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Design and Production of a Device for Remote Control by GSM of the Operating Parameters of a Biodigester

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Abstract: This article describes the design and creation of a remote monitoring and control system based on GSM (Global System for Mobile) communications technology for monitoring the key parameters of a biodigester. Biodigesters are widely used for the conversion of organic materials into biogas, thereby contributing to renewable energy production and organic waste management. However, real-time monitoring and regulation of parameters such as temperature, humidity, product gas level, pH are essential to ensure the efficiency and safety of the digestion process. We created the device for remote control of the operating parameters of the biodigester using an Arduino card, a DHT11 sensor, a pH sensor, a GSM module and a 2 ×16 LCD (Liquide-Crystal-Display) display. A biodigester (4.5 L plastic container) and accessories were used. The experimental device created made it possible to remotely monitor the evolution of the temperature, humidity, the gas produced as well as the pH in the digester loaded with cow dung, for 45 days. Examination of the real-time evolution of the parameters measured by the device produced showed the same results as those carried out locally by the usual instruments, with a correlation coefficient of around 98%. During this digestion period, the temperature provided by the sensor varied from 25 ℃ to 37 ℃ (mesophilic mode) and the humidity levels varied from 70% to 95%. The results obtained show the reliability of the device produced. This research represents a significant advance in the management of biodigestion facilities. It offers a powerful tool to maximize biogas production, reduce maintenance costs, minimize environmental impact and contribute to the transition to cleaner, renewable energy.

Key words: Biodigester, remote control, GSM, biogas, waste management.

1. Introduction

The advent of advanced technologies has transformed the way we approach environmental and energy challenges. In this context, the effective management of organic waste treatment facilities, such as biodigesters, plays a vital role in reducing environmental impact while maximizing renewable energy production [1]. The integration of advanced tools and remote control by a GSM (global system for mobile communications) module constitutes a major contribution in this direction.

In Guinea from 1982 to the present day there are more than 200 biodigesters installed across the country, but due to lack of monitoring, many of these biodigesters are dysfunctional and tend to gradually die out [2].

This bad reputation is due to the fact that rigorous monitoring of digesters was not a common practice in the past, particularly for large capacity installations. The increase in volumes to be treated and shorter residence times have sometimes led to overloads which have destabilized ecosystems [3]. To overcome this problem, we must have an automated and even remote-control device in order to facilitate monitoring for the operator and also make it possible to know information on the operating parameters of the process in real time. Several parameters can influence the proper functioning

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of a methanization process such as: temperature, humidity, pH, etc. Control of these parameters is essential for optimal biogas production [4].

Digesters, as complex biological systems, are designed to anaerobically break down organic materials into biogas and digestates. However, the optimal management of these processes depends closely on the understanding of the interactions between biological and environmental factors [5].

At the same time, remote control via a GSM module offers a new dimension to digester management. Using this mobile communication technology, operators can monitor critical digester operating parameters in real-time from anywhere. This allows for immediate responsiveness in the event of anomalies or adjustment needs, thereby minimizing potential disruptions to the digestion process.

This study makes a contribution to the remote monitoring of the operating parameters of a biodigester using a GSM module. We examine the benefits of this approach in the intelligent management of organic waste treatment facilities, providing all the necessary information in real time. Furthermore, we highlight the potential implications in terms of operational efficiency, environmental sustainability, cost reduction and maximum renewable energy production. The aim of this research is to monitor the operating parameters of the biodigester in real time for optimal biogas production.

2. Materials and Methods

2.1 Materials

2.1.1 Study Framework

This research was carried out in the Electronics Laboratory of the Department Instrumentation and Physical Measurements of the IST (Higher Institute of Technology) of Mamou. This department is one of the six departments of the said institute which was created by ministerial decree No. 2004/9245/MESRS/CAB of August 25, 2004. It is a public institution with a professional, scientific, technical and technological nature, reporting to the Ministry of Higher Education, Scientific Research and Innovation. It is located in the Telico district, 4 km from downtown Mamou [6].

The urban commune of Mamou, in Middle Guinea, is located on the southeastern foothills of Fouta-Djallon, 270 km from the capital Conakry, between 9°54′ and 11°10′ north latitude and 11°25′ and 12°26′ West longitude. It covers an area of 2350 km^2 with a total population of 391777 inhabitants in 2020 and an average density of 167 inhabitants per km^2 [7]. The urban commune of Mamou is characterized by a tropical climate and the alternation of two seasons of the same duration, the dry season from November to April and the rainy season from May to October with an average annual temperature of 24.2 °C. Precipitation is approximately 1869 mm per year [8].

2.1.2 Work Equipment

The materials used in this work consist of: design tools, electronic components and simulation software (plastic can, flexible tube, valve glue, Arduino card, temperature and humidity sensor, pH sensor, display LCD, LED (light-emitting diode), computer, USB (universal serial bus) cable, microcontroller and GSM module).

2.2 Methods

The methodology adopted in this work consists of: designing the biodigester, programming the sensors and the remote-control module, choosing the different electronic components, developing the program flowchart, designing and producing the device, making the diagram of the entire system and experimenting with the device.

2.2.1 Experimental Device

The experimental device is made up of two parts: the biodigester for the production of biogas composed mainly of methane and carbon dioxide and the remote monitoring and control device.

2.2.1.1 Biodigester

This experiment concerns the determination of the quantity of biogas contained in 1.5 kg of substrate (cow dung). To do this, we simultaneously used three 4.5 L plastic bottles as digesters: the first is the fermenter, the second is the gas tank filled with water and the third which is empty, allows us to recover the water. which will be emptied from the gasometer under the pressure of the biogas produced. It is graduated in centiliter and liter using graph paper in order to quantify the gas produced.

The fermenter was loaded with 1.5 kg of dung with a dilution of 1.5 L of water, the ratio of which is 1:1.

2.2.1.2 Device for Monitoring and Remote Control by GSM of the Operating Parameters of the Biodigester

This part consists of programming the various sensors which will display in real time the evolution and variation of the temperature, humidity and pH in the digester.

The programs and the different codes carried out in the Arduino software make it possible to operate the system, these are:

- Programming the DHT11 sensor and digital display via an LCD screen: this DHT11 Sensor installed in the digester, makes it possible to detect the variation in temperature and humidity then transmit them to the system for their alphanumeric display on the LCD screen;
- Programming the pH sensor: This sensor allows you to measure the pH value which is the unit of measurement for acidity or alkanity in order to display its value on the LCD screen;
- Programming the GSM (Global System for Mobile) module for monitoring and remote control of parameters: this remote-control system allows monitoring parameters of environmental conditions of the biodigester and receiving information in real time through a GSM mobile network.

2.2.1.3 Food Preparation

Power supply is an electrical circuit that provides the energy necessary for a device to function properly. In this work, it is a question of designing a power supply capable of providing voltages of 12 V/3 A, 5 V DC (direct current) for powering the Arduino board which is the unit for processing data from the sensors and 12 V DC/1.5 A for powering the GSM module which sends the information detected by the sensors.

The synoptic diagram of this power supply is shown in Fig. 1.

2.2.2 Choice of Components

The different electrical and electronic components for producing the power supply are as follows.

2.2.2.1 Choice of Regulators

For the proper functioning of our device, we have chosen two voltage regulators 7805 and 7812: (a) 7805 which delivers a direct voltage of 5 V when it receives a voltage higher than the voltage of at least 3 V which is the voltage drop across the integrated regulator; (b) 7812 which will deliver a direct voltage of 12 V and a current of 1.5 A when the applied voltage is at least greater than the output voltage of 3 V to power the GSM.

2.2.2.2 Choice of Filter Capacitor

A capacitor charges and discharges at constant current to maintain a constant voltage across its terminals by eliminating noise around a DC voltage. The minimum voltage at the input of the 7812 regulator is 1:

$$U_{cmin} = U_{output.reg.} + U_{reg\ dif.} = 12\ V + 3\ V = 15\ V \quad (1)$$

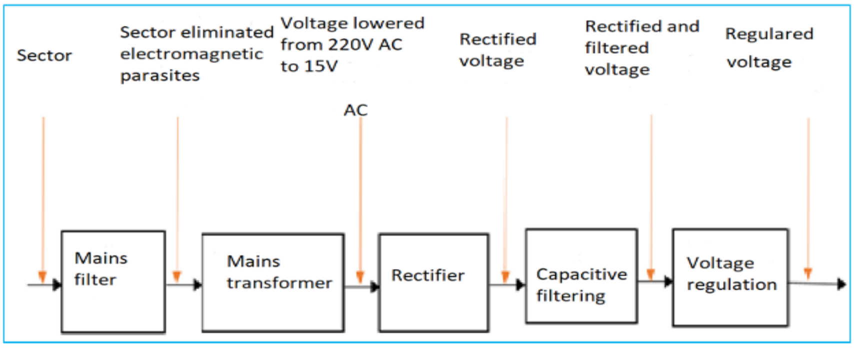

Fig. 1 Power supply block diagram.

The maximum voltage across the capacitor is 2.

$$U_{Cmax} = \sqrt{2}U_{2eff} - 2U_{Diodes} = \sqrt{2}\times 15\ \text{V} - 2\times 0.7\ \text{V} = 19.8\ \text{V} \quad (2)$$

The residual ripple across the capacitor is 3.

$$\Delta U = U_{Cmax} - U_{Cmin} = 19.8\ \text{V} - 15\ \text{V} = 4.8\ \text{V} \quad (3)$$

The capacitance of the filter capacitor is determined by Eqs. (2)-(4):

$$C = \frac{I_S}{\Delta U \times F} = 6{,}250 \quad (4)$$

Or: $I_S = 3$ A: Regulator output current; $F = 100$ Hz: Frequency;

2.2.2.3 Choice of Transformer

The choice of a power supply depends on the filtering capacitor and the transformer, it will therefore be necessary to find a compromise between the filtering capacitor and the transformer, the choice of which depends on the following quantities:

- Effective voltage at the primary of the transformer V_1;
- Effective secondary voltage V_2;

Apparent power: $S = V_2 \times I_2$, with $V_2 = 1.2 \times V_S$

Thus: $V_2 = 1.2 \times 12\ \text{V} = 14.4\ \text{V}$

We will take a transformer with a secondary effective voltage equal to 15 V.

2.2.2.4 Choice of Rectifier Diodes

We choose diodes which can withstand a current of 3 A, so 1N4007 diodes were used for this purpose. The electrical circuit of this power supply is given in Fig. 2.

2.3 Data Processing Unit

It is composed of an arduino uno card, responsible for collecting information from the potential hydrogen (pH) and humidity (DHT11) sensors to process it and display it on the LCD screen (Crystal-Liquid-Display). The SIM900 GSM module receives SMS (Short Message Service). Depending on the information provided by these sensors, the control unit orders the GSM to send SMS messages to the user in order to adjust the detected parameter.

2.4 Creation of the Device

The synoptic diagram of this achievement is represented by Fig. 3.

The processing unit reads data from the sensors at regular intervals. If the data exceed the predefined limits (e.g., too low temperature or pH), the microcontroller sends alerts to the GSM by displaying the detected values on the LCD screen and the GSM module in turn sends SMS to the users to take steps to correct the situation. The entire system is powered by a regulated 12 V power source. The entire device produced is presented in Fig. 4.

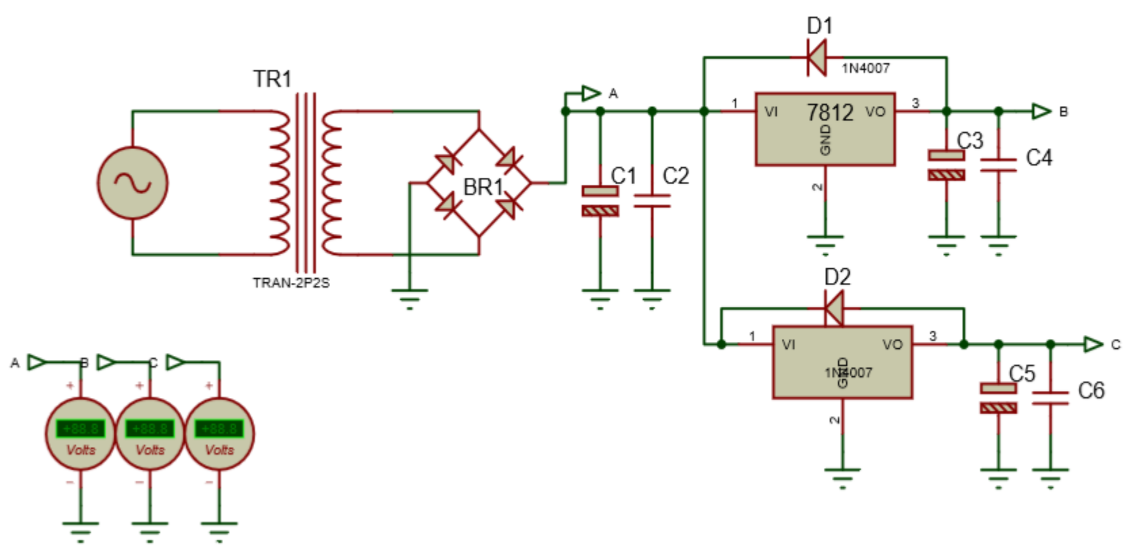

Fig. 2 Power supply diagram.

Fig. 3 System block diagrams.

Fig. 4 Device for monitoring and remote control of parameters.

3. Results and Discussions

The results obtained during this work are represented in the form of diagrams and curves for their analysis and interpretation. The remote-control device has been successfully produced and tested in laboratory conditions by displaying the different variations of the parameters on the screen. System responses to parameter variations were fast and accurate. The design and construction of this device offered a practical and efficient way to monitor and control key parameters of the biodigester remotely. It has notable advantages in terms of ease of use, economics, as well as reduced risks of interruption of gas production.

3.1 Biogas Potential of Cow Dung Waste

During the anaerobic digestion process for 45 days, we collected the daily volume of biogas using the displaced liquid method. The results of the experimental evaluation of the biogas potential of cow dung waste in anaerobic digestion are shown in Fig. 5.

Biogas production began on the third day after loading the digester and lasted 45 days with an average temperature varying between 26 and 30 ℃. The cumulative production of biogas was 0.033 m^3/kg of dung.

3.2 Evolution of Temperature inside and outside the Biodigester

Temperature is one of the important factors that influence anaerobic digestion. The temperature variation inside the digester and in the ambient environment is illustrated in Fig. 6.

3.3 Evolution of Humidity and pH

The variations in pH and humidity in the fermenter during production are shown in Figs. 7 and 8.

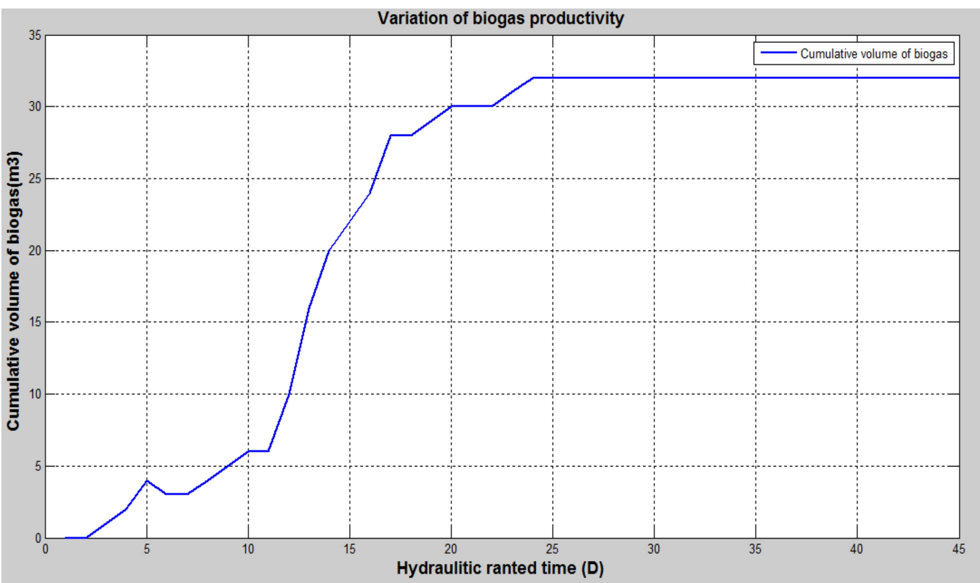

Fig. 5 Cumulative biogas production.

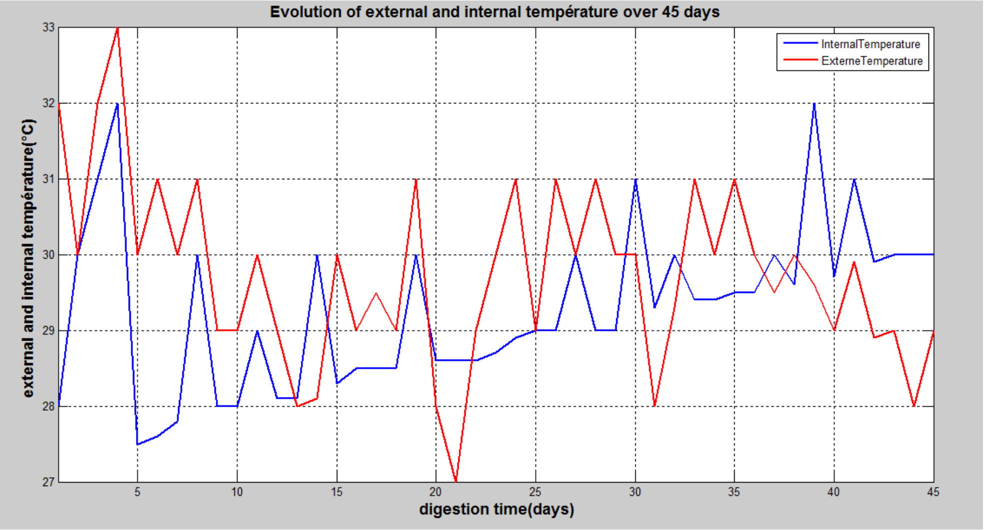

Fig. 6 Variation of internal and external temperatures of the biodigester.

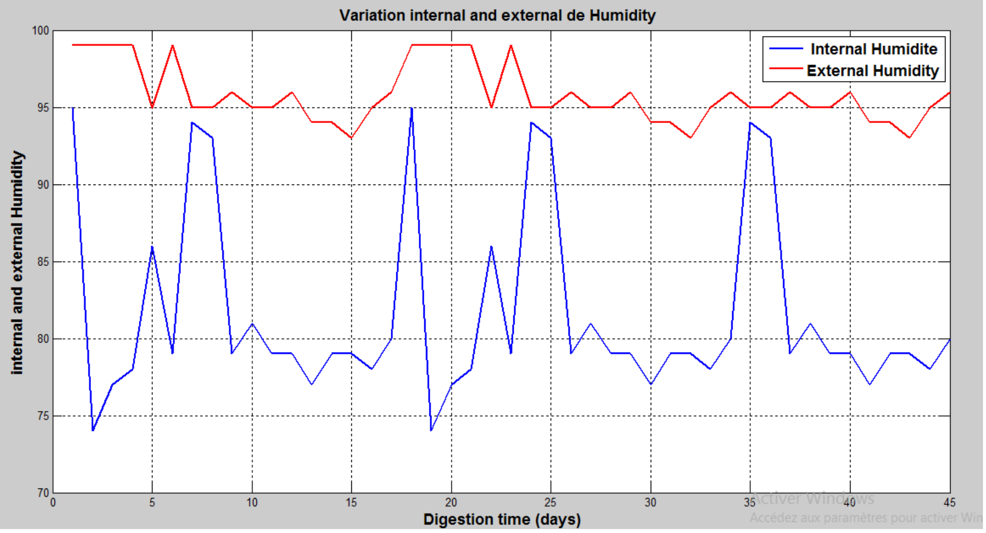

Fig. 7 Variation of internal and external humidity.

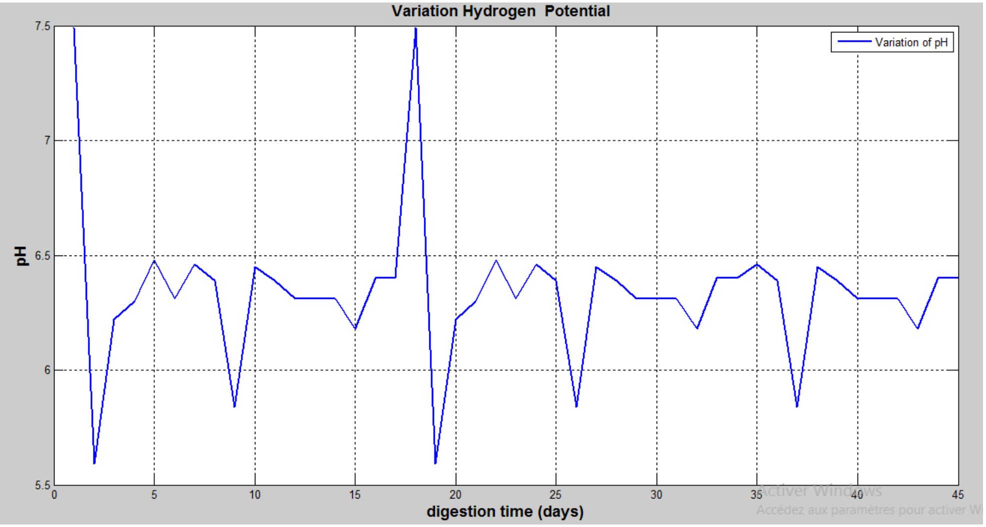

Fig. 8 pH variation.

Humidity levels ranged from 70% to 95% with an average of 81.60%. This humidity range is similar to other research work and it remains favorable to microorganisms for methanization [9, 10]. The pH variation is shown in Fig. 8.

The pH plays an essential role in the biochemical and physicochemical functioning of anaerobic digestion media, it should also be noted that the performance of a biodigester, from the point of view of gas production, depends on the adjustment of the pH.

The bacteria involved in anaerobic digestion tolerate a pH varying between 6 and 8, with optimal activity around seven [11, 12].

Monitoring of pH showed a drop in its value from 7.5 to 5.5 in the first three days. This drop is explained by the decomposition of organic matter and the production of VFA (volatile fatty acids) in the environment. This phase of VFA production would correspond to the first two phases “hydrolysis and acidogenesis” [13, 14].

4. Conclusion

In conclusion, this work represents a significant advance in the management of biodigestion facilities. It offers a powerful tool to maximize biogas production, reduce maintenance costs, minimize environmental impact and contribute to the transition to cleaner, renewable energy. Biodigesters equipped with this GSM remote monitoring and control system are better prepared to respond to current resource management challenges and play an essential role in the transition to a circular and sustainable economy.

Future research could focus on optimizing automated control algorithms, integrating artificial intelligence for predictive decision-making, and exploring new communications technologies for even more advanced monitoring. Furthermore, it would be interesting to extend this approach to other areas of organic waste management, thus paving the way for a more holistic management of organic resources. Ultimately, our goal remains the creation of more efficient, more sustainable and more environmentally friendly biodigester installations.

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