Design, Implementation and Testing of a Biogas Analyzer

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Abstract. Biogas is an ideal fuel for sustainable energy and an alternative to wood energy in sub-Saharan Africa. Its valorisation in rural areas is limited to cooking despite its enormous potential for electricity production. However, the inaccessibility of biogas analyzers to assess the quality of biogas and trigger its use in an engine is one of the main obstacles to this new trend. The aim of this work is to develop a simple and inexpensive portable digital device capable of analysing any biogas together with its production parameters. To achieve this, a prototype analyser using an Arduino card fitter with sensors was designed and built, then experimented with biogas produced from cow dung. Sampling tests were carried out after 4 and 10 days of loading 10-liter bioreactors with cow dung. A Better flammable biogas production was recorded at 10 days of loading with 66.41% methane (CH4), 32.43% CO2, and 1.14% water vapour (H2O). This biogas analyser was quite efficient and could identify gases produced by the methanization process while controlling the bioconversion parameters. Nonetheless, the biogas obtained can be purified for more efficient use.

Keywords: Methanization, substrate, biogas analyzer, Arduino card, bioconversion parameters.

1 Introduction

According to scientific forecasts, fossil fuels is likely to face exhaustion within a few decades [1]. Fossil Fuels are becoming increasingly scarce and expensive, even though they are the most widely used energy source in world [2]. In Africa, wood is the main fuel source for cooking, heating and this is due to low electrification rate and rampant poverty [3]. Unfortunately, the collection of fuelwood for various purposes such as energy needs amongst others, is the primary cause of deforestation in Africa, especially in the Sudan-Sahelian zone. [4]. This consumption of fuelwood increased at an annual rate of 2.6% between 1981 and 2001 [5]. In rural areas precisely in Cameroon, about 96.3% of the population depend essentially on wood fuel to prepare meals [3]. Generally, the wood collected is either used directly or converted to charcoal depending on the application. Direct use produces sooty flames and generates toxic fumes to which women and children are most exposed [6]. The Global Burden of Disease study [7-8], estimates that exposure to smoke from cooking with wood is the fourth worst risk factor for disease in developing countries, causing up to 4 million premature deaths per year [7 - 9]; a figure which exceeds the number of deaths from HIV/AIDS, malaria and tuberculosis combined. Consequently, the need to develop alternative energy sources such as renewable energy to curb this tragic situation while meeting societal energy demand is pertinent and indispensable. Among the different renewable energy sources, biogas is considered ideal to provide a sustainable solution to cooking energy sources in rural areas. However, most of the digesters built in these localities for this purpose are inadequate due to lack of reliable data for sizing. Data collection devices such as gas analysers are very expensive and less accessible. A study carried out by CIRAD in 1996 in the Caribbean shows that about 48% of these digesters were oversized for household use, 62% produced gas in quantities higher than daily demand, 32% produced an insufficient amount of biogas and only 6% of the production units met the energy demand. Indeed, the productivity of the substrates used varies from one area to another and is not well known. In Cameroon, the most common substrates used for gas production by anaerobic digestion are animal manure (cow dung, poultry droppings, pig manure). These excrements produce biogas less dangerous than the norm and are at the same time not very productive. However, co-digestion improves both the qualitative and quantitative production of flammable biogas [10]. On the other hand, some companies that produce large quantities of biogas are not able to valorise it due to the impurities contained in them. This is the case with

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HYSACAM, a company which specializes in the collection of household waste in Cameroon, which flares about 250 tons of biogas per day. This amount is sufficient to reduce the growing demand for Liquefied Petroleum Gas (LPG) in households. The biogas produced consists of several other gases, among which only methane is flammable. The other gases produced such as carbon dioxide, hydrogen sulphide, water vapor and nitrogen dioxide are inert gases and dangerous to human health thus must be disposed. The permanent analysis of biogas from such a substrate is indispensable for its valorisation even in the most simplified way such as cooking to be considered. It is important to find a sustainable, accessible and inexpensive method to achieve this analysis. It is for this reason that the design and manufacture of a portable digital biogas analyser is carried out in depth in this work. The analyser considered in this case is a prototype capable of identifying the different components of a biogas produced from by methanization. It also has the ability to measure the parameters of the methanization process such as temperature and yield. The performance of the prototype as well as its efficiency is studied and compared to data from literature.

2 Materials and Method: Functioning principle and realization of the biogas Analyzer

2.1. Functioning principle

The analyser is an electronic system equipped with probes for sampling and data collection via a laptop computer. It is composed of three (3) parts: the first part includes the electronic motherboard. The second part is composed of the sensors with wires and probes connected to the motherboard and finally, the fourth part is the arduino software installed on the laptop for data collection.

![Fig. 1. Data to be collected by the Biogas Analyzer.](Image)

Figure 1 shows the principle of collecting the physicochemical parameters and the different proportions of the gases found in the biogas. These parameters are the temperature and pH of the substrate in the digester during the conversion.

Below, is an illustration of the principle of functioning of the analyser during the biological conversion of substrate.

![Fig. 2. Functioning of the Analyser](Image)

On the right and left of figure 2, we have respectively a digester which is a large tank in which the convertible organic matter is housed. In the middle is the analyser with the five (5) probes. Two (2) probes in yellow and red colour will be immersed in the fermentable organic matter to determine the temperature of the substrate and the pH during the conversion period. The other three (3) probes will be immersed in the gas tank for analysis of the proportion of gas contained in the biogas. The digester is connected to the gas tank by a hose for the collection of the produced gas. The gas tank is divided into two (2) parts; the first part contains water to ensure the water-tightness of the tank, which will be nested in the second part which is a tank to which the produced gas will be collected. It is in this second part that the gas sensors will be fixed.

2.2. Implementation of the analyser

For the implementation of this prototype, the arduino board was purchased and then connected with the different sensors chosen. The different sensors used are methane, carbon dioxide, water vapour, and hydrogen sulfide sensor. A computer program was developed on Arduino software and installed on the computer. This program is linked to the Excel spreadsheet through the PLX-DAQ application to enable real-time data collection. The components used were summarized in Table 1 below.

![Table 1. Components used for assembling the analyser](Image)

<table>
<thead>
<tr>
<th>Components</th>
<th>Characteristics</th>
<th>Unit Price (XAF)</th>
<th>Picture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arduino UNO</td>
<td>Arduino Uno Rev3 SMD</td>
<td>15,000</td>
<td><img src="Image" alt="Arduino" /></td>
</tr>
<tr>
<td>Temperature Sensor</td>
<td>DS12b20 ranges (-55 to +125°C)</td>
<td>3,500</td>
<td><img src="Image" alt="Temperature sensor" /></td>
</tr>
<tr>
<td>Methane Sensor</td>
<td>MQ-2 Module, Ranges (300 to 10,000 ppm)</td>
<td>4,500</td>
<td><img src="Image" alt="Methane sensor" /></td>
</tr>
<tr>
<td>Carbon Dioxide Sensor</td>
<td>MQ-135 Module, Range (10 to 1000 ppm)</td>
<td>4,500</td>
<td><img src="Image" alt="Carbon dioxide sensor" /></td>
</tr>
<tr>
<td>Humidity Sensor</td>
<td>DHT11 Module of air humidity sensor</td>
<td>3,500</td>
<td><img src="Image" alt="Humidity sensor" /></td>
</tr>
</tbody>
</table>

**Notes:**
- **PLX-DAQ** is a data acquisition system.
- **Arduino** is a microcontroller board.
- **DS12b20** is a temperature sensor.
- **MQ-2** and **MQ-135** are gas sensors.
- **DHT11** is a humidity sensor.

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**Fig. 1.** Data to be collected by the Biogas Analyzer.

**Fig. 2.** Functioning of the Analyser
The total price of the electronic equipment purchased is 31,000 XAF. The box and the software program developed were not taken into consideration in this study.

2.3. Testing of the Analyzer

Biogas production was carried out with fermentable substrates collected in the city. The chosen substrate was fresh cow dung collected from the paddocks. The first two tests were carried out in two 10-liters bottles with fresh cow dung as substrate and water. These different treatments are summarised in Table 2 below.

Table 2. Different compositions of reformulated substrates

<table>
<thead>
<tr>
<th>Process</th>
<th>Cow Dung/CD (Kg)</th>
<th>Water (Liter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test N°1</td>
<td>//</td>
<td>//</td>
</tr>
<tr>
<td>Test N°2</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Test N°3</td>
<td>6</td>
<td>4</td>
</tr>
</tbody>
</table>

In each bottle, a specific amount of cow dung was introduced, measured with a balance, and supplemented with water. The bottles were sealed to prevent the presence of air in the chamber.

2.4. Measuring of Temperature

The temperature was measured by this analyser. The temperature probe was inserted into the 10-liters bottle containing the organic material. The data is collected directly on the computer via Excel software for analysis (see fig.3).

2.5. The measure of Biogas Produced

The measurement of the proportion of gases contained in the biogas produced by our two (3) reactors was carried out every day during the hydraulic retention time of 30 days. The gas sensors were inserted into a plastic container containing the biogas produced and connected to the analyser by probes. To collect the data, the analyser must be connected via cable to the computer. Figure 3 below shows the different parameters collected by the analyser on the computer.

Fig.3. The measure of methanization parameters, a- measurement of the proportion of gases in the open air, b- measurement of the percentage of gases, and temperature during the production of biogas.

Figure 3 shows the data collection process for anaerobic digestion, into fig.3a the test in the open air in the laboratory of methane’s measure, CO₂, and humidity air. Into fig.3b, the test was carried out with a 10-liters reactor. In the middle is the analyzer with probes immersed in the reactor to collect data on the computer.

2.6. Statistical Data Analysis (SDA)

The data collected as temperature, methane, carbon dioxide, and air humidity percentage will be analyzed and compared to other data from the literature. Curves will be plotted to better visualize the different proportions of gases as a function of temperature.

3. Results and discussion

3.1. The measure of temperature and Biogas produced

The data collected (temperature and gas rate) of this methanation test are displayed on the computer via the Excel spreadsheet. Figure 4 presented and overview of this data displayed on the computer.

Fig. 4. Data was collected on the computer via Excel software.

The spreadsheet includes the four data collected by the analyser. These are the temperature of the substrate, and the levels of methane, carbon dioxide, and water vapor contained in the biogas produced. In the middle of the Excel spreadsheet, is a PLX-DAQ program that allows linking the arduino software to our Excel spreadsheet.

3.2. Statistical Data Analysis collected

The data collected were analyzed, and the averages of these data were summarized in Table 3 below.

Table 3. The Average data of the methanization parameters

<table>
<thead>
<tr>
<th>Process</th>
<th>Temperature (°C)</th>
<th>CH₄ (ppmv)</th>
<th>CO₂ (ppmv)</th>
<th>H₂O (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test N°1</td>
<td>25.20</td>
<td>36.77</td>
<td>33.50</td>
<td>42</td>
</tr>
<tr>
<td>Test N°2</td>
<td>33</td>
<td>142</td>
<td>78.16</td>
<td>8.16</td>
</tr>
<tr>
<td>Test N°3</td>
<td>32.88</td>
<td>305.88</td>
<td>149.38</td>
<td>5.27</td>
</tr>
</tbody>
</table>

1ppm=1mg/kg et 1ppmv=1µL/L

Table 4 above shows that the three experimental tests were carried out in an ideal temperature range between 25 and 33°C (mesophilic temperature) for good anaerobic digestion. According to Shiwei et al. (2019), the methanogenic phase could perform great methane production efficiency in the temperature range of 35–25 °C. This probably justifies the
recommendation of Azadeh & Jalal (2020) to use the temperature in the range of 31–34°C as a base for biogas design purposes. In the first test, we obtained 32.75% methane (CH₄), 29.83% carbon dioxide (CO₂), and 37.40% water vapour (H₂O). The data obtained was normal because this first test was performed in the open air for the calibration of the sensors. In the second sampling test after 4 days of reactor loading, there was a flammable gas with a higher methane content than in the first sampling test. The methane content obtained was 62.18%, followed by carbon dioxide at 34.22% and water vapour at 3.57%. These results are close to those obtained by Igou et al (2002) using a gas chromatographic analysis which gave a rate of 61% methane and 35.65% carbon dioxide [12] which is also close to the results obtained with the OPTIMA BIOGAS 7 analyzer, of biogas composed of 58.52% methane and 39.24% CO₂ [13]. In the third sampling test carried out on the 10th day of production, the biogas obtained was also flammable with 66.41% methane, followed by water vapour at 1.14% and carbon dioxide at 32.43%. The methane content of the medium increased by 7.89% compared to the first test. The first sampling test by gas chromatographic analysis gave 58.30% methane and the second test gave 65.35% after 13 days of production, an increase of about 7% [3]. Knowing the proportions of gases in the biogas produced, it will be easier to purify them to increase its calorific value and avoid certain diseases. Several purification techniques already exist and will depend on the user of this gas.

![Fig.5. The proportion of gases recorded after 4 days by the analyser according to ambient air temperature](image5)

Table 5 below shows the proportions of methane, carbon dioxide, and water vapor recorded by the analyser. The first test was recorded in ambient air to see the operation of the sensors and calibrate them properly. The ambient air temperature fluctuated between 20 and 25°C, the medium contained more methane than the others in this room. The analyser works well for testing in a methanizer.

![Fig.6. The proportion of gases recorded by the analyzer as a function of temperature in a reactor](image6)

Figure 6 shows the different proportions of gases recorded by the analyser in a 10-liters bioreactor after 4 days of charging. A high proportion of methane is observed compared to the other gases present. The other gases present in the majority are CO₂ and H₂O which have almost the same proportions. The biogas obtained was flammable, which justifies the high rate of methane by other gases. The temperature was in the mesophilic zone, favorable for methanization.

![Fig.7. The proportion of gases recorded after 6 days by the analyzer according to ambient air temperature](image7)

Figure 7 shows the proportions of the different gases recorded after 6 days of charging by the analyser as a function of temperature. It can be seen in the figure that the temperature was almost constant at 25°C. We observed a high proportion of methane compared to other gases. The proportion of methane was 4 times higher than the other gases present. This justifies the flammability of this biogas.

![Table 4. Comparison of the data obtained with the data literatures tested with cow dung](table4)

<table>
<thead>
<tr>
<th>Analyzer</th>
<th>My Analyzer</th>
<th>Gas Chromatographic</th>
<th>OPTIMA BIOGAS 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₄</td>
<td>64.18</td>
<td>61</td>
<td>58.52</td>
</tr>
<tr>
<td>CO₂</td>
<td>33.22</td>
<td>35.65</td>
<td>39.24</td>
</tr>
<tr>
<td>H₂O</td>
<td>2.43</td>
<td>/</td>
<td>/</td>
</tr>
</tbody>
</table>

The data obtained by our analyser are in conformity with the proportions of gases contained in a biogas. The respective proportions of the gases obtained in Table 4 (CH₄ of 64.18; CO₂ of 33.22 and H₂O of 2.43) are within the range of the proportions of gases contained in a biogas [11]. Similarly, these proportions obtained with cow dung are close to those
obtained with the OPTIMA BIOGAS 7 biogas analyzers and the Gas Chromatograph [12 - 13].

4. Conclusion

This work has shown that it is possible to control the parameters of a methanization process and detect the composition of a biogas sample using a simple, effective, and inexpensive analyzer fitted with Arduino components and gas sensors. This analyzer is capable of recording the temperature of the substrate and the proportion of methane, carbon dioxide, and water vapor during methanization. This analyzer was first tested in ambient air for its calibration followed by two other tests in two 10-liters reactors. The first sampling test was performed after 4 days of bioreactor loading. Its test was first taken after 10 days of loading and the different proportions of gases obtained were much higher than in the first test, the methane rate was 66.41%, 33.32% CO₂, and 3.57% H₂O. As for the second test, the sample was taken after 10 days of loading, and the different proportions of gases obtained were much higher than in the first test, the methane rate was 66.41%, 32.43% of CO₂, and 1.14% of H₂O. We will improve this analyzer by adding a pH-sensor to monitor the degree of acidity and basicity of the substrate and a hydrogen sulphide sensor. At present, the analyzer is functional, and can solve the problem related to the high costs of analyzers. The biogas produced can be purified to use in the engine for electricity production or the water pumping in the rural zone.

References


