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Stabilizing Temperature and Humidity in a Cocoa Bean Dryer Using Fuzzy Logic

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***Abstract*—The objective of this research is to develop a cocoa seed drying device. The proposed research utilizes the thermal energy emitted by a light bulb as the heat source. The purpose is to replace the solar heat used in the traditional cocoa drying method. The device is set at temperatures of 45°C, 50°C, and 55°C to get the requirements target. The water content of cocoa seeds is approximately 68% at the beginning, and upon complete drying, the water content of fully dried cocoa seeds will vary between 7% and 7.5%. In prior studies, the experimental conditions involved subjecting the system to a temperature of 50°C for 14 hours. Additionally, when the temperature was increased to 55°C, an overshoot of 10.18% was observed. This phenomenon persists due to reliance on sunlight as the predominant heat source. This study uses a fuzzy logic method to control temperature and humidity at the desired setpoint. The results show that temperatures of 45°C, 50°C, and 55°C exhibit rise times of 405 seconds, 1,294 seconds, and 1,732 seconds, correspondingly. The recorded overshoots for the three trials were 0.11%, 0.39%, and 0.19%, respectively. The duration required for the drying process of cocoa seeds was measured to be 14.35 hours, 11.23 hours, and 6.65 hours, respectively. In contrast to prior investigations, the duration required for a reaction at a temperature of 50°C is 14 hours, while at a temperature of 55°C, an overshoot of 10.18% is seen. Our work has improved the performance of the cocoa bean dryer by reducing overshoots and accelerated drying durations.**

Keywords*—*Cocoa bean drying, incandescent light, fuzzy logic

I. INTRODUCTION

In 2010, Indonesia held the distinction of being the foremost global exporter of seed cocoa. The cultivation of cocoa fruit has significantly contributed to Indonesia's socioeconomic progress since the year 1930 [1]. Commodity cocoa exhibits greater market potential in comparison to commodity plantations, since it offers many advantages to industries, food production, and medicinal sectors. The processing of cocoa yields many items, including meat, fruit, and skin, while the resultant seeds are utilized for animal feed and fertilization purposes. The byproducts of cocoa processing, namely meat and skins, undergo a drying process to get dry cocoa [2], [3].

A portion of the cocoa plant is utilized for its seeds. Cocoa seeds are commonly utilized in the production of consumable products, such as chocolate. Prior to undergoing the transformation into chocolate, cocoa seeds undergo a preliminary stage of drying. This drying process is employed with the aim of diminishing the moisture content of the initially wet cocoa beans. Nevertheless, the duration required for the drying of cocoa seeds is somewhat lengthy, typically spanning a period of 2 to 3 days. The drying process is influenced by the prevailing weather conditions, and if these conditions are not conducive, it might result in a prolonged duration for the drying process. The aforementioned issue arises from the challenges faced by farmers in assessing the moisture level of cocoa beans, as well as their limited understanding of processing methods, leading them to rely on traditional sun-drying procedures [4]. The variability of weather conditions on a daily basis might introduce complexities to the drying and producing process.

In previous research on cocoa seed dryers, a DHT12 sensor [5], a heater, and a DC motor were utilized. The DHT12 sensor serves as an indoor temperature and humidity gauge for the purpose of maintaining warmth during the drying process. The sensor has a temperature range spanning from 0.5 °C to 25 °C, and a moisture range of 3.5% relative humidity (RH). The investigation did not employ techniques to regulate temperature and humidity within the drying container. In another investigation [6], the fuzzy logic approach was employed to facilitate the drying process of cocoa seeds. The research employed the Mamdani approach, a well-established technique within the field of Fuzzy Logic, and implemented it using the Atmega16 microcontroller. Nevertheless, the drying process still relies on sunlight as its main heat source.

Consequently, a cocoa seed drying device was developed as a potential alternative method for cocoa growers seeking to generate superior-grade dried cocoa. The ATmega2560 microcontroller [7], [8] is employed in conjunction with a load cell device [9] to ascertain the weight of cocoa seeds undergoing drying. Additionally, the DHT22 sensor [10] is utilized to record temperature and humidity data. Furthermore, a fuzzy logical control approach [11]–[13] is implemented to regulate the temperature during the cocoa drying process, specifically targeting temperatures of 45 °C, 50 °C, and 55 °C. The findings from this study suggest that the heater has been used as a substitute for sunlight in the drying of cocoa seeds, unlike its previous drying method. Furthermore, the temperature of the heaters can be adjusted according to specific requirements. The study has the potential to facilitate the expeditious drying of cocoa seeds for farmers.

II. METHODOLOGY

Figure 1 shows steps of the research method. The method used consists of hardware design, trial temperature with sensor, design fuzzy logic control, collect data, and result. Throughout the preliminary stages of hardware or device planning, it is crucial to consider the dimensions of the area required for the setup, including the form and size of the space, as well as the dimensions of the container that will be utilized for placing cocoa seeds during the drying process. In accordance with the devised space utilization strategy, the further implementation of the aforementioned design is to be undertaken.

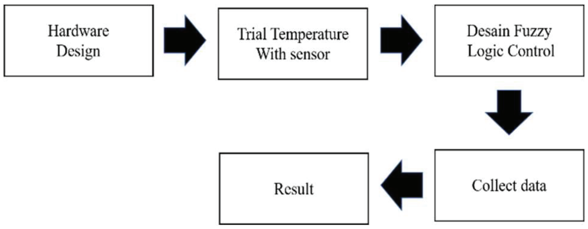

Fig. 1. Steps of the Research Method

Figure 2 shows the design of the front and back of the cocoa bean dryer. The length of the tool is 60 cm, the height is 40 cm and the width is 45 cm. The glass of the tool has a width of 50 cm with a height of 25 cm and a size of 10 cm × 10 cm, and there is a small box-shaped hole with a size of 8 cm × 8 cm to place a DC motor fan used to regulate moisture in the dryer.

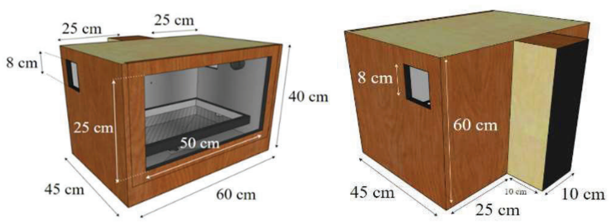

Fig. 2. Design of the Front Right and Rear of the Tool [14]

Figure 3 is the design of the cocoa bean tray used to place the cocoa beans during the drying process, which has a length of 50 cm, a height of 5 cm and a width of 35 cm. The design of the fuzzy logic controller is carried out using 2 different software, namely the Arduino IDE as a medium for the ATmega2560 microcontroller [7], [8] and Matlab as a medium using the fuzzy logic control method.

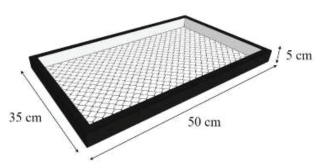

Fig. 3. Container Design for Placement of Cocoa Beans [14]

Figure 4 shows temperature response to time. The purpose of this temperature test is to find out how long it takes the device to reach the setpoint temperature and the maximum temperature generated by the device. The time it takes to reach a temperature of 45ºC of 348s (5,8 minutes) with a maximum temperature of 80,3ºC. The procedure of processing input data into output data in the form of Pulse Width Modulation (PWM) utilizing fuzzy controller logic. During the drying process, the DHT22 sensor functions to adjust the temperature and humidity in the device at setpoint 45ºC. Further, the temperature will be adjusted to the setpoint of 50ºC and 55ºC, whileining the humidities below 50%. The value provided in the crisp set is converted into a fuzzy set during the process of fuzzification [15]–[17]. The input value is specified in the form of a fuzzy set, which is utilized in the process of fuzzy inference. The user's text does not contain any information to rewrite. The user did not provide any text to rewrite. In order to achieve a precise measurement of fuzziness and establish the governing principles of the drying procedure. The obtained fuzzy value, referred to as the mark output, undergoes quick processing in steps of defuzzification [18] to return to a crisp shape. This crisp shape is then converted into a pulse width modulation (PWM) value, which is then read in the form of a PWM value by the AC light dimmer module [19].

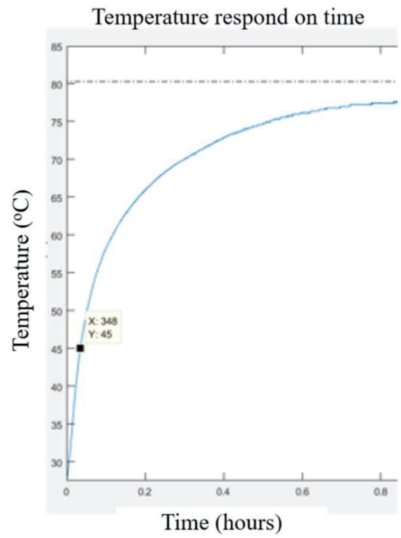

Fig. 4. Temperature response

III. Results and Discussion

A. Prototype Design Results

Figure 5 is the result of the system design of the cocoa bean dryer that will be carried out in this study. The fuzzy logic controller that has been designed is applied to the design by placing the DHT22 temperature and humidity sensor on the top and bottom centers of the room, the heater (a 100-watt incandescent lamp) [18] on the left and right sides of the room, the container at the bottom of the room, which has a load cell sensor on the bottom side, and the LCD on the front side of the room.

Fig. 5. (a) Front left view (b) Front right (c) Front view (d) Inside view [14]

B. System Testing Results

In testing the DHT22 sensor there are two experiments, namely on reading temperature and reading humidity. According to testing result between thermometer with DHT22 sensor in terms of temperatures and between hygrometer with DHT22 sensor in terms of humidity. The temperature and humidity data obtained after the tests are shown in Table I. The results test shows that the highest percentage error was at 1.946% and the percentage error lowest namely 1,518%. It can be concluded that the DHT22 sensor can be used in this research as a drying temperature regulator because the percentage error is Still by the data sheet, where the sensor's level accuracy temperature is by ±0.5 °C.

TABLE I. COMPARISON OF TEMPERATURE ON THE DHT22 SENSOR WITH A THERMOMETER

Upper DHT22 Temp (ºC)	Lower DHT22 Temp (ºC)	Average DHT22 Temp (ºC)	Thermometers Temp (ºC)	Error (%)
50,30	40.50	45,40	46,1	1.518
52,10	39.00	45.55	46,1	1,831
57,40	43,60	50,50	49,7	1,609
63,60	47,20	55,40	56.5	1,946

TABLE II. DHT22 HUMIDITY SENSOR WITH HYGROMETER

DHT22 Upper Humidity (%)	Humidity Lower (%)	Average DHT22 Humidity (%)	Hygrometer Humidity (%)	Error (%)
46.20	44.70	45.45	47	3.29
38.10	44.70	41.55	42	3.45
33.20	44.30	38.25	38	0.657
25.60	44.90	35.25	35	0.714

Table II shows the results that the highest percentage error in the marks was 3.29%, while the lowest error was 0.657%. Consequently, it can be inferred that the DHT22 sensor holds potential for utilization in research as a reliable indicator for monitoring humidity levels during the drying process of containers. This conclusion is supported by the fact that the percentage errors fall within the range specified in the sensor's data sheet, which indicates an accuracy level of ±5% for humidity measurements.

When conducting tests on the load cell sensor, the greatest recorded percentage error was found to be 1.271%, while the lowest recorded error was 0.406%. It may be inferred that the utilization of load cells for determining the weight of heavy cocoa seeds remains a viable method in research. Subsequently, experimentation is conducted to obtain a diverse range of illuminations that exhibit optimal responsiveness to the temperature within the enclosure. The purpose of this experiment was to measure the temperature sensitivity of a 100-watt light bulb [18] and two 100-watt incandescent lights. The temperature response in an awakening room, as influenced by the number of lamps utilized, can be described as follows.

C. Fuzzy Logic Control Mechanism

The mechanism work of controller fuzzy logic is considering mark temperature and humidity from the DHT22 sensor. Then, the mark will be processed in system inference fuzzy and got top PWM outputs light used as heating and PWM to move the motor fan.

In Figure 6, we can see the degrees membership for variable inputs set temperature fuzzy. In our work, the parameters used are cold temperature, desired temperature, and hot temperature. If the sensor reading is 43 ºC, then include the membership cold and normal.

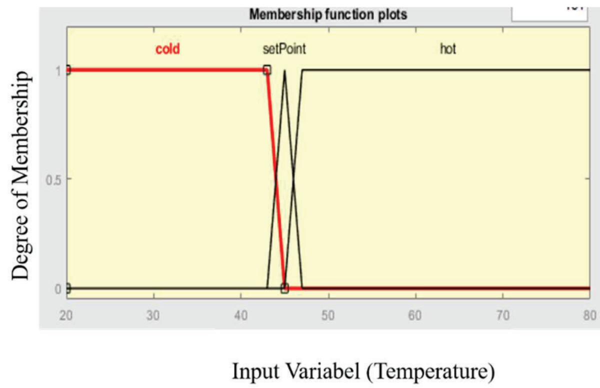

Fig. 6. Degree of membership of the temperature input variable at 45 ºC

- Cold

$\mu\ (x) = (b\text{-}x) / (b\text{-}a)$ (1)

$\mu\ (43) = (45\text{-}43) / (45\text{-}40)$

$= 2 / 5$

μ cold (43) = 0.4

- Normal

$\mu\ (x) = (x\text{-}a) / (b\text{-}a)$ (2)

$\mu\ (43) = (43\text{-}40) / (45\text{-}40)$

$= 3/ 5$

μ normal (43) = 0.6

Figure 7 shows the degree of membership for the variable humidity input to the fuzzy set. in this experiment the parameters used are dry and moist. If the sensor reading is at 49.5% humidity, then included it in the section membership dry.

- Dry

$\mu\ (x) = (c\text{-}x) / (c\text{-}b)$ (3)

$\mu\ (49.5) = (50\text{-}49.5) / (50\text{-}49)$

$= 0.5/1$

μ dry (49.5) = 0.5

- Moist

$\mu(x) = (x\text{-}a) / (b\text{-}a)$ (4)

$\mu\ (49.5) = (49.5\text{-}49) / (50\text{-}49)$

$= 0.5 / 1$

µ moist (49.5) = 0.5

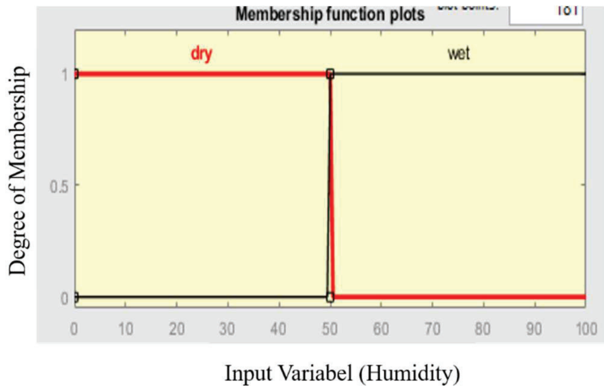

Fig. 7. Degree of membership variable humidity input

D. *Testing the Stability of the Fuzzy Control System on Cocoa Beans*

Figure 8 shows The graph illustrates that the system has a temperature response and demonstrates a notable degree of stability. The graph additionally illustrates that the temperature can attain the designated setpoint at a time of 19 minutes and 36 seconds. The graph presented above illustrates that the response time, also known as the rise time, is 405 seconds (412 seconds minus 7 seconds), whereas the duration required to achieve a stable condition is 1478 seconds at a temperature of 45°C. In a time span of 30 minutes and 12 seconds, the temperature can increase to the required setpoint of 50°C. The temperature graph of the cocoa bean drying process exhibits a significant increase until the DHT 22 sensor detects a temperature value that aligns with the predetermined setpoint of 50 ºC. The provided graph additionally illustrates a response time (rise time) of 1294s (1311s - 17s), with the attainment of steady state occurring at 1970s. In prior studies, the experimental conditions involved subjecting the system to a temperature of 50 ºC for a duration of 14 hours. Additionally, when the temperature was increased to 55 ºC, an overshoot of 10.18% was observed. This phenomenon persists due to the continued reliance on sunlight as the predominant heat source [6]. At a temperature of 55 ºC, the desired setpoint can be achieved within a time frame of 36 minutes and 26 seconds. The temperature graph of the cocoa bean drying process exhibits a sharp incline until the DHT 22 sensor registers a temperature value that aligns with the predetermined setpoint of 55 ºC. The graph depicted above also illustrates the rising time, or response time, which is calculated as 1732s (1740s - 8s), and a steady state value of 2451s. In a prior investigation, a quantity of 2.5 kilograms of cocoa seeds was subjected to a temperature of 55 ºC, resulting in a duration of 12 hours for the process. [6]. The present study was conducted with the aim of achieving a reduced overshoot of 0.19%. Humidity produced at 45 ºC, 50 ºC and 55 ºC as follows.

Figure 9 shows that at 45°C, humidity ranges from 44% to 32%. Then it goes up to 38% and finally it goes back down. The temperature is 50°C the humidity is around 43% then rises to 47% and finally drops back down. The temperature is 55°C, the humidity is around 53% then drops. This is already included in the required humidity criteria.

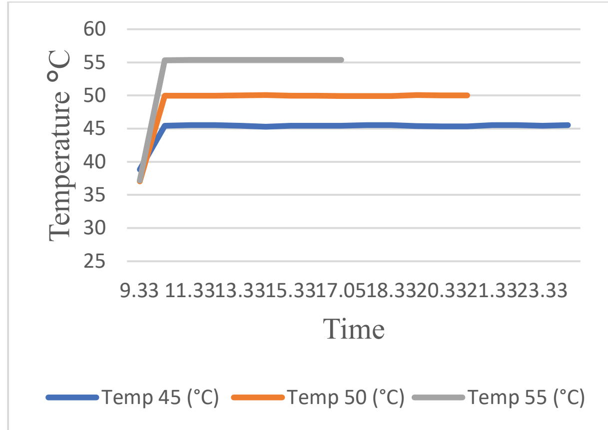

Fig. 8. Graph of temperature response at setpoints of 45°C, 50 °C, and 55°C

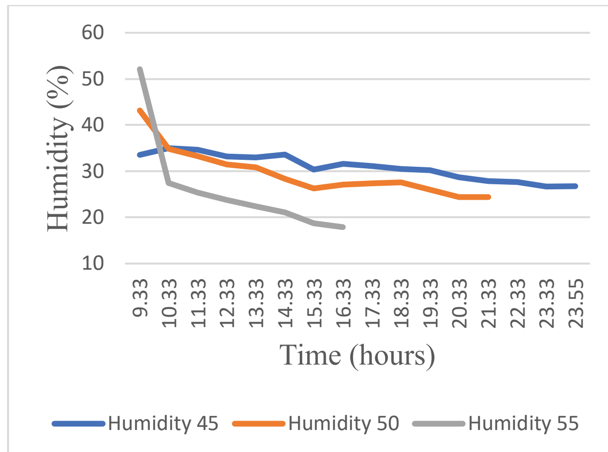

Fig. 9. Graph of humidity response at setpoints of 45°C, 50°C and 55°C

Table III shows that to reduce the water content at 45 °C it takes 14.35 hours. where the initial weight of 247 grams becomes 110 grams.

TABLE III. CAPTURED DATA AT SETPOINT 45°C

No.	Time (hours)	Weight (gram)
1	9.33	247
2	10.33	222
3	11.33	217
4	12.33	203
5	13.33	195
6	14.33	183
7	15.33	176
8	16.33	162
9	17.33	152
10	18.33	146
11	19.33	143
12	20.33	131
13	21.33	118
14	22.33	116
15	23.55	110

Table IV shows that to reduce the water content at 50 °C it takes 11.23 hours. where the initial weight of 280 grams becomes 126 grams. The length of the drying process at the

50 °C setpoint is because the temperature given is greater than the 45 °C temperature.

Table V shows that to reduce the water content at 55 °C it takes 6,65 hours. where the initial weight of 233 grams becomes 103 grams. The length of the drying process at the 55 °C setpoint is because the temperature given is greater than the 45 °C and 50 °C temperature. From the three temperature experiments conducted, it can be concluded that the heavier the object used and the higher the temperature, the longer the system response will increase. the higher the desired temperature, the faster the process of reducing the moisture content in the beans is wasted but still in accordance with the standard drying of cocoa beans according to experts.

TABLE IV. CAPTURED DATA AT SETPOINT 50°C

No.	Time (hours)	Weight (gram)
1	9.13	280
2	10.13	261
3	11.13	246
4	12.13	230
5	13.13	211
6	14.13	192
7	15.13	179
8	16.13	162
9	17.13	155
10	18.13	142
11	19.13	130
12	20.29	126

TABLE V. CAPTURE DATA AT SETPOINT 55°C

No.	Time (hours)	Weight (gram)
1	10.25	233
2	11.25	188
3	12.25	164
4	13.25	140
5	14.25	125
6	15.25	113
7	16.25	108
8	17.05	103

Previous research has employed temperature values of 50 °C and 55 °C to dry cocoa beans [6]. At a temperature of 50°C and a weight of 100 grams, the duration required for drying is 14 hours. At a temperature of 55°C and a weight of 2.5 kg, the duration needed is 12 hours, accompanied with an overshoot of 10.18%. The findings of this investigation indicate an overshoot of 0.19% with a time duration of 6.65 hours. These results suggest that the current research outperforms earlier studies. Figure 10 shows the result of cocoa beans obtained based on an experiment using a fuzzy logic controller taken after 14 hours of drying.

Fig. 10. Cocoa beans after 14 hours of drying

IV. CONCLUSION

This study presents the development of a cocoa seed dryer utilizing the fuzzy logic approach. This technique is employed to effectively control the temperature and humidity levels within the dryer containers, so ensuring the maintenance of consistent temperature and moisture conditions. According to the data obtained from the dryer's system response, it can be observed that the system exhibits a steady state error of 1.09% when the setpoint is 45°C. Similarly, when the setpoint is increased to 50°C, the steady state error decreases to 0.2%. Furthermore, at a setpoint of 55 °C, the steady state error is measured to be 0.72%. Additionally, the system demonstrates overshoots of 0.11%, 0.59%, and 0.19% at the setpoint of 55°C. The response speed, also known as uptime, has a value of 405 seconds when the temperature is set at 45°C. At 50°C, the response speed decreases to 1.294 seconds, and further decreases to 1732 seconds when the temperature is raised to 55°C. The method demonstrates optimal compatibility with designs aimed at decreasing the moisture content of cocoa seeds to 7 - 7.5% within specific time intervals: 14.35 hours at 45°C, 11.23 hours at 50°C, and 6.65 hours at 55°C. The temperatures of 45°C, 50°C, and 55°C were observed, accompanied by a humidity level below 50%. The findings of this study demonstrate a more precise approach to determining the duration required for cocoa beans to undergo drying, so effectively lowering the moisture content of the dried cocoa. Potential avenues for future investigation may involve alongside the utilization of the Internet of Things (IoT) for real-time monitoring of the drying procedure.

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