Gas measurement system for Bio-hydrogen production based on nejayote’s dark phase fermentation

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Abstract. Nejayote is the residual water from the corn nixtamalization process, this is considered a pollutant when it is discharged into the public sewer system due to its high demand for oxygen, high temperature, and pH. There is Biohydrogen production with the use of dark-phase fermentation of nejayote in the presence of clostridius. To determine the concentrations of the different gases produced H2, CH4, CO2, was designed and build a data acquisition system on Lab View development platform, using MQ-X type sensors and Arduino UNO prototyping board. Was adapted an airtight plastic container with capacity of 30 ml with special nozzles to allow multiple needle entries and injections of different samples. This device allows us to quantify the biohydrogen obtained from the various concentrations used in the reactors to obtain the optimal mixture.

1. Introduction
The term nixtamalization comes from the etymological root derived from the Nahuatl word nextamalli, which means “lye or water passed by ashes” and from the word tamalli that means “wrapped bread” [1]. This technique consists of alkaline leaching of corn kernels at high temperature. Corn is cooked in water (3:1) and lime (CaO) at 1% for several hours. At the end of the cooking time, two products are obtained; the first is softened corn ready for grinding and subsequent flour manufacturing, while the second refers to residual water from cooking it in the presence of lime (nejayote). The term nejayote comes from the Nahuatl nextli which means “lime ash” and from the word áyoh “broth or watery thing.” The nejayote is mainly composed of suspended organic material from the endosperm and the pericarp of corn at temperatures above 150ºC, with the presence of CaO [2].

The molecular hydrogen, H2, is considered the main alternative source of energy for human consumption in the fairly near future, mainly because the product of its combustion is not CO2 or any of the greenhouse effect gases [3].

Another reason why hydrogen is an attractive element to replace fossil fuels, is because it can baffle making up almost all the matter on the planet. However, the main challenge to adopt hydrogen as a feasible source for large-scale power generation, is that this gas is not free in nature, but extracting it by itself represents an energy and monetary expense for which they must be to seek new methods of extraction or sources of hydrogen that are more viable, non-polluting, such as dark fermentation.

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1.1. Dark phase fermentation
The generation of biohydrogen through dark fermentation is mainly achieved by the action of strictly anaerobic bacteria. In general, they are species of the genus Clostridium, spore-forming those responsible for carrying out this biochemical process; likewise, facultative bacteria of the genus Enterobacter and Bacillus, and some thermophilic and anaerobic acidogenic bacteria from residual sludge may be useful [4]. Carbohydrates are the preferred source of organic carbon for the metabolic pathways that produce biohydrogen.

1.2. Design and construction
To determine the concentrations of gases produced in the different mixtures of nejayote and bacterial consortium, was designed and build a data acquisition system on Lab View development platform using sensors from the MQ family, which are gas sensors by ignition. When these are in the presence of a characteristic gas, they increase their internal resistance and consequently the output voltage changes. The gas measurement system consists of different parts, which are listed below.

1.3. Measuring vessels
An airtight plastic container with a capacity of 30 ml was adapted with special nozzles to allow multiple needle entries and to be able to carry out different injections of samples in the same device.

1.4. Electronic
Three different types of sensors were used, one for each gas generated by the fermentation reactors.
- MQ-8 for the detection of molecular hydrogen, \( \text{H}_2 \), which is the main cause of interest in this work
- MQ-4 for the detection of methan, \( \text{CH}_4 \)
- MQ-135 for the detection of carbon dioxide, \( \text{O}_2 \)

The acquisition of the electrical signals from the different sensors was done with the Arduino UNO prototyping board which through the USB port connects to the computer to have direct communication with the software.

1.5. Software
In Labview was installed extra libraries for the correct communication and compatibility with the Arduino UNO. Later, a data acquisition algorithm was designed, which consists of two states, calibration status and preheating and measurement status.

Twelve reactors were built with 1.23 litres capacity amber containers, rubber plugs modified to guarantee tightness, connected by hoses to two systems, as described in image 1, one for volumetric control from displacement tubes and the other for the storage of produced gas, using 50 ml capacity bags and closure airtight

![Figure 1. Procedure diagram](image)
2. Experimental Procedure
Each of the relationships shown in Table 1 were tested at 37 °C and 57 °C to check at what temperature there is the greatest production of hydrogen, as well as the most optimal nutrient-Nejayote relation for generation of biogas, extracting 30ml samples in hermetically sealed plastic bags.

| Sample | Nejayote | Nutrients |
|--------|----------|-----------|
| 1      | 100      | 0         |
| 2      | 80       | 20        |
| 3      | 60       | 40        |
| 4      | 40       | 60        |
| 5      | 20       | 80        |
| 6      | 0        | 100       |

Figure 2. Experimental setup for biogas measurement

A data acquisition algorithm was designed in LabView, shown in figure 3, which has two states: the calibration state and the direct reading state.
The first state is the sensor preheating. The calibration is done using an inert gas, in this case Helium, He, which is not detectable by the three MQ sensors. When purging the hermetic container with this gas a first recursive reading occurs and all sensors are zeroed, for a finer adjustment, it is recommended to leave more recursive readings.

Once this sequence is finished, the calibration is turned off and immediately afterwards it goes to the direct reading sequence, once in this state with the calibrated sensors and the purged system, a 10 ml sample is injected with the mixture of gases produced in the reactors.

Figure 4. Front panel of the gas measurement virtual instrument.

Figure 4 shows the variation in gas concentration within the 30ml container. Showing the graphs of the simultaneous measurements on each sensor expressed in parts per million (PPM).
3. Results
The measurements of the reactors were obtained at different concentrations, which are shown in Table 2, noting that the greatest amount of hydrogen was achieved in the ratio of 80% nejayote and 20% nutrients.

| Relation | CO₂ PPM | CH₄ PPM | H₂ PPM |
|----------|---------|---------|--------|
| 100:0    | 10.31   | 14.79   | 0.19   |
| 80:20    | 117.98  | 229.58  | 1120.01|
| 60:40    | 245.61  | 369.23  | 719.24 |
| 40:60    | 348.13  | 371.96  | 431.27 |
| 20:80    | 409.26  | 374.29  | 248.49 |
| 0:100    | 514.23  | 362.12  | 10.32  |

Both the measurements at 37 °C and 57 °C corroborate this maximum production in the ratio 80:20 and secondly in the 20:80, only to a lesser extent in the temperature of 57 °C as shown in the figure 5 and figure 6.

3.1. Data checking
The gas samples obtained from each reactor with their corresponding concentrations were subjected to a hydrogen measurement process by the gas chromatography method, this in order to validate that the data obtained with the proposed device were compatible with the data from a standardized device. In this case, the Argilent 5890 HP Series II plus chromatograph shown in Figure 7 was used.
Figure 7. Data validation by gas chromatography

Table 3. Data checking

| Chroma method | Electronic method proposed |
|---------------|-----------------------------|
| PPM H2        | PPM H2                      | Error      | % Error  |
| 12.46461454   | 12.46781283                 | 2.57E-04   | 0.025658%|
| 22.57998073   | 22.57998133                 | 2.68E-08   | 0.0003%  |
| 32.91244369   | 32.91243583                 | 2.39E-07   | 0.002387%|
| 40.40356961   | 40.403522                   | 1.18E-06   | 0.011783%|
| 47.63890255   | 47.638954                   | 1.08E-06   | 0.010801%|
| 60.77352652   | 60.77354483                 | 3.01E-07   | 0.00301% |
| 68.12122333   | 68.121278                   | 8.03E-07   | 0.00803% |
| 79.48493826   | 79.486337                   | 1.76E-05   | 0.001759%|

4. Conclusions

The proposed device is a highly viable alternative for the measurement in the production of biogas and other applications that require gas measurements since its compact design makes it totally portable, as well as it provides reliable measurements, if we compare it with a gas chromatograph, this device It takes the readings much faster, it is low cost and it does not need an infrastructure or specialized secondary instruments for its operation.

Due to its modular development in hardware and software, it can be scaled by adding sensors for more gases or different ones for other variables that intervene in the reactors and also, analyse the signals in real time for possible automation of the hydrogen production process.
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