27th ABCM International Congress of Mechanical Engineering
December 04-08, 2023, Florianópolis-SC, Brazil

COB-2023-0533
CALIBRATION OF A LOW-COST DIGITAL HYGROMETER FOR MEASURING MOISTURE IN SUGARCANE BAGASSE

Gabriel Junior Leal
Júlia Maria Leal Firme
Angélica Marcelina de Souza Gomes
Ricardo Carrasco Carpio
Reginaldo Gonçalves Leão Junior
Federal Institute of Minas Gerais, Arcos, Brasil
gabrielleal6201@gmail.com, lealjulia2900@gmail.com, angelica.gomes@ifmg.edu.br, ricardo.carpio@ifmg.edu.br, reginaldo.junior@ifmg.edu.br

Abstract. *The global efforts to reduce the demand for fossil fuels and the decarbonization of gaseous effluents in the most diverse production processes have increased the participation of alternative energy sources in the world energy matrix. Due to its emissivity profile and significant energy potential, biomass has been gaining space among these alternative sources. Previously used mainly for combustion, biomass has a high yield for the production of synthesis gas and bio-oil when thermally decomposed through gasification and pyrolysis. However, it is almost always accompanied by a high moisture content, which reduces the efficiency of the different thermal conversion processes employed. In gasification, the presence of high levels of moisture reduces the temperature of the bed, resulting in a greater need for energy input and residence time. The study performed here used sugarcane bagasse to validate a low cost methodology for the determination of the moisture content of these materials using an OS49 type hygrometer. The sugarcane bagasse used in the study came from a cachaça production mill located in the municipality of Córrego Fundo, Minas Gerais, Brazil. The sample was collected soon after milling, stored in a plastic container, wrapped in plastic film and stored in a freezer at temperatures ranging between -3°C and 3°C. After three days the sample was taken to the Physics and Chemistry Laboratory of the Federal Institute of Minas Gerais - Arcos Campus, where it remained at room temperature until the moment of processing. The sugar cane bagasse went through a milling process that allowed the screening of the sample that had an initial mass of 225.79g (0.005g).Four sieves with meshes of 16mm, 8mm, 4.75mm and 2mm were used, resulting in samples with five different granulometries, being the fifth granulometry smaller than two millimeters. The samples were dried in an oven with temperatures of 45°C, 60°C, and 70°C, being weighed every 30 minutes to verify the loss of humidity; each test was finished after the stabilization of the samples' mass. Then the tests were performed to configure the program that will read the data collected by the hygrometer sensor, for this a 400 ml beaker and a 3ml pipette were used, the process happened with the addition of 3ml of water every two minutes in the beaker filled with sugarcane bagasse samples previously dried. The collected data will be part of the Arduino's database to calibrate the sensor and allow the display of the humidity*

Keywords: *Biomass, Humidity, Sugarcane, bagassedigital, hygrometer.*

1. INTRODUCTION

Given the current environmental situation and the consequences the planet is facing, it has become increasingly urgent to seek sustainable energy sources and reduce dependence on fossil fuels. In response to this global need, the search for a clean energy matrix has gained prominence worldwide (Borges *et al.*, 2017). Brazil, aligned with this trend, has also been working tirelessly to strengthen its energy matrix with renewable and sustainable sources.

Since the creation of the National Alcohol Program (Proálcool) in 1975, the country has invested in subsidies for ethanol production within its territory This investment has resulted in significant growth in annual ethanol production, going from 600 million liters in 1975 (Teodoro, 2016) to an impressive 26.45 billion liters in 2017 (Koga, 2017). Along with ethanol, the production process also generates byproducts, including sugarcane bagasse.

Previously, sugarcane bagasse was discarded in an uncontrolled and careless manner, resulting in low added value. However, as efforts emerged to maximize the energy potential of this byproduct, it was realized that moisture plays a fundamental role in its calorific value. Reducing the moisture content of sugarcane bagasse has become one of the best ways to increase its potential as biomass.

It is in this context that this study aims to develop a low-cost moisture reader model for sugarcane biomass. The objective is to provide an efficient and accessible solution for measuring the moisture content of sugarcane bagasse, as the laboratories where the project is being developed lack equipment with this function.

For the construction of the moisture reader, resources such as 3D printing, waterproofing materials, and a hygrometer sensor integrated with an ESP8266 board were used. Additionally, a calibration process for the hygrometer sensor was carried out, creating a database that includes different granulometries of sugarcane bagasse.

By developing this moisture reader model for sugarcane biomass, it is expected to contribute to the maximum utilization of the energy potential of sugarcane bagasse, advancing towards a more sustainable energy matrix. This study will present the obtained results, discussing their relevance and opening possibilities for future research and applications in this promising field.

2. OBJECTIVE

Develop a moisture reader to be used in the field and in the laboratory for collecting data on biomass, especially sugarcane bagasse, with the requirement of low cost and high practicality.

3. THEORETICAL FRAMEWORK

To facilitate the development and implementation of the proposed device within the laboratory of IFMG Campus Arcos, a thorough understanding of the fundamental principles regarding the hygrometer sensor and the significant improvements in biomass energy potential associated with low humidity is essential. These subject areas are aligned with the objectives of this research and provide the necessary foundation for its advancement, particularly considering the absence of equivalent equipment for measuring humidity.

3.1 Hygrometer Sensor

Calibrating the hygrometer sensor is crucial to ensure accurate and reliable data analysis. When calibrating the sensor specifically for biomass, it is important to have a dry biomass sample to minimize moisture content. This enables the accurate assessment of data and facilitates the monitoring of data patterns as moisture is introduced to the test medium.

The commercially available hygrometer sensor is designed to measure the electrical conductivity capacity of a substance, such as soil. It consists of a probe with two rods that emit a current when in contact with the substance, encountering resistance in the path between them.The signal produced by the sensor changes in accordance with the amount of water present in the substance. As the substance becomes wet, the electric current experiences less resistance (Santos, 2018).

The hygrometer sensor itself consists of two main parts: the probe and the module. The module operates with a comparator chip, (LM393 in this study) which enables both analog and digital readings. The digital reading functions on a binary scale of 0 and 1, while the analog reading operates within a range of 0 to 1023, allowing for more precise measurements (Santos, 2018).

3.2 Moisture in Biomass

After the milling process, the residual by-product, sugarcane bagasse, contains moisture levels ranging from 47% to 55%. This moisture significantly reduces the calorific value of sugarcane bagasse, as a portion of the fuel's energy is used to evaporate the wet portion of the bagasse. It is well-known that reducing the humidity of sugarcane bagasse is the main factor contributing to improved energy efficiency and is directly proportional to the final temperature of the exhaust gases (SILVA, 2018).

Additionally, the properties of sugarcane bagasse favor drying due to its low density and stack porosity, which can reach up to approximately 96.2% when not compacted. This porosity facilitates heat exchange between the hot gases passing through the sugarcane bagasse and the fluid contained within its fibers (SILVA, 2018).

4. METHODOLOGY

For the development of the proposed device, it was initially necessary to collect samples of sugarcane bagasse biomass and carry out proper preparation procedures for subsequent utilization. The samples were obtained from one of the mills provided by the Cooperativa dos Produtores de Cachaça de Córrego Fundo (COOPERCALC), located in the municipality of Córrego Fundo, Minas Gerais. The collection took place immediately after the sugarcane crushing process, and the samples were transported to the laboratory at IFMG Arcos Campus. At the laboratory, a complete process of preparation and cataloging was conducted.

Upon arrival, the samples exhibited large dimensions, as they consisted of whole milled sugarcane, resulting in bagasse fragments measuring between 1 m and 1.5 m. To facilitate handling, the samples were subjected to further crushing using a wood chipper, reducing their size. Subsequently, a screening process was employed, leading to the segregation of the samples into five distinct granulometries, as depicted in Figure 1. These granulometries included particle sizes of < 2 mm, 2 mm, 4.75 mm, 8 mm, and 16 mm. This approach aimed to enhance sample manageability and establish a comprehensive database containing information regarding the different granulometries obtained.

Figure 1. Samples separated by particle size.

Afterwards, the samples went through the drying process, in which they were taken to an oven at a temperature of approximately 60°C, where they remained until they were completely dry. The samples were shaken every one hour, so that the drying could occur in a more homogeneous way, and thus allowing a higher quality of these samples for storage, avoiding degradation/fermentation of these samples until the moment of use.

To develop the low-cost humidity sensor, a hygrometer sensor and a probe integrated with an 8266 ESP board, along with a custom Arduino program, were utilized. Calibration of the sensor was essential to obtain accurate humidity readings expressed as a percentage.

In order to achieve calibration, a series of tests were conducted, enabling the creation of a comprehensive database for the five distinct particle sizes of the biomass under investigation. A standardized approach was adopted for all particle sizes tested. For the calibration tests of the hygrometer sensor, a 400 ml beaker was employed, serving as the container for the sample. Additionally, a 3 ml pipette and a 500 ml beaker filled with water were used to introduce moisture to the sample.

During the calibration process, 3 ml of water was added to the sample every 2 minutes, and the data read by the sensor was recorded and stored for database construction. The recorded information is depicted in Figure 2

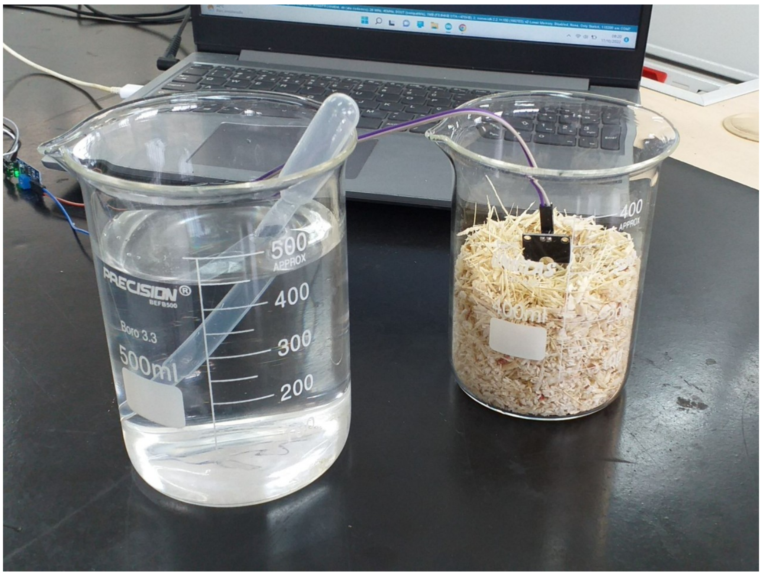

Figure 2. Calibration test of the hygrometer sensor for 2mm granulometry.

In parallel with the sample preparation and testing processes, efforts were made to develop a container that would serve as a prototype for constructing a low-cost humidity sensor and accommodate the hygrometer sensor. To facilitate prototyping and potential adaptations, 3D printing technology was employed. The current model consists of two components: a rectangular box produced using poly lactic acid (PLA) via 3D printing, which underwent waterproofing to prevent moisture loss from the sample, and a lid with a housing specifically designed for the hygrometer sensor probe, also 3D printed using PLA.

It is important to note that, being a prototype, the configuration of the low-cost humidity reading device does not yet conform to commercial standards. Consequently, the creation of an enclosure becomes necessary. This enclosure should provide a suitable environment for inserting the samples and incorporate a slot for accommodating the system responsible for reading and storing the data collected by the sensor probe.

It is worth noting that because it is a prototype, the set that will compose the low-cost humidity reading device does not have a commercial configuration yet, so it requires the creation of a fairing that has, besides the environment to insert the samples, a slot for the allocation of the system that will be responsible for reading and storing the sample data collected by the probe.

4.1 Prototype

The construction of the prototype was based on the assumption that small volume samples will be analyzed, already in predisposition for processing and subsequent use in energy generation or other activities. The prototype was built with PLA material using 3D printing, and for safety reasons was waterproofed with material that does not cause contamination to the samples to be analyzed.

As seen in Figure 3 , the device is compact and allows the use connected to a computer, for being a prototype, it can be adapted to make the reading without the need of a connected computer, only with the use of an external power supply to run the sensor and the information processing board. Thanks to the use of 3D printing the device can have a reduced production cost, if compared to other production methods, besides having the possibility to make changes according to the users needs, in a way that allows high modularity.

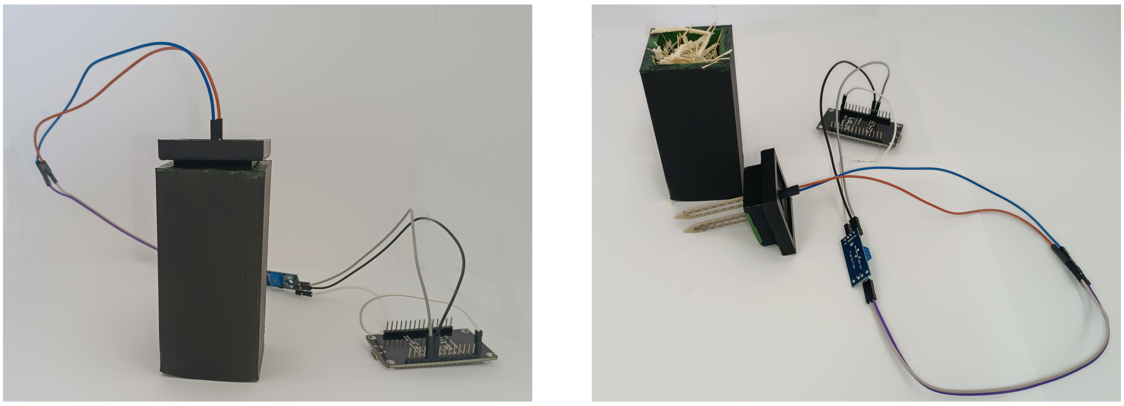

Figure 3. Prototype analyzing 8 mm sample

5. RESULTS AND DISCUSSION

The calibration tests of the hygrometer sensor yielded a dataset representing the sensor readings as water was added to the biomass samples. As depicted, water was added at 2-minute intervals, during which sensor data was collected. The results were plotted on graphs, with the x-axis representing time and the y-axis representing the data recorded by the hygrometer sensor.

It is important to note that data points near 1024 indicate biomass samples with minimal moisture content, approximately 0%, while values below 500 indicate samples with high moisture concentration, around 100%. These values varied according to the granulometry of the samples, thus requiring separate discussions for each granulometry.

For the <2 mm sample, as depicted in Figure 4, the hygrometer sensor recorded data ranging from 1024 (dry sample) to 486 (completely wet and stabilized sample). These values were adopted as the 0% and 100% moisture levels, respectively, for the <2 mm samples in the Arduino code.

Similarly, for the 2 mm sample, as shown in Figure 4, the recorded data ranged from 1024 (dry sample) to 525 (wet sample). These values were considered as the 0% and 100% humidity levels for the 2 mm samples in the Arduino code.

In Figure 5, the data for the 4.75 mm and 8 mm samples is displayed. The graph of the 4.75 mm sample exhibited a reading of 1024 for the dry sample and 544 for the stabilized wet sample. These values were adopted as the 0% and 100% moisture levels, respectively, for the 4.75 mm biomass samples. Likewise, the graph of the 8 mm sample showed a reading of 1024 for the dry sample and a stabilized maximum value of 574 for the wet sample. These values were considered as

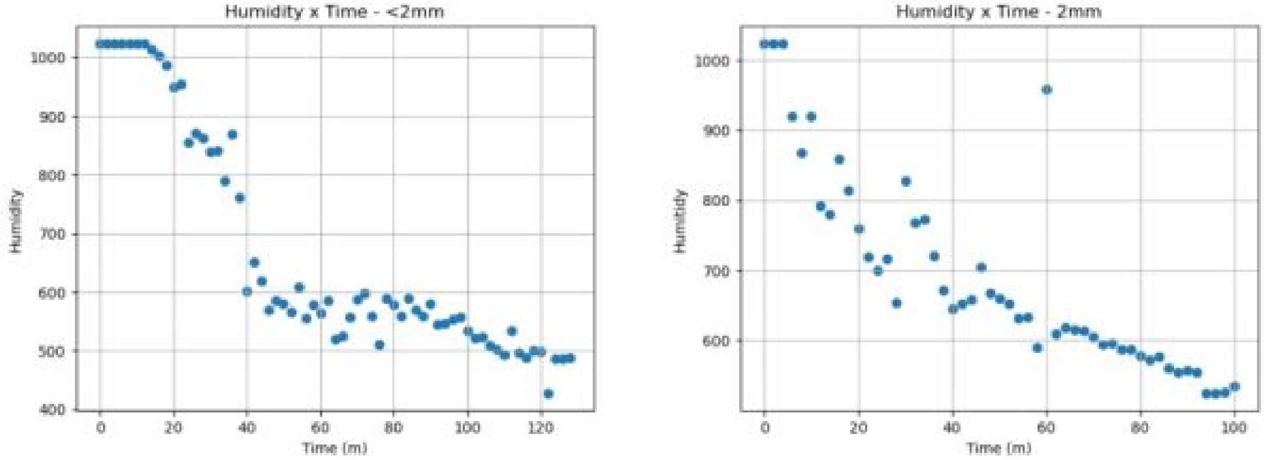

Figure 4. Hygrometer sensor data for particle sizes < 2 mm and 2 mm

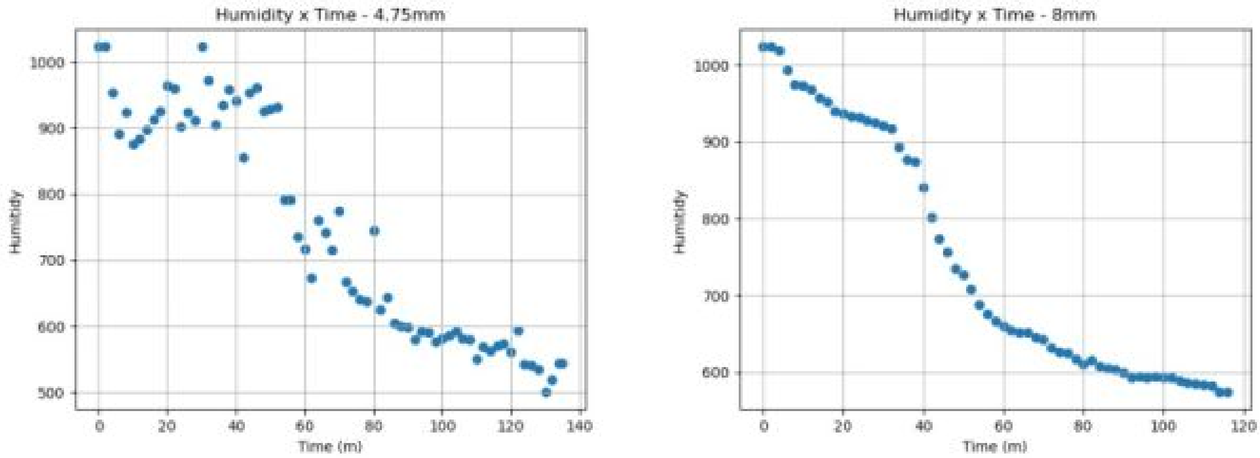

Figure 5. Hygrometer sensor data for particle sizes 4.75 mm and 8 mm

the 0% and 100% moisture levels in the Arduino code for the 8 mm samples.

Finally, in Figure 6, the graph represents data collected by the hygrometer sensor for the 16 mm sample. The dry sample had a value of 1024, while the sample at maximum humidity reached a stabilized value of 576. These respective values were considered as the 0% and 100% moisture levels in the Arduino code for the 16 mm samples.

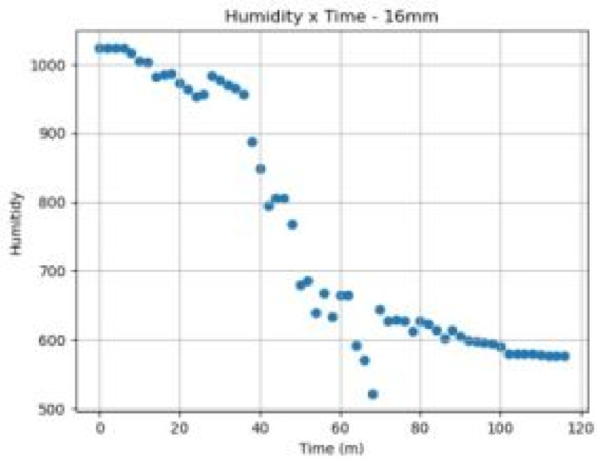

Figure 6. Hygrometer sensor data for particle sizes 16 mm

6. CONCLUSION

The demand for new sources of energy is increasing, and clean energy sources are growing fast. In view of this, it was seen in the midst of the production processes of Sugar and Alcohol a way to produce energy with the by-products of this production process in a more efficient and sustainable way and so that it has greater added value. In this process of research and analysis of new ways to use this biomass, it was seen that humidity has a great impact on the productive process of biomass use, and that biomass with less humidity can offer a greater energy capacity.

Therefore, a series of studies were started in order to develop a device that allows the analysis of the sugarcane bagasse moisture that is compact, simple and low cost, but that presents accurate results, so that the operator has access to the information quickly.

During the research process a database was created with information from different sugarcane bagasse granulometries, these being < 2 mm, 2 mm, 4.75 mm, 8 mm, and 16 mm. This database allows the code created based on the arduino to convert the data collected by the hygrometer sensor into percentage of biomass moisture, which facilitates the understanding of the information obtained by the moisture reader,

With the use of 3D printing it was created a prototype consisting of two parts, where it has the place to allocate the biomass, and a cover, where it has a housing for the hygrometer sensor probe. This device was waterproofed in order to avoid moisture loss from the biomass to the environment. Still in its initial stage, the project can be updated thanks to 3D printing in order to improve the device, creating slots to allocate components, such as the 8266 ESP board and the hygrometer sensor.

The proposed device has great usability and applicability in the day to day productive processes that work with the use of sugarcane bagasse as a source of energy generation. Furthermore, the device can receive updates that allow its use with other types of biomass, without the need for new investments. Only by creating calibration data for the biomass in question.

7. ACKNOWLEDGEMENTS

We would like to thank the Cooperativa dos Produtores de Cachaça de Córrego Fundo (COOPERCALC) in the person of its president Neurimar José Pinto, who kindly allowed the collection of samples from the mills affiliated to the cooperative, in addition to providing support and answering all questions during the sample collection process. I would also like to thank Mr. Ivan Caetano Costa, owner of the mill where the São Caetano Cachaça is produced in an artisanal way, and Mr. Pedro Henrique Mendes Pinto for intermediating the conversations and thus allowing the realization of this work.

8. REFERENCES

Borges, A.C.P., Silva, M.S., Alves, C.T. and Torres, E.A., 2017. "Energias renováveis: uma contextualização da biomassa como fonte de energia". *REDE-Revista Eletrônica do Prodema*, Vol. 10, pp. 23–36.

BRIDGWATER, A.V., 2003. "Renewable fuels and chemicals by thermal processing of biomass". *Chemical engineering journal*, Vol. 91, pp. 87–102.

Koga, P.S.L., 2017. *Expansão do setor sucroenergético e avaliação socioeconômica da produção de cana de açúcar na região noroeste do estado de São Paulo*. Ph.D. thesis, Universidade Estadual Paulista (Unesp), Sô Paulo, Brasil.

Lorensetti, R., 2022. "Umidade da biomassa? como ela prejudica o desempenho da caldeira?" Coontrol Tecnologia em Combustõ, Rio do Sul,https://blog.coontrol.com.br/umidade-da-biomassa-como-ela-prejudica-o-desempenho-da-caldeira/". Accessed 05 May 2023.

PAGEL, Uonis Raasch; CAMPOS, A.F.C.J., 2018. "Análise dos principais desafios ao desenvolvimento das energias renováveis no brasil". *XICongresso Brasileiro de Planejamento Energético*, p. 13.

QAISS, A. E. K.; BOUHFID, R.E.H., 2014. "Biomass and bioenergy processing and properties." *Switzerland: Springer International Publishing*.

Santos, M.M.d., 2018. *Sistema inteligente de baixo custo para o monitoramento automatizado da umidade do solo*. Ph.D. thesis, Universidade Federal Rural do Semi-Árido, Angicos-RN, Brasil.

SILVA, A.C.d.M.S.e., 2018. *Estudo da influência da umidade do bagaço da cana de açúcar na produção de energia em plantas de cogeração*. Master's thesis, Universidade Federal de Pernambuco, Recife, Brasil.

Teodoro, M.A., 2016. *Concentração Econômica do Capital Especialização Territorial Produtiva no Setor Sucroenergético na Região de Iturama (MG)*. Ph.D. thesis, Universidade Estadual Paulista (Unesp), Rio Claro-SP, Brasil.

9. RESPONSIBILITY NOTICE

The authors are solely responsible for the printed material included in this paper.