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# Automation of an anaerobic digester with embedded system for the production of biogas from palm oil waste

## *Automatización de un digestor anaerobio con sistema embebido para la producción de biogás a partir de residuo del aceite de palma*

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**Abstract:** This work presents the automation of an anaerobic reactor used for the production of biogas from waste sludge in the palm oil extraction (POME) process. The automation process is carried out using embedded systems such as the Arduino DUE board. The variables that are measured in this process are temperature, PH and agitation; most critical parameters to control that significantly affect biogas production and its quality. To control process variables, sensors were used to determine the amount of methane (CH4), carbon dioxide (CO2) and hydrogen sulfide (H2S). To acquire the data, USB communication was used between the embedded card and the PC, using Visual Basic.NET, a data acquisition, storage and visualization system for the variables of the POME biodigestion process, the biogas produced is measured in time. real and the information is displayed and stored for later statistical analysis.

**Keywords:** acquisition system, anaerobic digestion, automation, biogas.

**Resumen:** Este trabajo presenta la automatización de un reactor anaerobio utilizado para la producción de biogás a partir de lodos residuales en el proceso de extracción del aceite de palma (POME). El proceso de automatización se realiza utilizando sistemas embebidos como la tarjeta Arduino DUE. Las variables que se miden en este proceso son la temperatura, el PH y la agitación; parámetros más críticos a controlar que afectan significativamente la producción de biogás y la calidad del mismo. Para controlar variables del proceso se utilizaron sensores para determinar la cantidad de metano (CH4), dióxido de carbono (CO2) y ácido sulfhídrico (H2S). Para la adquisición de la data se utilizó comunicación USB entre la tarjeta embebida y el PC, utilizando Visual Basic.NET, sistema de adquisición, almacenamiento y visualización de datos de las variables del proceso de biodigestión de POME, se mide el biogás producido en tiempo real y se visualiza y almacena la información para un posterior análisis estadístico.

**Palabras clave:** sistema de adquisición, digestión anaerobia, automatización, biogás.

## 1. INTRODUCTION

Anaerobic fermentation is a process in which usable products such as biogas, biomass, biofuel, among others, can be obtained. Currently, the energy generated by fossil resources has been constantly questioned, for being the cause of the greenhouse effect, China today is the one that produces the most emissions, due to the burning of coal to satisfy the electrical energy demanded by air conditioners [1] [2] [3] .

For this reason, renewable energies have taken on great importance, currently they have increased 9.7%, slower than the 10-year average (13.4% annually), solar capacity had an expansion of 127GW and wind energy grew 11 GW, almost the double its previous largest annual increase [4] .

Another solution to take advantage of renewable energy, apart from wind energy and solar energy, is the use of reactors, which, through anaerobic bacteria, convert organic waste into gas or biofuels for later use and slightly reduce greenhouse gases. greenhouse effect.

With the use of these reactors and anaerobic fermentation, the aim is to automate the process for the generation of biogas, a product that is generally used as fuel, thus reducing the use of fossil resources. To automate the process it will be done through free software, today free software is widely used due to its versatility with various embedded devices [5] , free software was generated as a social movement born in the 1990s. 70 due to the privatization advance that was given to knowledge, that is why the importance of automation with open source [6] . Automation in chemical processes is of great importance today because it makes the processes more optimal, generating greater production of what is being worked on. There are different types of automation, from the monitoring of basic variables to the automation of large devices [7] .

The automation of bioreactors through LabVIEW is efficient; a supervision and control system was developed through LabVIEW to also monitor parameters in the fermentation process located in the laboratories of the agroindustry institute of the Technological University of Mixteca, there it is also They controlled the basic parameters such as temperature and pH, as well as the on and off of actuators such as heating resistance and peristaltic pumps. The entire system was developed under the supervision of the USB1208FS data acquisition card [8] . Both the Datalogger CR1000 and the USB1208FS data acquisition card allow historical data from the sensor readings to be stored, to analyze and predict the best substrates to be integrated into the bioreactors [9] [10] .

Automation is so extensive and so versatile that Carlos López, Fanny Martínez and Oscar Paredes created an automated system to monitor the fundamental parameters of the biodigestion process, such as temperature, pH and pressure, the above to obtain a gas usable for industrial and domestic use, this system was developed in programming environments such as FlowCode , Proteus and Visual Basic, in order to communicate with the hardware, in the same way information is also transmitted in real time [11] . From the above, it can be determined that for the automation of a bioreactor it is necessary to have substrates or organic waste as long as it works under optimal conditions. For example, the work of Ibeth Viviana Ordoñez and company was research aimed at automating the reproduction stage of a yeast called Saccaharomyces Cerevisiae for the production of ethanol, the different variables and the instrumentation required were identified. A description of the process for the generation of ethanol was detailed, in order to determine what parameters need to be measured, consequently, determine the type of electronic instrumentation, then a biomass control analysis was carried out where the balance of ethanol and the oxygen concentration required by the substrate. Finally, the automation proposal was detailed as an end to what was required, the process described above is the one that is desired to be developed, but with other types of substrates [12] .

The SCADA system is very important for any chemical process or other process that involves data acquisition and sensor conditioning. In Taiwan, a research group analyzes the energy consumption in wastewater plants and does the simulation using a system. SCADA, this allowed the authors to determine the percentage of contaminating compounds and the way in which they can be treated [13] .

## 2. MATERIALS AND METHODS

This section presents the description of the processes associated with anaerobic digestion, in addition to the selection of the reactor and electronic instrumentation. The designed control method and the SCADA software that allows the reading, visualization and storage of variables such as temperature, PH and agitation are also described.

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### 2.1. Anaerobic Digestion

They are chemical reactions, in which organic material decomposes through metabolic routes of organisms in the absence of oxygen. Anaerobic digestion can be processed into any carbon-containing material, such as paper, food, wastewater, solid waste, among others [14] . Anaerobic digestion is defined as the work of anaerobic bacteria in a fermentative process, that is, it is a series of processes that interact with each other through metabolic reactions in the total absence of oxygen. These metabolic processes are divided into four stages, hydrolysis, acidogenesis or fermentation, acetogenesis and methanogenesis [15] [16] . Fig. 1 shows how the four stages of anaerobic digestion are intertwined [17] .

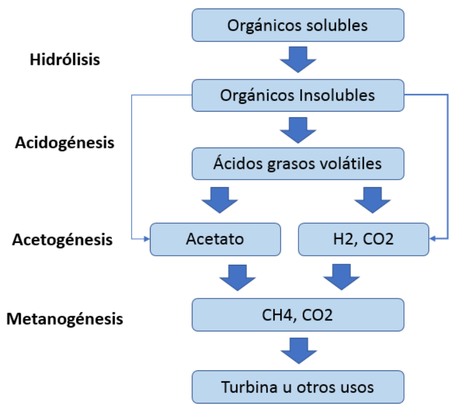


***Fig. 1*** *. Stages of Anaerobic Digestion* [18] .

Hydrolysis is the first stage of anaerobic digestion, where soluble monomers are the result of protein conversion into amino acids such as fatty acid, glycerol and triglycerides, carbohydrates such as polysaccharides, lignin, cellulose and starch; Finally the fiber is converted into simple sugars such as glucose. Hydrolysis also involves processes in insoluble solids, that is, particles such as cellulose or hemicellulose that are organic particles or organic colloids, referring to protein [18] .

Acidogenesis or fermentation is the next step after hydrolysis, in this process the acidogenic bacteria convert the product resulting from hydrolysis into simple compounds that are mostly volatile acids (propionic, lactic, formic and succinic acid) or into ketones (ethanol , glycerol, acetone, methane) and in alcohol. The amount of product varies depending on the bacteria and culture conditions, generally temperature and pH [19] .
Acidogenesis or fermentation is a process to produce organic compounds and energy from the oxidation of organic substances. This transformation is carried out by yeasts and bacteria in the absence of oxygen. There are several types of fermentation such as lactic, butyric, alcoholic among many others.

Acetogenesis is the phase in which the bacterial metabolic transformation of enzymes, hydrolysis, proteins, nucleic acids into other compounds that function as a source of energy is accelerated. Acetogenesis occurs through the fermentation of carbohydrates, of which acetate is the main product, and other metabolic processes. The result of this stage is the mixture of CO2 and H2, hydrogen is the intermediate in the anaerobic digestion reactions. In fermentation, some products are metabolized directly by methanogenic organisms and others must be produced through the mixture of simpler products (acetate and H2) through acetogenic bacteria. These substances are generally ethanol, butyrate, some aromatic compounds, among others. others [20] .

### 2.2. Variables that Influence Anaerobic Digestion

Anaerobic digestion (AD) is a chemical process used for the production of biogas that requires certain favorable conditions so that the microorganisms responsible for the degradation of organic matter have an adequate environment that benefits their development and growth since these are the ones in charge. to generate different gases such as Methane, CO2, O2 among others. Below, we look at some of these variables that most affect the AD process.

#### *2.2.1. Temperature*

For an optimal and fast process, it will depend on the growth rate of the microorganisms and these in turn depend on the temperature, as the temperature increases, the growth of the microorganisms will increase, consequently, the process of digestion so the final production will be greater [21] .
Anaerobic microorganisms can work in three temperature ranges: psychrophilic which is below 25°C, mesophilic with a range between 25°C to 40°C and thermophilic with a range between 50°C and 65°C. . The recommendation is to work in the mesophilic stage where the reactor must be maintained at a temperature of approximately 30°C [22] . The temperature can be maintained through different treatments such as insulation, water baths through passive solar heating, or through the flow of water inside a chamber that covers the raw material.

For heating, heat exchangers, heating coils or steam injection directly into the reactor can be used [23] .

*2.2.2 Hydrogen Potential - pH*

pH is one of the most important variables for the diagnosis of anaerobic processes, it is one of the variables that is too slow, making control difficult, since there are many factors that influence it. An example of this occurs in the fermentation or acidification stage where imbalances occur in the production and consumption of volatile fatty acids; this accumulation causes a decrease in pH [16].
The pH level is a primary indicator for reactor efficiency. A stable pH indicates that the system is balanced and a decrease in pH may indicate a buildup of acids, consequently, reactor instability. Most methanogenic processes operate in a pH range between 6.7 and 7.4 and optimally between 7 and 7.2 [24] .

*2.2.3. Agitation*

Providing agitation to the product is essential for better biogas production, the objective of this is to bring the substrate into contact with the microorganisms, provide a uniform density of the microorganisms around the substrate, prevent foaming and sedimentation in the reactor and eliminate thermal stratification, maintaining a uniform temperature throughout the reactor [25] .

**23. Types of Bioreactors**

Bioreactors or also called reactors, fermenters, are a hermetically sealed container where the anaerobic digestion process is carried out. The design must provide conditions for microorganisms to grow and be able to convert the mixture into new products. There are different types. of reactors on which the convenience will depend according to the product to be obtained.

- Discontinuous ( batch ): The entry of the raw material is carried out in batches, without feeding, the total load for fermentation is placed inside the reactor and the process is put into operation with the appropriate time depending on the raw material. which is called retention time.
- Semi-Continuous ( fed-batch ): It is carried out through fed batches, with input feeding. The way it works is to remove 80% or 90% of the final product at the end of the process and it is returned with an amount equivalent to what was removed.
- Continuous: generally used for industrial purposes, they have a uniform input and output flow, the quantity extracted must be equal to that which is input again, thus generating greater production in less time. Fig . 2 shows the design of the types of reactors most commonly used in AD [26] [27] .

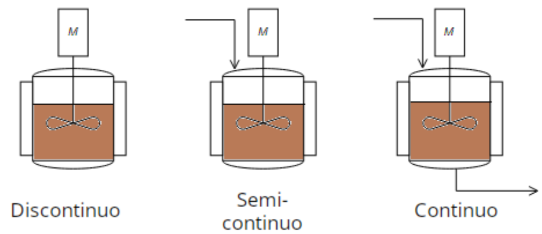


***Fig. 2.*** *Types of bioreactors.*

**2.4. SCADA System**

Called Supervision Control and Data Acquisition, SCADA allows the management and control of a local or remote system thanks to a graphical interface that communicates the system with the user. A SCADA system can be defined as the collection of information and transfer of data to central servers, thus carrying out the necessary analysis and control of the systems, then displaying information on a screen that allows interaction and the actions placed there are reflected at a new process [28] . According to [29] the main characteristics of a SCADA system are:

- Data acquisition and storage to collect, process and store information continuously and securely.
- Graphic and animated representation of the variables present in the process and generation of alarms.
- Execute control actions to modify the process if applicable.
- Capacity to adapt and expand systems.
- Easy communication with applications and database distributed on communications networks.
- Supervision to observe the evolution of the process from a screen.

**2.5. Embedded System**

They are called an electronic circuit capable of performing a specific task in a product. Unlike computer systems such as PCs, these systems solve specific problems and are generally found in everyday products. There are many development platforms which can implement software for specific hardware; generally these platforms have applications such as signal processing, automation, among others [30] .

## 3. RESULTS

The methodology begins with the search for information regarding the embedded system and the software that allow the automation of the substrate fermentation process to obtain biogas. According to the search and selection of the embedded system and the free access software, a design was determined that shows the components that the reactor will have to carry out the automation. The system has actuators (input and output solenoid valves, heating element, DC motor and indicators), sensors (pH, temperature, methane gas, CO2, H2S and level), embedded system, backup system (LCD, battery and inverter) .

### 3.1. Temperature Sensor Selection

The temperature sensor selected is Type K for measuring the temperature of the substrate that recirculates through the reactor and a second sensor to measure the ambient temperature inside the reactor. These sensors are linearized by means of a MAX6675 module, these modules send the signal through the SPI protocol, which is compatible with the embedded system. Type K thermocouple: These are sensors that are manufactured using two wires of different material joined by welding at one end. When testing the temperature at the junction of the metals, they generate a voltage in millivolts, which is an effect called Seebeck, which is proportional to the increase in temperature; The thermocouples are encapsulated within a stainless steel tube. Below are the characteristics of the thermocouple that senses the temperature of the water that recirculates through the reactor, see Fig. 3. Probe length: 100 mm o Probe diameter: 5 mm o Thermocouple type: K o Thread fixing probe: M8 o Measurement range: 0 to 400°C o Cable length 1 meter o Manufacturing material: Cable +: Nickel/Chrome alloy; Cable -: Nickel/Aluminum Alloy o Internal insulation: Fiberglass o External insulation: Metallic shielding [31] .

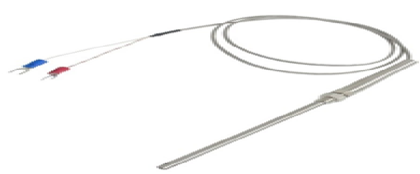

***Fig. 3.*** *100 mm type K thermocouple [26].*

The MAX6675 module performs cold junction compensation and digitizes the signal coming from the type K thermocouple. This data is output with a 12-bit resolution, and the format is compatible with SPI. This converter resolves temperatures to 0.25°C and its range. maximum is +1024°C, the accuracy of the thermocouple is 8 LSB for temperatures ranging from 0°C to +700°C.

Before converting thermoelectric voltage into proportional temperature values, it is necessary to balance the difference between the cold junction side of the thermocouple and a virtual reference of 0°C, in the case of the type K thermocouple, the voltage changes by 41 µV /°C, which approximates the thermocouple characteristic with equation (1 ):

$$Vout = (41\ \mu\ V/° \ )\ x\ (\ TR - TAMB\ )\ (1)$$

- Vout is the thermocouple output voltage (µV) .
- TR is the remote thermocouple junction temperature (°C) T AMB is the ambient temperature.

The digitization function is performed when the ADC adds the cold junction diode measurement with the amplified thermocouple voltage and reads the 12-bit result at the SO pin. A sequence of zeros means the thermocouple reading is 0°C. A sequence of all ones means that the thermocouple reading is +1023.75°C [29]. Fig. 4 shows the MAX6675 module which is implemented to read the temperature values of the project [32] .

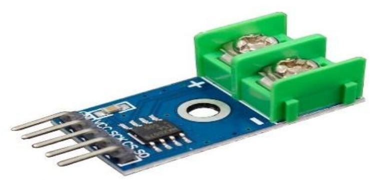

***Fig. 4.*** *MAX6675 converter module.*

### 3.2. pH Sensor E-201-C

It is a module that consists of a pH sensor, also called a pH probe, which has a signal conditioning board, which sends a signal proportional to the pH value, and can be easily used with any microcontroller. The components that make up this sensor consist of a module and a combined pH electrode, which can be seen in Fig. 5, the electrode is made of glass that is quite fragile, the preamplifier (module) is a device that records the electrode signal with high impedance and converts it into a low impedance signal that can be analyzed by the transmitter, the preamplifier can also stabilize the signal, making it more susceptible to electrical noise [33] .


***Fig. 5.*** *Signal conditioning module and pH electrode.*

### 3.3. Embedded Card

The reading of the data coming from the temperature sensors, PH, gas sensors, and for the control of the actuators, the Arduino DUE embedded card is selected, which was chosen among several devices that, although there are others that are more advanced and with greater resources, this was sufficiently adequate for what was required, it was also the one that presented the best response to electrical and other noises since other cards such as the ESP32 and the Raspberry pi pico could be tested. The physical appearance of the Arduino DUE board is shown in Fig. 6 [34] .

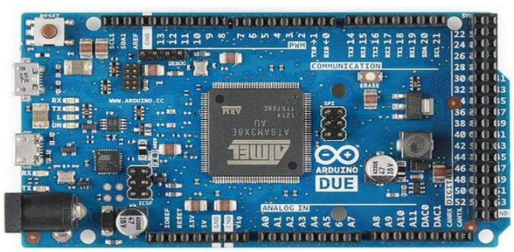

***Fig. 6.*** *Arduino DUE embedded board.*

Several digital inputs and outputs were used on this card, as well as three analog ports for the gas sensors and two SPI communication ports for the PH and Temperature sensor.

### 3.4. Data Acquisition Interface.

The visualization of the data acquired in real time is done with the Visual Basic 2022 software in its free version, which is very suitable for the development of the SCADA system since all sensors can be displayed (PH, temperature, methane gas, CO2 Gas , H2S), in addition to controlling the solenoid valve for measuring the generated biogas and the actuator modules for the peristaltic pump for feeding the substrate in the CSTR-type continuous reactor. Another variable that can be manipulated with the interface is agitation, since this is an important parameter in the anaerobic digestion process. Fig. 7 shows the developed graphical interface.

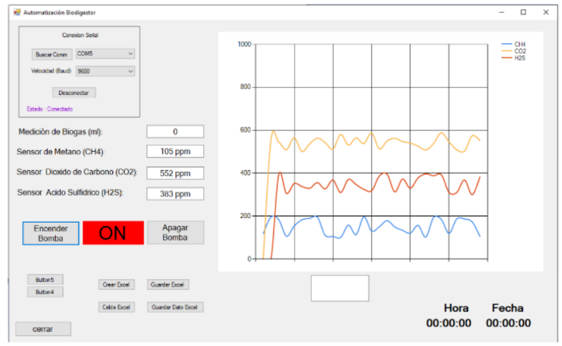


***Fig. 7.*** *Graphic interface of the SCADA system.*

### 3.5. Biogas Quality Measurement

To measure the quality of the biogas generated in the Anaerobic Reactor in real time, a multisensory system (Electronic Nose) was designed, which consists of an array of sensors that measure the gases with the highest percentage in the biogas.

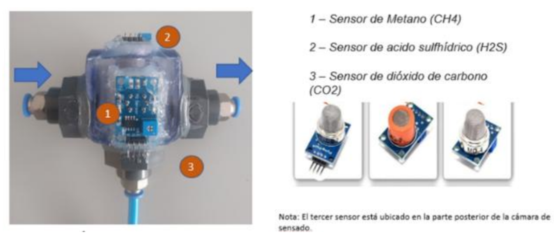


***Fig. 8.*** *Biogas quality measurement system.*

The automated system of the continuous stirred tank reactor or simply CSTR reactor, is shown in Fig. 9, there we can see the parts of the system such as the anaerobic reactor with its respective temperature and PH sensors, substrate feed pump, the tank for feeding the reactor, container for storing the digestate, the embedded card, the mixer, the multisensory system for measuring the quality of the biogas (Methane, CO2 and H2S) [35] .

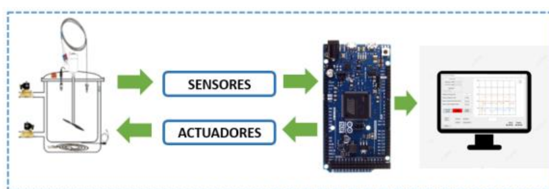


***Fig. 9.*** *Implementation of reactor automation.*

## 4. CONCLUSIONS

The automation of the chemical anaerobic fermentation process was carried out using embedded devices programmed with free access software, this allows the user to view the temperature, pH and agitation data and also control

the temperature and agitation variables to homogenize the mixture that is is processing.
The temperature is controlled by valves that recirculate the water stored in a container to avoid waste of the drinking liquid.
Stages were set up so that the sensors took coherent readings according to the measurement variable.
The design of the graphical interface allows the visualization of the measurement variables, the state of the actuators, an emergency stop button and a button to store the data of the process being carried out, in this way the behavior of the the variables in the anaerobic fermentation process.

**RECOGNITION**

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