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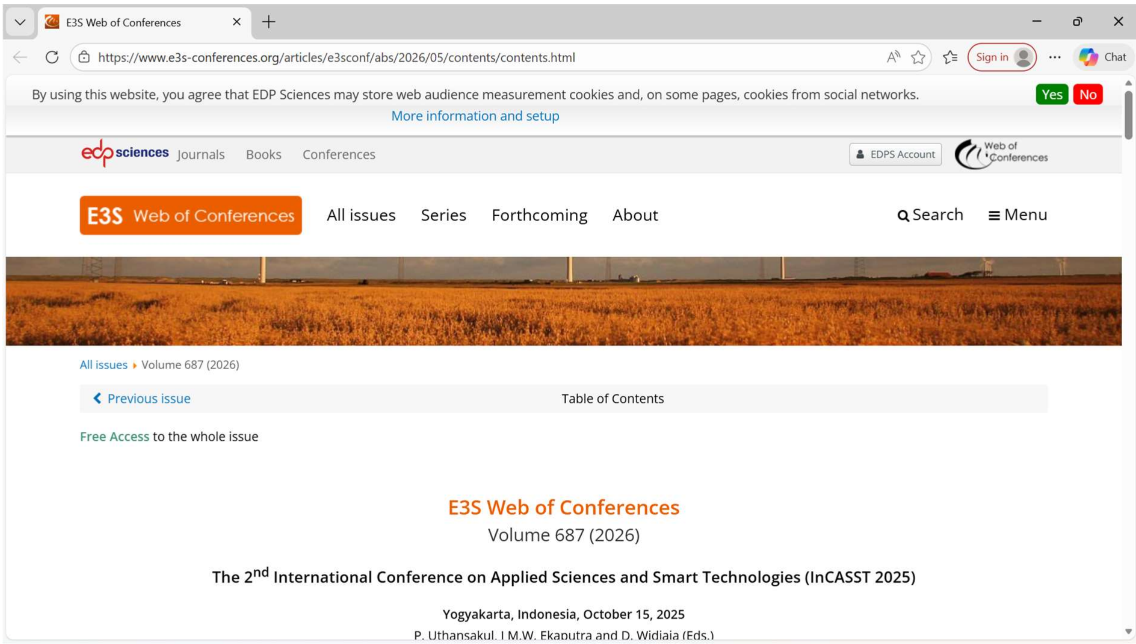
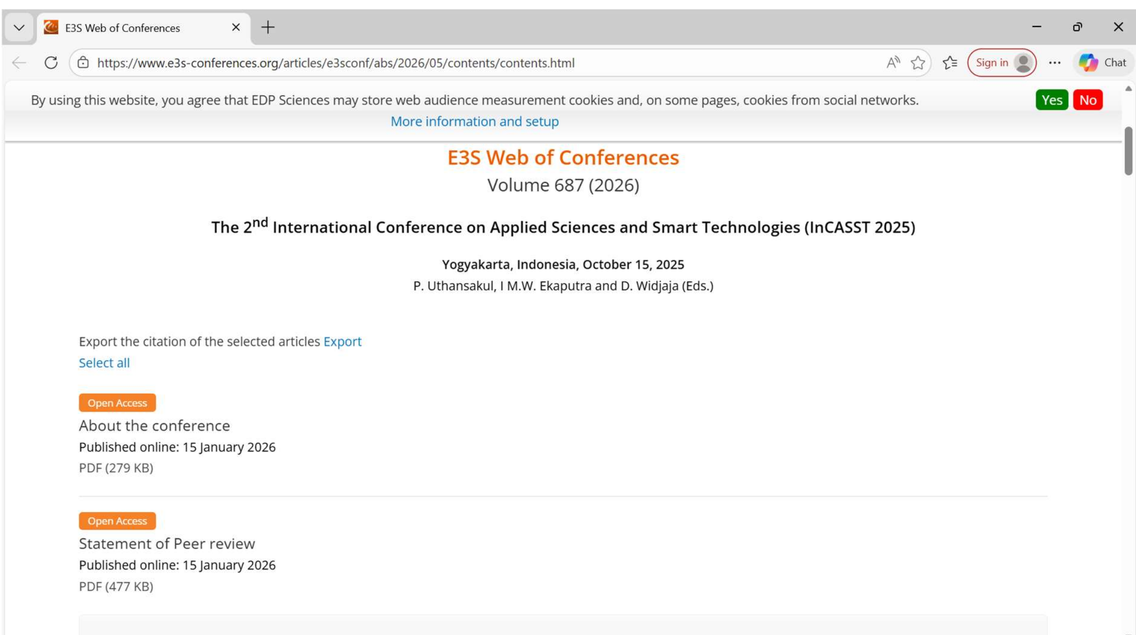
Volume 687 (2026)





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Automation of moisture level measurement in charcoal briquettes

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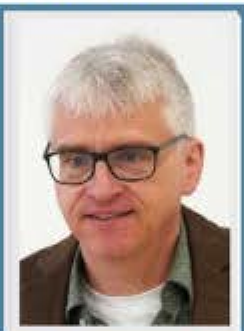

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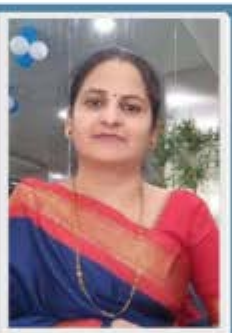

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Automation of moisture level measurement in charcoal briquettes

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Abstract. Charcoal briquettes, made from organic waste. Their quality depends significantly on moisture content, which affects electrical conductivity. This study focuses on automating moisture measurement using electrical resistance. The device employs a current-sensing circuit, an analog-to-digital converter, Hall effect sensors, and servo-driven clamps with plate-shaped electrodes to grip briquettes and measure resistance. Briquettes are fed into the system by a rotary feeder. Testing on batches of 10 briquettes classified as dry, half-dry, and wet showed classification success rates of 100% for either dry or wet conditions and 55.6% for half-dry conditions, despite occasional errors from resistance values outside predefined ranges. Resistance ranges recorded were 11.38–15.80 MΩ (dry), 3.37–7.59 MΩ (half-dry), and 0.02–0.80 MΩ (wet), corresponding to moisture contents of 0–3.03%, 7.27–11.52%, and 11.52–16.36%, respectively. The half-dry resistance values were closer to the wet range, indicating the half-dry batches were not distinctly intermediate between dry and wet. The rotary feeder showed practical reliability with 88% success for loading briquettes into chambers and 77.5% for positioning them on the measurement table, enabling effective automation. Overall, the system demonstrated the capability to measure moisture content and classify briquettes by dryness.

1 Introduction

The world seeks sustainable renewable energy sources to replace fossil fuels. One option is charcoal briquettes, made by crushing biomass wastes like paddy stalks, husks, rice hulls, and coconut shells into powder, mixing with a binder, shaping, and drying. Briquetting raises the energy-to-mass ratio of low-value biomass waste. Quality indicators include ignition and burning times. Briquette readiness depends on moisture content at the end of drying, which also influences ignition, burning duration, and Higher Heating Value (HHV) in a non-linear way, as shown in Figure 1 [1], [2], [3].

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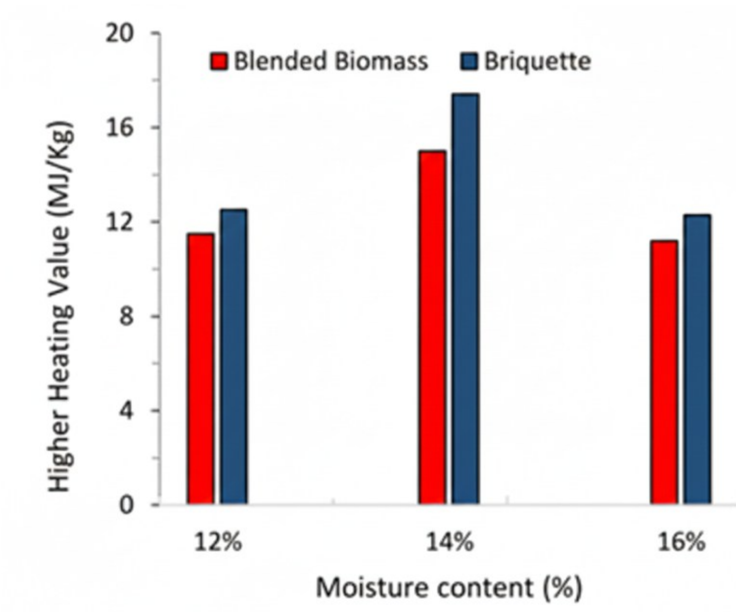

Fig. 1. Higher Heating Value of charcoal briquettes in relation to moisture content [4].

Previous research found that moisture content affects briquette resistance measured by conventional ohm-meter probing as depicted in Table 1, with half-dry batches having the highest resistance and wet batches the lowest, guiding resistance-based classification ranges. Manual measurement risks human errors, so developing an automated robotic resistance measurement system aims to improve accuracy and efficiency by minimizing human involvement. The study goal is to build this automatic moisture measurement system for charcoal briquettes [5], [6], [7].

Table 1. Measurement results from the previous study [5].

Condition	Probe Placement			Unit
	RL	RH	RS	
Wet	151,10	101,75	63,14	kΩ
Half Dry	9,08	6,62	5,82	MΩ
Dry	7,61	6,2	5,33	MΩ

2 Methods

The automatic moisture level measurement system consists of two main systems. These systems are the feeding system and the measurement system. The feeding system's role is to ensure the briquettes enter the measurement process in one by one or in sequence, while the measurement system's role is to take electrical measurements of the fed charcoal briquette. Together, they form an automatic moisture level measurement system. The simplified flowchart of the whole system is shown in Figure **2**.

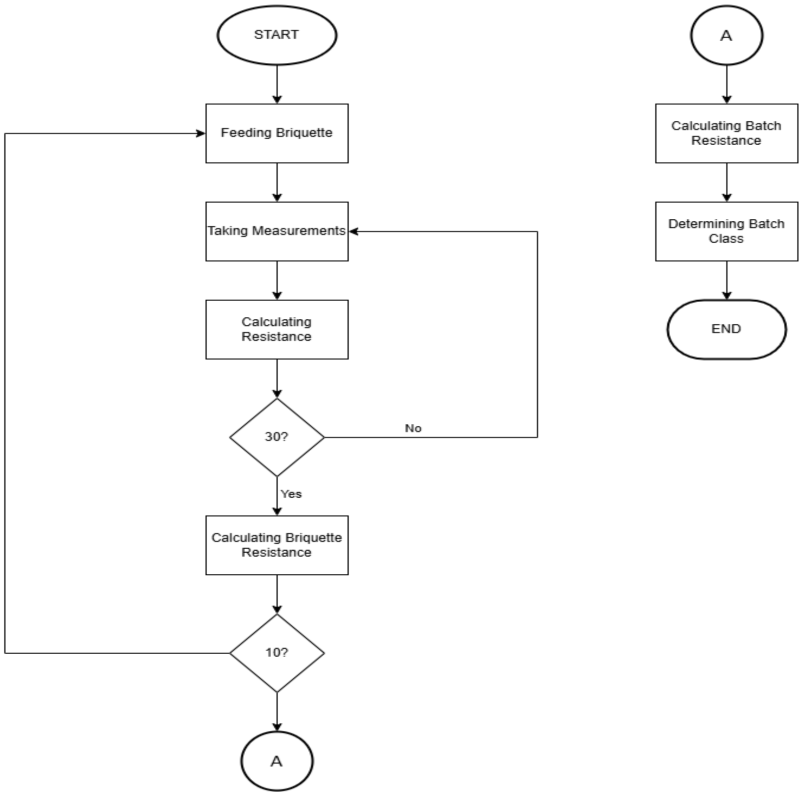

Fig. 2. General flowchart of the automatic moisture level measurement system.

2.1 Feeding System

The feeding system uses a rotary feeder to deliver briquettes one by one from a rectangular magazine attached with a slide-lock. The feeder has a static rail guiding the briquettes and a rotating part that pushes them clockwise to an outlet leading to the measurement device. It employs an S49E Hall effect sensor, MG996 servo, and PCA9685 controller to detect and control the rotating part's position. Magnets on each feeder chamber generate a magnetic field sensed by the Hall sensor, providing feedback to the microcontroller to stop the servo rotation via interrupts, as shown in Figure **3** [8], [9], [10], [11].

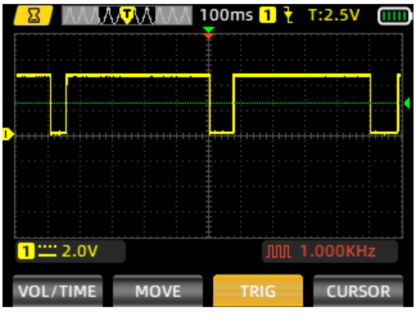

Fig. 3. Signal from the Hall effect sensor seen using oscilloscope.

2.2 Measurement System

Moisture level measurement of charcoal briquettes is done by estimating the resistance value of a briquette batch through electric current passed between the briquette and a fixed current sense resistor via plate-shaped electrodes, as shown in Figure 4. These plates contact opposite surfaces of the briquette using a clamping mechanism driven by a servo motor attached to a rack and pinion gear system. The electrodes and resistor form an open-loop circuit that completes into a voltage divider when the briquette is present. The simplified voltage divider circuit is shown in Figure 5. The voltage across the briquette and current sense resistor is sensed by an analog-to-digital converter, which converts the analog voltage into digital data. This data is then transmitted via I2C protocol to the microcontroller for collection and processing [13], [14], [15].

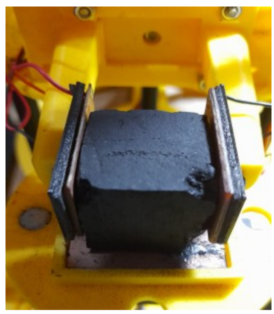

Fig. 4. Measurement system gripper mechanism.

Data from the measurement device is used to calculate charcoal briquette resistance as in (1), where R_s is the current sense resistor. Each briquette's resistance is averaged from 30 measurements, and averages from ten briquettes form the batch resistance. The wet and dry batch weights are measured to calculate relative moisture content using (2), based on the "green based", where $MC_{relative}$ equals the weight difference between the sample W_n and driest briquette W_{driest} divided by the heaviest briquette weight $W_{wettest}$. Average resistance and moisture content are compared to verify results.

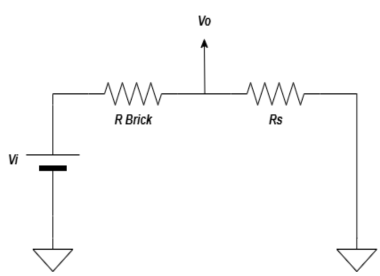

Fig. 5. Voltage divider circuit of the measurement system.

$$R_{brick} = R_s \times \left(\frac{V_i}{V_o} - 1\right) \tag{1}$$

$$MC_{relative} = \frac{W_n - W_{driest}}{W_{wettest}} \times 100\% \tag{2}$$

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2.3 Classification Method

Classification of the charcoal briquette's moisture level is done by using three simple if-else statements shown in Figure **6**. The three classification ranges are obtained by doing trial and error process by testing charcoal briquettes conditioned in the three conditions. It is done by sampling about 10 times of each dry and wet batch for the dry and wet threshold and then the middle range selected between the dry and wet value. The conditioning process is done by drying under the sun for the "dry" condition and submerging into tap water for about a minute for the "wet" condition. A dry batch is a batch of ten sun-dried charcoal briquettes. A wet batch is a batch of ten wet charcoal briquettes. The half-dry batch condition is achieved by constructing a batch of each five dry and wet charcoal briquettes.

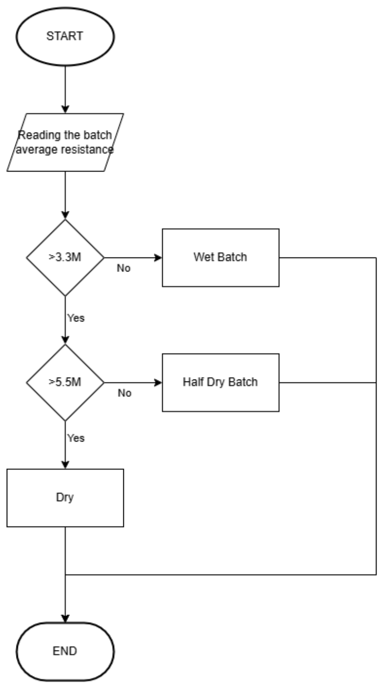


Fig. 6. Classification flowchart of the automatic moisture level measurement system.

2.4 Implementations

The system is implemented as follows, the electronics of the system shown and explained in Figure **7** and explained in Table **2** while the mechanics of the system shown and explained in Table **3**. The interface of the system shown and explained in Table **4**.

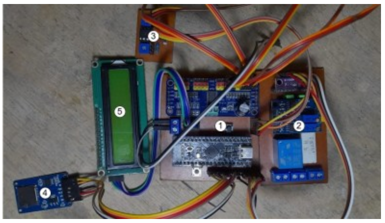


Fig. 7. Electronics of the automatic moisture level measurement system.

Table 2. Details of the electronic modules of the automatic moisture level measurement system.

Part Num.	Name of Part	Description
1	Control Module	Controls the whole system and processing collected data.
2	Measurement Module	Measuring the voltage induced by the current sense resistor.
3	Hall Effect Sensor	Detects magnetic field for controller position feedback.
4	Storage Module	Stores measurement data including the classification results.
5	I2C LCD Module	Shows the data and system informations.

Table 3. Details of the mechanical system of the automatic moisture level measurement system.

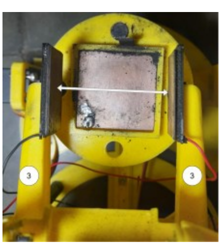
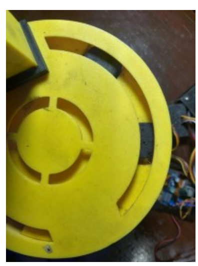
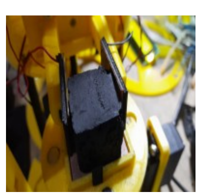
Device Picture	Part	Num.	Description
	Rotary Feeder	1	The Static part which acts as rail or guide for the charcoal briquettes.
		2	The dynamic part which moves in rotating clockwise motion.
	Measurement System	3	The gripper of the measurement system which physically clamps the briquette to enable measurement.

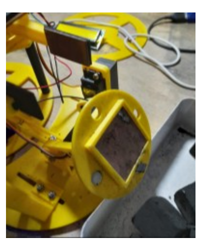
Table 4. Details of the interface of the automatic moisture level measurement system.

Interface	Num.	Description
	1	ON/OFF switch used to cut or connect the power supply to the system.
	2	RESET button used to do total restart of the whole system.
	3	START button used to start the measurement sequence session.

The step-by-step operation of the system after the start button is pressed is shown in the Table **5**. Initially, it will prepare the system, then take measurements after the system is initialized. If the process runs properly, the measurements taken will be stored on an SD card storage device. The system can handle undetected charcoal briquettes by nudging, with the assumption that the charcoal briquette is jammed at the feeding system's outlet.

Table 5. Operation sequence of the automatic moisture level measurement system.

Num.	Process Name	System	Description
1	Cleaning up the measuring table		Ejecting the objects on the table by tilting the table's servo motor.
2	Calibrating the measurement system		Touching the probes to create a short-circuit to obtain the offset value.
3	Filling the chambers		Moving the rotary feeding system to fill the rotary feeder's chambers.
4	Briquette feeding		Pushing a charcoal briquette into the measuring table.
5	Charcoal briquette existence checking		Checking the charcoal briquette existence by closing the electrodes until a certain threshold voltage that indicates briquette is sensed.

Num.	Process Name	System	Description
6-a	Measuring table flicking		Flicking the charcoal briquette forward to make sure that the briquette is parallel on any sides.
6-b	Nudging		Nudging the rotary feeder to push charcoal briquette that might be stuck. This step is done when step 6-a is not completed.
6-c	Abnormal system stop		Stopping the whole operation if step 6-a is not completed for 5 times in a row.
7	Resistance measurement		Measuring the resistance value of a charcoal briquette.
10	Measuring table clean up		Ejecting the charcoal briquette after measurements are done.
11	Normal system stop		Calculating and classifying the average resistance value of a charcoal briquette batch.

3 Results and Discussion

The automatic moisture measurement system consists of three main steps: feeding briquettes from the magazine into the system, measuring their resistance, and classifying the resistance values into three categories.

3.1 Mechanics

The mechanics of the automatic moisture level measurement system can deliver charcoal briquettes into the measuring table with a success rate of about 77.5% while 88% of the briquettes in the magazine are successfully inserted into the chambers. This success rate is calculated based on how many briquettes can complete the process without being stuck or thrown off the system. Table **6** shows the success in-out count of charcoal briquettes.

Table 6. In-out count of the charcoal briquette moisture level measurement system.

Num.	Into The Chambers	Into The Measurement System
1	7	5
2	9	8
3	10	8
4	9	5
5	8	8
6	9	6
7	8	7
8	10	8
9	9	7
10	9	6

3.2 Measurements

Measurements on three charcoal briquette batches with three iterations each are shown in Tables 7–9. Figure **Error! Reference source not found.** illustrate an inverse relationship between resistance and moisture content: lower moisture yields higher resistance. The first measurements show good linearity across batches, but non-linearity appears in later ones, especially in Batch 1, likely due to imperfect conditions like briquette dryness, electrode dirt, and contact issues. Differences from a previous manual study are attributed to electrode shape: the prior study used needle-shaped electrodes that focus current on a small area, resulting in lower resistance and different linearity compared to the plate-shaped electrodes used here.

Table 7. Batch weight of charcoal briquettes in the three conditions.

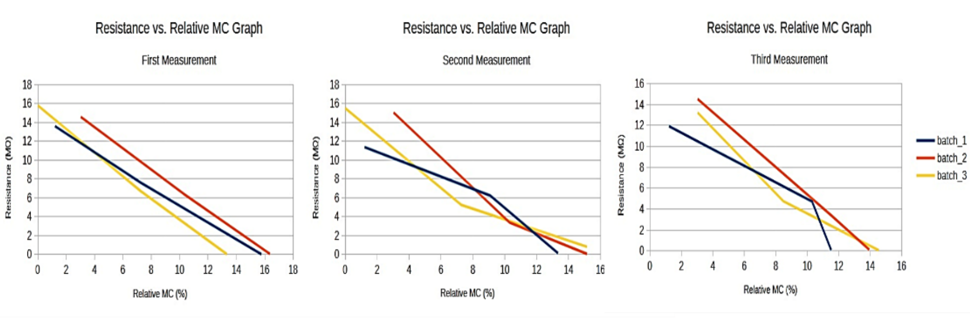
Batch	*i*	Batch Weight (g)		
		Dry	Half-Dry	Wet
1	1	14.00	15.00	16.40
	2	14.00	15.30	16.00
	3	14.00	15.50	15.70
2	1	14.30	15.50	16.50
	2	14.30	15.50	16.30
	3	14.30	15.70	16.10
3	1	13.80	15.00	16.00
	2	13.80	15.00	16.30
	3	14.30	15.20	16.20
Average		14,09	15,3	16,17

Table 8. Relative moisture content of the charcoal briquettes.

Batch	*i*	MC (%)		
		Dry	Half-Dry	Wet
1	1	1.21	7.27	15.76
	2	1.21	9.09	13.33
	3	1.21	10.3	11.52
2	1	3.03	10.3	16.36
	2	3.03	10.3	15.15
	3	3.03	11.52	13.94
3	1	0	7.27	13.33
	2	0	7.27	15.15
	3	3.03	8.48	14.55
Average		1,75	9,09	14,34

Table 9. Average resistance value of charcoal briquettes in three conditions.

Batch	*i*	Resistance Value (MΩ)		
		Dry	Half-Dry	Wet
1	1	13.61	7.59	0.02
	2	11.38	6.22	0.12
	3	11.92	4.73	0.08
2	1	14.59	6.40	0.05
	2	15.05	3.37	0.04
	3	14.53	3.40	0.11
3	1	15.80	6.69	0.02
	2	15.51	5.24	0.80
	3	13.22	4.74	0.05
Average		13,96	5,38	0,14



(a) **(b)** **(c)**

Fig. 8. First moisture content vs. resistance graph (a) First moisture (b) Second moisture (c) Third moisture.

3.3 Classification

Classification testing was conducted by measuring resistance values of batches containing ten charcoal briquettes under three conditions, using program-defined classification ranges. The system achieved 100% success in classifying dry and wet batches but only 55.6% for half-dry batches, with occasional errors due to average resistance values falling outside the defined ranges. After data collection, resistance ranges were established as 11.38–15.80 MΩ for dry, 3.37–7.59 MΩ for half-dry, and 0.02–0.80 MΩ for wet conditions, corresponding to relative moisture contents of 0–3.03%, 7.27–11.52%, and 11.52–16.36%, respectively.

The data also revealed that the half-dry resistance range is closer to the wet range and less aligned with the dry range. This suggests that the half-dry briquettes tested were not distinctly intermediate between dry and wet, indicating that the classification labelled as half-dry may represent batches more similar to wet conditions than truly in between.

4 Conclusion

This study confirms that the automatic charcoal briquette moisture measurement system effectively gauges moisture levels by analyzing resistance values, with success rates of 100% for dry and wet conditions, and 55.6% for half-dry. Resistance ranges clearly correlate with moisture content, though half-dry values are closer to wet, indicating less distinct intermediates. The rotating feeder system proved reliable, with 88% success in loading and 77.5% in positioning briquettes. Overall, the system demonstrates practical accuracy for industrial applications, with potential for future enhancements like improved feeders, machine learning classification, and supplementary sensors for comprehensive quality control.

This study provides additional proof that the moisture content of charcoal briquettes significantly influences their resistance value, which can be measured using a resistance divider-based current sensing circuit. The experimental results clearly show a strong correlation between moisture levels and resistance, underscoring the importance of precise measurement techniques for quality control and performance evaluation. Furthermore, the research demonstrates that complete automation of the measurement process is feasible through the integration of a rotary feeder and a gripping mechanism, enhancing the consistency, repeatability, and efficiency of measurements, making the system suitable for industrial applications. This work lays a solid foundation for future studies aimed at developing improved feeder designs and instrument configurations to achieve greater accuracy and reliability. Additionally, there is considerable potential for exploring advanced classification methods, including machine learning models, to better fit and interpret the collected data. Future research could also expand the capabilities of the measurement system by incorporating complementary sensors, such as built-in weighing scales for mass monitoring or surface area estimation tools to assess physical briquette characteristics, thereby enabling a more comprehensive evaluation. These enhancements would contribute to improved product quality, process optimization, and sustainability in charcoal briquette manufacturing and use.

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