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Monitoring of biodigesters through a computerized system integrated to IoT platform

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***Keywords*— Biodigester, Anaerobic Digester, Monitoring System, Internet of Things.**

***Abstract*— *The purpose of the biodigester is to provide the proper treatment of organic waste that would be inappropriately disposed of in the environment. These residues in their decomposition process are responsible for the release of gases that cause the greenhouse effect, such as carbon dioxide (CO_2) and methane gas (CH_4). In this context, the objective of this work was the construction of a computational system that would allow the real-time monitoring of the parameters of physical quantities involved in the digestion process, applied to the study of filters for biogas. For the development of this work, four prototypes of batch digesters were built, adapted with electronic sensor modules to collect, and send data in real time, through the IoT (Internet of Things) platform. Hardware and embedded software platforms based on low-cost microcontrollers using Industry 4.0 concepts were used. The parameters monitored by the sensors were: concentration of methane (CH_4), carbon dioxide (CO_2) and hydrogen sulphide (H_2S), temperature, humidity, and gauge pressure in the biogas. It is concluded that the biodigesters monitoring system through the ability to monitor factors in real time allows a better understanding of the anaerobic digestion process, allowing a better analysis and optimization, as well as the performance study of the elements involved in the process such as biomass, filters, and environmental factors.*

I. INTRODUCTION

In Brazil, cattle and swine farming are among the agricultural activities responsible for a large part of greenhouse gas (GHG) emissions, making it necessary to adopt measures to mitigate these emissions. One of the main strategies is the construction of anaerobic digesters so that there is an adequate treatment of the waste generated in these properties. The adoption of this method shows that the emission levels of these gases can be reduced (GARCIA JUNIOR, PIRES & DA CUNHA *et al.*, 2016; ALCÓCER *et al.* 2019).

The digester is defined as a hermetically closed chamber in which a process called anaerobic biodigestion of an organic compound occurs (NOGUEIRA, 1986).

In this process, a series of microorganisms act by transforming molecules of complex organic matter into simple structures that, when metabolized, result in a mixture of gases and a series of reduced compounds (SILVA *et al.*, 2012).

Such a process can be used in several applications that minimize the environmental impacts that would be caused by the incorrect destination of organic waste, having as a by-product two new value-added products, namely: biogas, which can be used as fuel for several applications, and the biofertilizer, which can be used as organic fertilizer in plantations (ALCÓCER *et al.*, 2014; BARREIRA, 2011).

According to reports by Alcócer *et al.* (2019) in practical experiments to implement biodigesters on properties in rural areas, this equipment has the following advantages for use: sustainable management in the destination of organic waste; affordable cost for deployment and operation; production of biofuel and biofertilizer that add value to the project; and environmental sustainability and improvement in soil characteristics through non-contamination with animal waste.

The dissemination of anaerobic digester technology has been a proposal of relevance for sustainability, whose environmental and economic results have been positive for both owners and the environment (PINTO *et al.*, 2018).

Biogas is the popular name used to refer to a flammable mixture of gases that are generated when organic material undergoes anaerobic digestion. This mixture usually contains 40% to 70% methane, 25% to 45% carbon gas, and the remainder hydrogen, nitrogen, and hydrogen sulfide. This mixture has good caloric power and can be used as fuel or to generate electricity indirectly (ABBASI, TAUSEEF & ABBASI, 2011).

The biofertilizer consists of a residue obtained through the process of biodigestion, which can be diluted in water to be used directly in the crops through fertigation or after going through a drying process, being considered as a high quality fertilizer in agriculture (MILANEZ *et al.*, 2018).

Monitoring and control are extremely important strategies to achieve adequate stability and greater efficiency in the anaerobic digestion process. Monitoring is a fundamental requirement for better control of the process, in which the lack of adequate indicators can result in losses in the efficiency of the biodigestion process. An ideal indicator tends to reflect on the state of the process and should be easy to access and simple to use, parameters such as temperature variation among others are considered valuable in decision making, always aiming to keep the process functioning in balance (BOE *et al.*, 2010).

Despite the vast literature on biodigesters and the process of anaerobic digestion, a lack of data collection on the control and monitoring of physical quantities and the reactions that occur in biodigesters was identified, especially in rural areas, in which the use of sustainable technological tools would promote a better efficiency in the biogas and biofertilizer generation process.

The purpose of this research was focused on the modeling and construction of a solution for electronic monitoring in real time of the parameters of physical quantities occurred during the anaerobic digestion process, using a computational technological system that will be responsible for the collection through electronic sensors, storage and analysis of data that will be accessible via the Internet. The solution here entitled: UNIBIO - Biodigesters Monitoring System.

Through this system, the following parameters could be monitored during the anaerobic digestion process: concentration of gases (sulfide, methane, carbon); temperature, relative humidity, and gauge pressure of the gas chamber; temperature of the biomass and of the external environment to the biodigester.

In this context, the objective of this work was to develop a computer system for real-time electronic monitoring of parameters of physical quantities that occur during the life cycle of the anaerobic digestion process in rural biodigesters connected to the internet through an IoT platform.

II. MATERIAL AND METHODS

The present research is of an applied nature and of a descriptive character using an experimental method through a quantitative approach. To meet the specific objectives of this proposal, the methodology was divided into four stages.

2.1. Batch Biodigester Prototype

In the first stage, to support the experimental phases of the research as well as the validation of the computational system to be built, the modeling and construction of 4 (four) prototypes of batch digesters that were compatible with the proposed electronic monitoring system was elaborated. Which resulted in the model shown in Fig. 1.

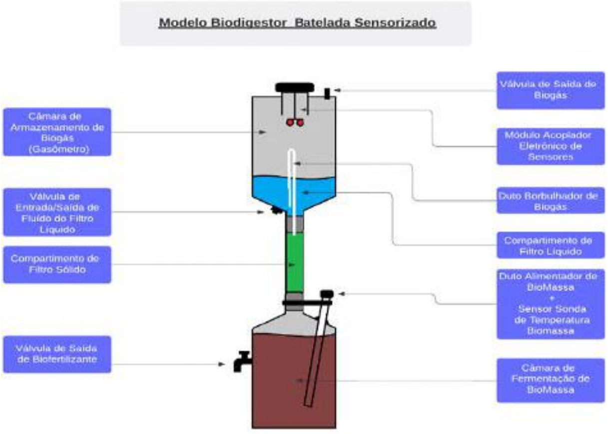


Fig. 1: *Batch Biodigester Model*
Source: Produced by the author (2021)

The following features were used in the prototypes: anaerobic environment in the biomass chamber, valve for loading primary biomass, unloading valve for processed biomass, biodigestion vessel, biogas storage vessel (gasometer); removable compartment for filters (solid and liquid) of biogas; coupling with electronic sensor module device; and low-cost materials to enable the application of the equipment in small farmers in the rural area.

2.2. Hardware

In the second stage, the biodigester monitoring system hardware was developed based on an ATMEGA2560 microcontroller on an Arduino-compatible platform, consisting of 2 (two) physical modules, as shown in Fig. 2.

Electronic sensor module, located in the biodigesters, has the following characteristics: universal coupling in any biodigester model; easy access for maintenance, inspection, and sensor replacement; suitable for use in critical operating conditions in environments subject to weather conditions such as exposure to sun, rain, wind, humidity, temperature variations and corrosion.

IoT controller module , presenting the following characteristics: controlling the biodigesters' sensor modules; capture the reading values of all sensors; process the readings and send them to an online database on the internet; manage connectivity through media (wifi / 2g/3g/4g mobile network); ability to store collected data for a period of 90 days; have a failure control system for data security, in case of problems with access: to the internet, to the web server and to the database server; and allow the storage of data locally when the system is offline;

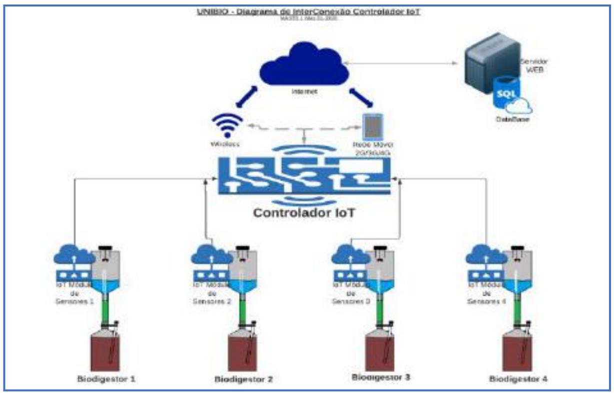


Fig. 2: IoT Connectivity and Sensor Modules Diagram
Source: Produced by the author (2021)

2.3. Software

During the third stage, the software used in the solution were designed, whose objective was to build a system for real-time monitoring and analysis of data obtained during the anaerobic biodigestion process.

The biodigesters monitoring system was called the UNIBIO system and is represented according to the diagram shown in Fig. 3.

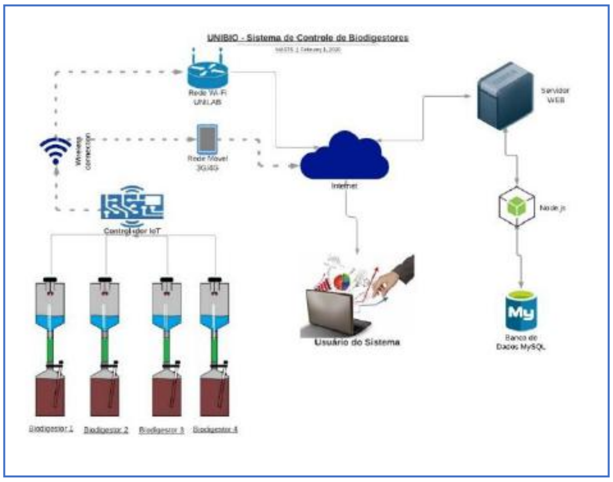


Fig. 3: Functional Structure Diagram of the UNIBIO System
Source: Produced by the author (2021)

The macro view of the development of the software architecture of the UNIBIO system can be classified into two parts: the REST API server and the Web Client Application.

The REST API Server was responsible for providing an interface that served as a basis for other parts of the system. The REST architecture was chosen because it provides a simple and direct interface to access services on the internet, especially in IoT applications, in addition to offering good performance (DE MELO SILVA *et al.*, 2016).

Maalej & Robillard (2013) define an API as a contract between the component that provides functionality and the component that uses the functionality (the client), allowing the reuse of libraries and frameworks in software development.

The Web Client application was responsible for providing the end user with a way to interact with the data from the monitored biodigesters. It can be accessed by any device connected to the internet that has a web browser.

The Web Client application has the function of performing the registration of biodigesters projects in the UNIBIO system, according to the functions described below: accessing graphs and data report of the monitored biodigesters; monitor the real-time monitoring of biodigesters; and register and catalog new projects of biodigestors; efficiently consult the information consolidated in the database of the

The DBMS chosen for the implementation was MySQL because it has a GPL license and has broad community support, being one of the most used DBMSs on the market today.

The data model was defined following the normalization of the data, prioritizing the speed of queries, the scalability of the system and the prevention of future problems. Allowing the inclusion of new biodigesters to the system without the need for code changes.

The communication of the modules of the UNIBIO system takes place through an API, providing better data security, scalability of the system and simplification of complexity.

The embedded software used in the IoT microcontroller was developed in the C++ programming language, which is an object-oriented language and because it is a native language of the Arduino IDE programming tool along with the C language for the microcontrollers used in the project. (ATMEGA2560 and ESP-8266) you have greater control over the resources of microcontrolled devices.

2.4. Anaerobic Digestion

The fourth step of the methodology was carried out with the anaerobic digestion experiment using the four prototypes of biodigesters monitored with sensors, and each prototype used a different combination of filter for the biogas as shown in Fig. 4.

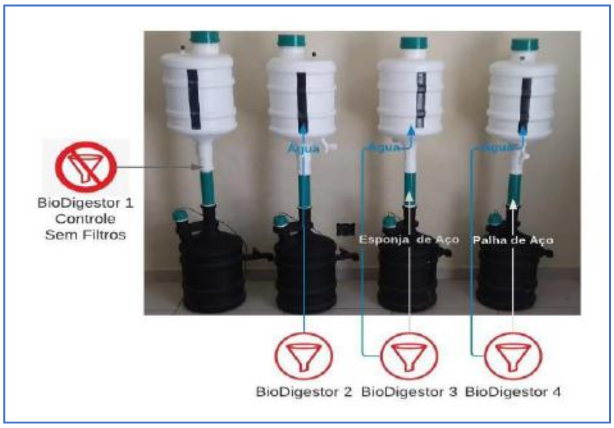


Fig. 4: Arrangement of Filters in Biodigesters
Source: Produced by the author (2021)

The prototypes were organized as follows: prototype 1: control element had no filter; prototype 2: filter: water column (10 cm); prototype 3: filter: water column (10 cm) + steel sponge column (20 cm); and prototype 4: filter: water column (10 cm) + steel wool column (20 cm).

Two repetitions of the experiment were performed. The first experiment took place between the dates (06/07/2020 and 08/10/2020) and the second experiment between the dates (04/16/20210 and 06/04/20210) in the city of Fortaleza, state of Ceará at the coordinate’s latitude (-3.8414890), longitude (-38.482589) and altitude (28 meters).

The biomass used was composed of 36 liters of fresh bovine manure diluted in 36 liters of drinking water at room temperature (26°C), later the 72 liters produced in the mixture were used to feed the 4 digesters homogeneously with 18 liters of biomass. each one.

2.5. Sensors

Sensors are electronic devices that send electrical signals according to the variation of the physical or chemical phenomenon that they propose to measure, with the objective of relating information through the output signal with the quantity to be measured, such as temperature, speed, current, among others (THOMAZINI & DE ALBUQUERQUE, 2020).

In the construction of the biodigester sensor modules, the components as shown in Table 1 were used.

Table 1: Sensors used in UNIBIO Monitoring

Item	Description	Qty	Type	Reading Interval	Unit
1	Methane gas sensor	4	Analog	300 to 10,000	ppm
2	Hydrogen sulfide gas sensor	4	Analog	1 to 200	ppm
3	Carbon dioxide gas sensor	4	Digital	0 to 5,000	ppm
4	Pressure sensor	4	Analog	0 to 1,200	kPa
5	Humidity and temperature sensor	4	Digital	0 to 95	%RH
				-40 to 80	°C
6	Temperature probe sensor	4	Digital	-55 to 125	°C

Source: Produced by the author (2021)

2.6. Sensor Calibration

For the calibration of the sensors, the methods recommended by the manufacturer in the datasheet of the components were used, in addition to each specific sensor was compared with an industrial calibration equipment. After the individual calibration of each component, a method called set calibration was applied, in which the four sensor modules of the project were subjected to the same gas sample in a controlled environment and the reading values for each sensor were compared.

After the completion of the biodigestion cycle, measurements were carried out on the gases stored in the four prototypes of batch digesters with the professional equipment gas analyzer GEM5000.

III. RESULTS AND DISCUSSION

3.1. Batch Biodigesters Prototypes

As a result, the benchtop batch biodigesters developed to carry out the anaerobic digestion process were built in 4 prototypes as shown in Fig. 5.

Fig. 5: Constructed Prototypes of Biodigesters
Source: Produced by the author (2021)

These prototypes showed the following characteristics during use in anaerobic biodigestion tests, with positive characteristics to be highlighted: easy biomass feeding and filter loading at the beginning of the process; easy disassembly after the end of each cycle, being practical to discharge the waste substrate after the digestion process; easy washing of the biodigester to prepare the device for cycle restart; good sealing and retention of odors expelled by equipment and use; and good mechanical resistance of the biodigester equipment, preventing the appearance of cracks and biogas leaks

3.2. Monitoring Hardware

The construction of the sensor modules for the digester and the IoT controller module were carried out, which allowed real-time communication of the monitored digesters with the internet through the IoT platform, with the result as shown in Fig. 6.

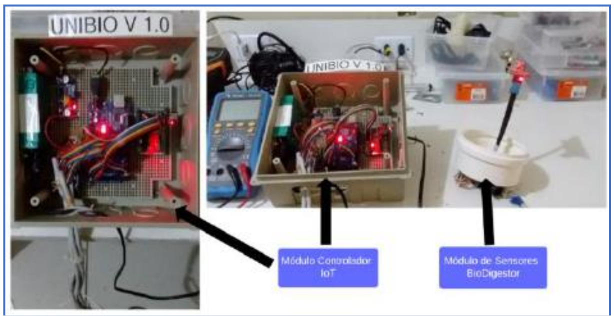


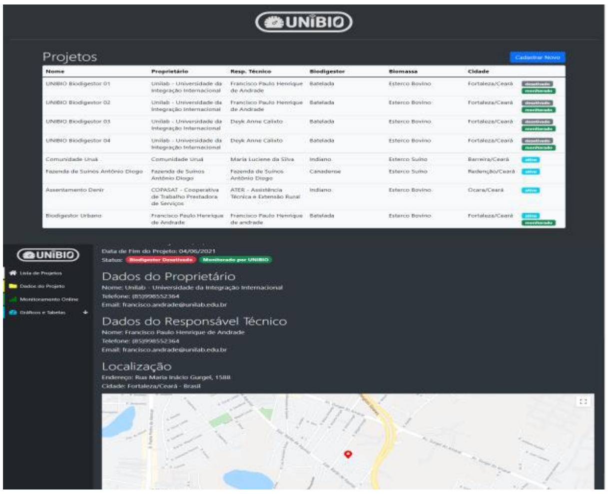
Fig. 6: IoT Controller Constructed Module
Source: Produced by the author (2021)

The hardware components such as the IoT controller and the sensor module for the biodigester had their functioning fully in accordance with the requirements for which they were defined, with the following highlighted results: the operation of the system uninterrupted throughout the period of biodigestion, having its adverse failure control system successful in data preservation in case of contingency saving on local memory card in sporadic failures of communication channels with the cloud, so data can be synchronized when re-establishing communication channels maintaining integrity the data collected by the sensors; and the biodigester sensor modules achieved easy coupling with the biodigestion device and simplified access for maintenance.

3.3. Monitoring Software

The software systems modules developed for the UNIBIO system presented the expected performance and performance for the proposed objectives. The results achieved with Software modules are as follows:

The UNIBIO system made it possible to create a register to catalog new or already implemented biodigester projects in the field. In Fig. 7 the screen of biodigester projects registered in the system is displayed.



Projetos

Nome	Proprietário	Resp. Técnico	Biodigestor	Biomassa	Cidade
UNIBIO Biodigestor 01	Unilab - Universidade da Integração Internacional	Francisco Paulo Henrique de Andrade	Batelada	Esterco Bovino	Fortaleza/Ceará
UNIBIO Biodigestor 02	Unilab - Universidade da Integração Internacional	Francisco Paulo Henrique de Andrade	Batelada	Esterco Bovino	Fortaleza/Ceará
UNIBIO Biodigestor 03	Unilab - Universidade da Integração Internacional	Deyk Anne Calixto	Batelada	Esterco Bovino	Fortaleza/Ceará
UNIBIO Biodigestor 04	Unilab - Universidade da Integração Internacional	Deyk Anne Calixto	Batelada	Esterco Bovino	Fortaleza/Ceará
Comunidade Uruá	Comunidade Uruá	Maria Luciene da Silva	Indiano	Esterco Suíno	Barreira/Ceará
Fazenda de Suínos Antônio Diogo	Fazenda de Suínos Antônio Diogo	Fazenda de Suínos Antônio Diogo	Canadense	Esterco Suíno	Redenção/Ceará
Assentamento Denir	COPASAT - Cooperativa de Trabalho Prestadora de Serviços	ATER - Assistência Técnica e Extensão Rural	Indiano	Esterco Bovino	Ocara/Ceará
Biodigestor Urbano	Francisco Paulo Henrique de Andrade	Francisco Paulo Henrique de andrade	Batelada	Esterco Bovino	Fortaleza/Ceará

Data de Fim do Projeto: 04/06/2021
Status: Biodigestor Desativado Monitorado por UNIBIO

Dados do Proprietário
Nome: Unilab - Universidade da Integração Internacional
Telefone: (85)998552364
Email: francisco.andrade@unilab.edu.br

Dados do Responsável Técnico
Nome: Francisco Paulo Henrique de Andrade
Telefone: (85)998552364
Email: francisco.andrade@unilab.edu.br

Localização
Endereço: Rua Maria Inácio Gurgel, 1588
Cidade: Fortaleza/Ceará - Brasil

Fig. 7: Screen of Registered Projects
Source: UNIBIO System (2021)

The system presented the functionality of visualizing in real time the updated parameters of the readings of the sensors installed in the monitored digesters, issuing alerts to the user in case any parameter exceeds the predetermined limits for the monitored data. As illustrated in Fig. 8**.**

Fig. 8: Biodigester Online Monitoring Screen
Source: UNIBIO System (2021)

Fig. 9 shows the Cartesian graph of the gases read as: methane gas, carbon dioxide and hydrogen sulfide during the anaerobic digestion process, followed by the data table of these gases.

Fig. 9: Comparative Table of CH_4 Gases
Source: UNIBIO System (2021)

Fig. 10 shows a comparison of the readings performed on the four prototypes of biodigesters for the measurements of hydrogen sulfide.

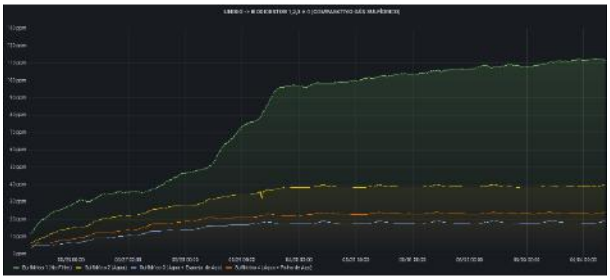


Fig. 10: Comparative Chart of H_2S gases
Source: UNIBIO System (2021)

Fig. 11 shows a comparison of the readings performed on the four prototypes of biodigesters for carbon dioxide measurements.

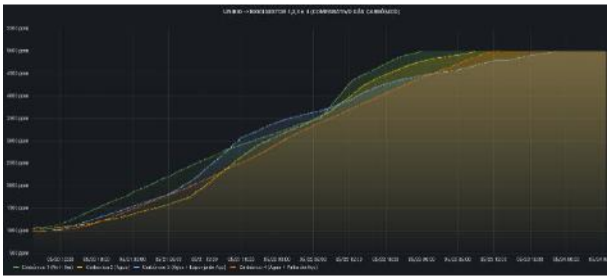


Fig. 11: Comparative Chart of CO_2 gases
Source: UNIBIO System (2021)

Fig. 12 shows the Cartesian graph represented over time of parameters such as temperature variations (gasometer, biomass and environment), relative humidity variation and internal gauge pressure of the biogas chamber.

Fig. 12: Temperature x Humidity x Pressure
Source: UNIBIO System (2021)

3.4. Anaerobic Biodigestion Results Analysis

The anaerobic biodigestion process was carried out in the four biodigester prototypes to study the biogas filters, with the test repeated later to validate the results obtained. The data collected by the system are presented in consolidated form in Table 2.

It was observed that: The application of filters generates a thermal barrier that retains greater heat in the biomass during periods of exposure to the sun; The application of the liquid filter layer with water greatly increases the relative humidity of the air dispersed in the gasometer; The temperature in the biomass, during the process, was kept within the safe margin for the conservation of the biological health of the anaerobic digestion process. The set of filters (Biodigestor3: Steel Sponge + Water) had the best performance, followed by the set (Biodigestor4: Steel wool + Water) which had the second best performance in biogas filtration.

3.5. Filter Performance and Data Analysis

From the database generated by the electronic monitoring during the anaerobic biodigestion test, which was accessible through the WEB client module of the UNIBIO system. We obtained the following consolidated data readings for the 4 prototypes, as shown in Table 3.

Under the Table 3 were considered for data reading, due to the reading limits of the methane and carbon dioxide gas sensors being respectively 10,000ppm and 5,000ppm, the moment when the CO2 sensor reached a reading of 5,000 was considered as the cut-off point. ppm in each cycle.

For calculating the proportion of methane / carbon dioxide present in the biogas. At this point, a reading of 4,600ppm for carbon dioxide was considered, compensating for the initial presence of 400ppm of Co2 in the atmospheric air that was present in the gasometer at the beginning of each cycle.

Soon after the methane gas sensors reached the 10,000ppm mark, the gasometer chambers were emptied so that the sensor reading cycles could be restarted. The process of anaerobic digestion, however, continued uninterrupted. The sensors began to read the new concentrations of gases as they were being generated by the

Table 2: Consolidated Report of Readings Biodigestor UNIBIO

	Biodigestor 1 No Filters				Biodigestor 2 Filter: Water				Biodigestor 3 Filters: Water + Steel Sponges				Biodigestor 4 Filters: Water + Steel Wool			
	1st Test		2nd Test		1st Test		2nd Test		1st Test		2nd Test		1st Test		2nd Test	
temp. MAX Biomass	29.7°C		30.8°C		32.2°C		31.5°C		32.6°C		32.3°C		32.8°C		31.3°C	
temp. MIN Biomass	26.1°C		23.1°C		25.6°C		23.5°C		25.1°C		23.8°C		24.9°C		23.6°C	
temp. MAX Gasometer	39.8°C		47°C		38.5°C		44.9°C		38.2°C		43.4°C		39.1°C		42.3°C	
temp. MIN Gasometer	24.1°C		25.5°C		23.8°C		25.9°C		23.7°C		26°C		24.1°C		24.3°C	
HR MAX Gasometer	92%		89%		95%		95%		95%		95%		95%		95%	
HR MIN Gasometer	68%		50%		78%		83%		79%		81%		76%		88%	
	ppm	%	ppm	%	ppm	%	ppm	%	ppm	%	ppm	%	ppm	%	ppm	%
$CH_{4\ gas}$	7350	61.5	7251	60.7	8920	65.9	8576	64.9	9550	67.4	9278	66.7	9385	67.1	8998	66.1
$CO_{2\ gas}$	4600	38.4	4600	38.5	4600	34	4600	34.8	4600	32.5	4600	33.1	4600	32.8	4600	33.8
H_2S gas	67	<1	88	<1	24	<1	31	<1	8	<1	16	<1	12	<1	18	>1

Source: Produced by the author (2021)

Table 3: Data Collected in the UNIBIO System for Biodigestor 1

BIO	Cycles	Time (Days)	Reading CO$_2$ (5000 ppm) Date/Time	Pressure (kPa)	CH$_4$ ppm	CO$_2$ ppm	H$_2$S ppm	MCS* CH$_4$(%)	MCS* CO$_2$(%)
1	Cycle 1	22	05/07/2021 16:41	3	7081	4600	130	59.95	38.95
	Cycle 2	7	05/14/2021 12:14	3	7288	4600	101	60.79	38.37
	Cycle 3	4	05/18/2021 01:58	3	7272	4600	97	60.76	38.43
	Cycle 4	4	05/23/2021 03:07	3	7297	4600	58	61.04	38.48
	Cycle 5	4	05/28/2021 15:31	3	7315	4600	54	61.12	38.43
	Average Values - Biodigestor 1:				7251	4600	88	60.73	38.53
2	Cycle 1	23	09/05/2021 20:36	4	8476	4600	30	64.68	35.10
	Cycle 2	6	05/15/2021 21:35	4	8605	4600	29	65.02	34.76
	Cycle 3	4	05/19/2021 03:44	4	8594	4600	33	64.97	34.78
	Cycle 4	4	05/23/2021 12:03	4	8608	4600	31	65.02	34.75
	Cycle 5	5	05/29/2021 01:23	4	8596	4600	34	64.97	34.77
	Average Values - Biodigestor 2:				8576	4600	31	64.93	34.83
3	Cycle 1	24	05/10/2021 06:07	4	9052	4600	16	66.23	33.66
	Cycle 2	6	05/16/2021 00:45	4	9333	4600	16	66.91	32.98
	Cycle 3	3	05/19/2021 14:28	4	9337	4600	17	66.91	32.96
	Cycle 4	4	05/24/2021 01:33	4	9327	4600	17	66.89	32.99
	Cycle 5	5	05/28/2021 19:21	4	9339	4600	16	66.92	32.96
	Average Values - Biodigestor 3:				9278	4600	16	66.77	33.11
4	Cycle 1	24	05/10/2021 03:07	4	8870	4600	17	65.76	34.11
	Cycle 2	6	05/16/2021 02:17	4	9031	4600	18	66.17	33.70
	Cycle 3	3	05/19/2021 10:26	4	9034	4600	17	66.18	33.70
	Cycle 4	4	05/23/2021 16:13	4	9035	4600	19	66.17	33.69
	Cycle 5	5	05/28/2021 10:45	4	9022	4600	20	66.13	33.72
	Average Values - Biodigestor 4:				8998	4600	18	66.08	33.78

*MCS Proportion: Percentage in relation to the total sum of gases read (Methane Gas + Carbon dioxide + Hydrogen Sulfide Gas)

Source: Produced by the author (2021)

biodigester. Table 4 presents the consolidated result of the performance of the biogas filtration system.

It can be seen from Table 4 that the set of filters that obtained the best performance in filtering biogas was the one present in the Biodigestor 3 set composed of carbon steel sponge + Drinking water.

According to Alcócer *et al.* (2019) the expected values for the composition of the biogas generated from bovine manure vary between the values: Methane Gas (from 55% to 75%), Carbon Dioxide (25% to 45%), Hydrogen Sulfide (<1%) and other gases (<5%). In which the values obtained in the monitored biodigesters are within the expected margins in the literature for the type of biomass involved.

It was observed in the anaerobic digestion process a more accentuated production of hydrogen sulphide after the first 20 days until approximately 30 days of biodigestion process, showing a sharp drop after the first month.

The UNIBIO system also allowed the detailed visualization of the temperature variation and relative humidity of the air in the biodigester. Taking biodigester 1 as an example, we can see that the biomass reached a minimum temperature of 23.1 °C and a maximum temperature of 30.8 °C throughout the anaerobic biodigestion cycle, thus staying within a safe range for the biodigestion process that it is between 15 °C and 40 °C (SOUZA, 1984).

Table 4: Consolidated result of all prototypes (biodigester 1,2,3 and 4)

Prototype	Filter		CH_4 (ppm)	CO_2 (ppm)	H_2S (ppm)	Gases Proportion		Filtering performance	
	Liquid	Solid				CH_4 (%)	CO_2 (%)	CO_2	H_2S
Biodigestor 1	No filter	No filter	7251	4600	88	60.73	38.53	4th	4th
Biodigestor 2	Potable water	No filter	8576	4600	31	64.93	34.83	3rd	3rd
Biodigestor 3	Potable water	Steel sponge	9278	4600	16	66.77	33.11	1st	1st
Biodigestor 4	Potable water	Steel wool	8998	4600	18	66.08	33.78	2nd	2nd

Source: Produced by the author (2021)

IV. CONCLUSION

It is concluded that the development of a biodigester monitoring system through the IoT platform with hardware support through microcontrollers and low-cost sensors, in which we call this solution the UNIBIO system, proved to be technically and financially adequate for application in systems of anaerobic digestion, providing data that enable decision making that results in improved efficiency and optimization of the anaerobic digestion process. It allows measuring and quantitatively comparing the performance of different biomasses in the production of biogas as well as analyzing the efficiency of filter elements for the biogas produced.

The values obtained by the monitoring system were within the levels expected by the literature and are suggested for future research. The continuity of tests with the UNIBIO system using other sources of biomass and new combinations of biofilters.

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