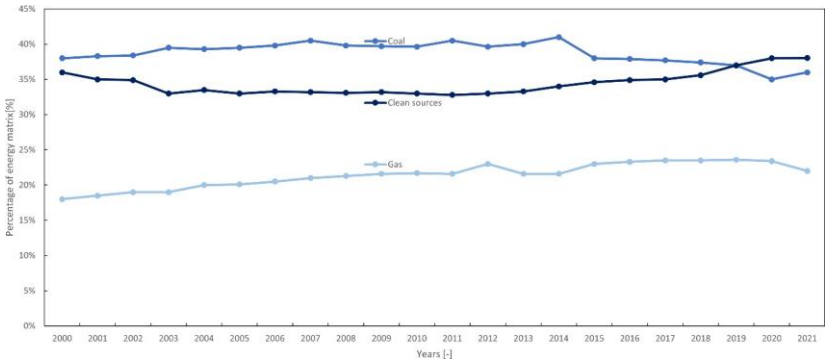

Fig.1. Comparison of world energy matrix evolution *Clean sources include hydro, nuclear, wind, solar and bioenergy.

Biomass has become an attractive alternative for energy generation, as it produces biogas through a process called anaerobic decomposition [9]. This process is useful for dealing with waste that is biodegradable, as this process oxidizes the glucose in the organic compounds generating methane. Honduras has many resources such as sugarcane bagasse, King Grass, African palm, sawdust, and cocoa acorns to produce biomass, highlighting the generation of biogas from cocoa shells [10]. The country has approximately 7,000 hectares of cocoa, which are distributed in nine departments: Cortés, Santa Bárbara, Copán, Copán, Yoro, Atlántida, Colón, Olancho, El Paraíso and Gracias a Dios [11].

That said, a study was conducted in Ecuador in which it was shown that, thanks to the cocoa waste available in the area, 8,341 MWh of electricity could be produced, satisfying 88% of the current electricity demand in Balao. This study highlighted the potential of cocoa waste as a renewable energysource in rural areas[12].

Although there are few studies on the anaerobic reaction using cocoa shells, a study funded by the National Council for Technological and Scientific Development of Brazil analyzed the potential of cocoa waste for energy conversion through anaerobic digestion and the evaluation of strategies for the optimization of feedstock and substrate mixtures, thus improving methane production yields. This study concluded that cocoa waste biomass has a high potential for energy conversion through anaerobic digestion, being a sustainable process to treat these wastes and an alternative to the use of fossil fuels [13].

3 Methodology

3.1 Approach

A quantitative approach methodology has been adopted, which means that the focus has been on the collection and analysis of numerical data to address the hypotheses put forward. By using this approach, a more precise and verifiable understanding of the phenomena studied is sought, which provides a solid basis to support the conclusions and recommendations of the research.

3.2 Research variables

Dependent Variable

Concentration of methane (CH_4) in the biogas produced because it is the variable to be optimized and represents the proportion of methane in the biogas resulting from the anaerobic digestion process.

Independent Variable

Cocoa husk: Refers to the different combinations and proportions of organic materials used in the biogasproduction process.

Water: The amount of water added to the system can influence the efficiency of anaerobic digestion andthus affect methane production.

Inoculum: Refers to the amount and type of microorganisms added to the anaerobic reactor to initiatethe process of organic matter decomposition.

3.3 Technique and instruments

Within the framework of this project, pH strips and a digital thermometer were used as control variables to monitor the pH and temperature of the biodigester. By using the pH strips, it was possible to adjust and maintain the pH within the ideal parameters, which are above six and below eight during the entire test period, since a pH within this range favors

microbial activity and methane production, while significant deviations from the optimal range can negatively affect biogas production. Temperature directly influences microbial activity and thus biogas production; an ideal temperature is considered to be above 30°C-40°C [14]. A laboratory oven was used to analyze the percentage of moisture in the cocoa shells. Also, in order to perform gas measurements, as shown in fig.2. The gas analyzer MRU Optima 7 was used. These tests consisted of the analysis of two types of two samples: the first sample was made with fermented cocoa shells and the second with unfermented cocoa shells, since there was a large amount of cocoa, the average percentage of moisture in the shell was determined for both samples,which was 75.5%.

Fig.2. Gas analyzer MRU Optima 7.

3.3.1 Moisture content

Since there was a large quantity of cocoa shells (150 kg), it was decided to extract two cocoa acorns from each of the five bags. The acorns were then crushed, placed in the oven and left to rest for 24 hours. The same process was carried out for the unfermented cocoa shells. The inclusion of both types of samples in the tests made it possible to evaluate how the fermentation process influences the moisture content of a fresh plant material, the following formula 1 can be used:

$$Humidity\ percentage = \left(\frac{initial\ weight - fianl\ weight}{initial\ weight}\right) \times 100\%$$

Equation 1- Moisture percentage

3.4 Materials

The biodigester used was based on the design of [15]. To avoid biogas leakage, certain specific modifications were carried out. Also, an adapted tire was implemented to perform tests on the chemicalcomposition of the biogas generated from cocoa husk.

3.5 Population and sample

In Honduras, cocoa is found on approximately 7,000 hectares distributed in nine departments due to factors that favor its harvest, such as suitable climatic conditions, soils suitable for cultivation and its cultural importance. The cocoa used was extracted from two farms located in different areas of Honduras. Both farms have mixed cocoa, which means that the crop includes different varieties of cocoa. The first farm is in Trascerros, Santa Barbara, Honduras, while the second is located in La Másica, Atlántida, Honduras as shown in Fig.3.

Fig.3. Ground cocoa and cocoa sample from Trascerros Santa Barbara.

3.6 Study methodology

A detailed record of the research is provided below, covering each stage, from the initial configuration of the biodigesters, the collection of the feedstock, the level of grinding of the feedstock, the mixture that was fed into each biodigester, the parameters that were measured, which were pH and temperature, and finally the analysis of the biodigesters as shown in Fig 4.

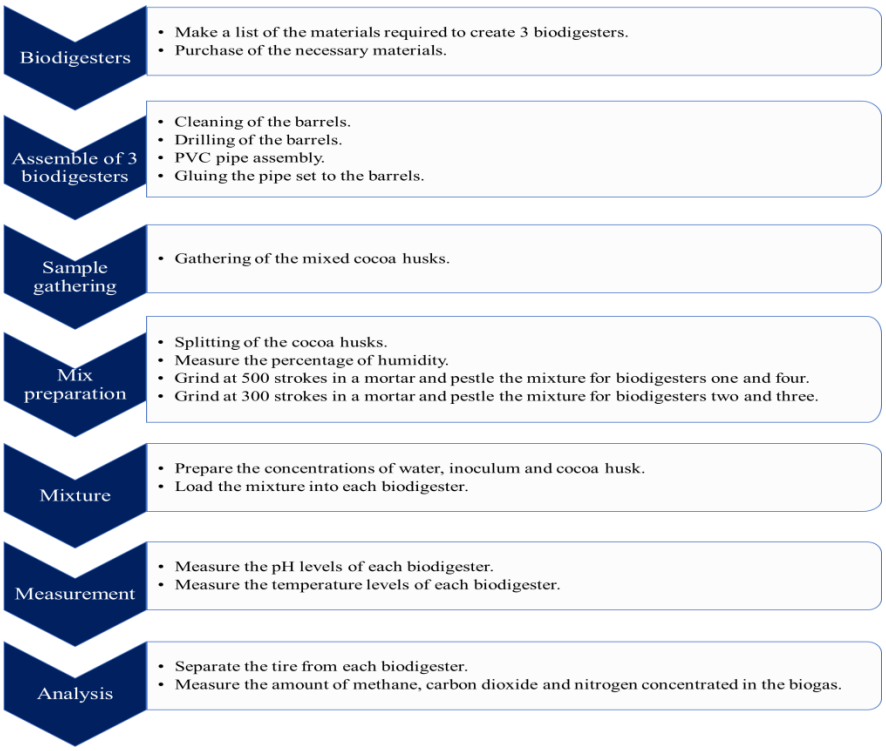

Fig.4. Study methodology record.

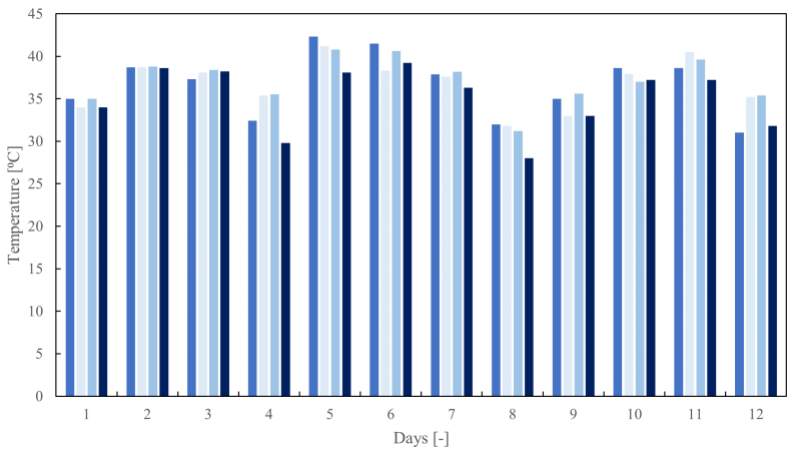

Fig.5. Temperature of biodigesters

4 Results and analysis

Monitoring was carried out every two days after the start-up of the biodigesters, in order to obtain the ideal temperature data inside the digester. Each bar represents the biodigesters in which measurements were taken over a 12-day period. The ideal temperature data to be

maintained by the biodigesters is between 30 and 40 degrees Celsius. As shown in fig.5. The temperature graph below displays the measured values for each biodigester, with each color corresponding to a biodigester, ranging from biodigester one to four.

4.1 PH Level of the Ratio of Each Biodigester

The pH level within each biodigester was calculated for the purpose of determining if the bacteria present in the mixture of water, cocoa husk and inoculum are in the proper conditions to carry out the anaerobic reaction. The ideal range of pH levels should be between six and eight, with six being the lowest possible value and eight being the highest. As shown in fig.6. The pH graph below displays the measured values for each biodigester, with each color representing the days on which the acidity level of each biodigester was measured.

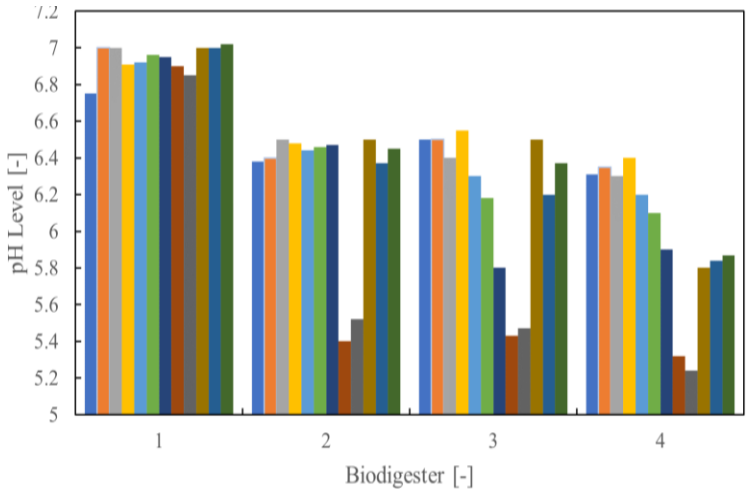

Fig.6. pH level in the biodigesters.

4.2 Analysis of the Biodigesters

As can be seen in the diagram, various types of mixtures were introduced into each of the biodigesters. Each number in the diagram represents a gallon, as it was not hermetically sealed properly due to the mixture introduced, and it is associated with its corresponding grind level. In the case of biodigester number one, a unique situation was encountered because it experienced failures due to improper sealing.

In biodigester two, the results in terms of methane (CH_4) generation were considerably lower than ideal, reaching only 12.87% methane gas. However, the level of hydrogen sulfide (H_2S) particles was reduced to one, with a percentage of carbon dioxide (CO_2) of 19.62% and oxygen (O_2) of only about three points two percent. It is important to note that this ratio is based on a 5:10:1 ratio, where each number represents one gallon. In addition, the amount of feedstock, in this case cocoa husk, was lower compared to the other biodigesters. Regarding the crushing of the feedstock, it can be stated that it was moderately crushed (300 mortar strokes) and that the husk was in a mature state.

In biodigester three, the results for methane (CH_4) generation were also lower than ideal but the highest percentage of methane with 14.27% methane gas. The level of hydrogen sulfide (H_2S) particles was two, and the percentage of carbon dioxide (CO_2) was 36.27% and oxygen (O_2) was only one percent. It is important to note that this ratio is based on a ratio

of 7 ½ ,12 ½ ,2 where each number represents one gallon. Regarding the crushing of the raw material, it can be stated that it was moderately crushed (300 mortar blows) and that the peel was in a mature state.

As can be seen in table 1. The ratio of cocoa hulls, water and inoculum used in the biodigester 4 was 20:17 ½ :2, respectively, where each number represents one gallon. In other words, 10 gallons of cocoa hulls, 17 ½ gallons of water and two gallons of inoculum were used. In terms of the crushing of the raw material, it can be stated that it was adequately crushed (500 mortar strokes) and that the husk was in a mature state. As shown in fig.7 and 8. All biodigester diagrams are identical.

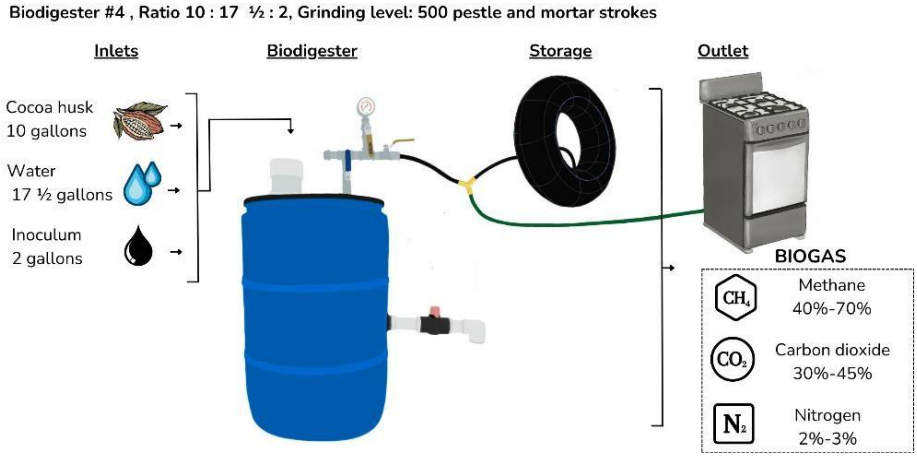

Fig.7. Concept Diagram of biodigester 4.

Fig.8. Biodigester 4 based on [15]

Table 1. Results of biodigester 1-4

N°	COMPONENT	EXPRESSION	BIO 2	BIO 3	BIO 4
1	Methane (CH4)	[%]	12.87	14.27	20.64
2	Hydrogen Sulfide (H2S)	[ppm]	1	2	404
3	Carbon Dioxide (CO2)	[%]	19.62	36.27	74.42
4	Oxygen (O2)	[%]	3.32	1.0	1.91
5	Net heat	[BTU/lb]	3.5	3.6	528
6	Gross heat	[BTU/ft^3]	4.8	5.4	60.7

5 Conclusions

Four biodigester experiments were carried out to compare the amount of methane that can be generated by using cocoa hulls as feedstock. In each of the biodigesters, the composition of the mixture, consisting of cocoa hulls, water and inoculant, was varied in order to determine which ratio produces the best biogas concentration. Monitoring was carried out in the biodigesters in order to measure the temperature and pH level. These measurements were carried out with the objective of maintaining the anaerobic digestion in optimal conditions, which allows the methanogenic bacteria to have the proper environment for the generation of methane in the biogas. The following results were obtained:

1. Three biodigesters were successfully completed. Biodigester number one did not show results, as it had more leaks. Each biodigester was set up and operated according to a pre-established plan, and subsequently underwent a detailed analysis using a gas analyzer.
2. Analyses were carried out on several cocoa shell samples, each weighing 200 grams, in order to determine the moisture content present in the shells. Using an oven at a temperature of 75 degrees Celsius for a period of 24 hours, a moisture content of 76% was obtained in the cocoa shell samples.
3. From the moisture percentage, which was found to be 76%, it was determined that for every 5 gallons of cocoa shells, 1.05 gallons of water should be added at the time of grinding.
4. Monitoring techniques, such as the measurement of acidity in the biodigesters and temperature using a digital thermometer, were implemented to control these crucial parameters for methanogenic activity. When the temperature was below the optimum level, a steam engine was used, and in those biodigesters whose acidity levels were not as desired, lime was added.
5. Methane measurement was carried out in each of the biodigesters using a gas analyzer.
6. The biodigester with the best biogas conditions was biodigester number four with a 10:17.5:2 ratio, which gave us a total of 20.64 methane, since it was the one with the rawest material of the three biodigesters; however, it did not reach the pre-established methane quantity, which was 40-70% methane.

The main limitation of this research was not having an instrument that could grind the cocoa faster and achieve a homogeneous mixture. As could be observed in biodigester number four, which had the best grinding level (500 pestle strokes), it was the one that obtained the most methane from the biogas. Since the higher the grinding level, the faster the methanogenic bacteria decompose the feedstock, the methane gas production could be increased.

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