

Multi-Directional Forced Convection Kiln Oven Drying System for Bamboo Culms

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Abstract. The bamboo industry in the Philippines is at the commencement of its development in terms of co-existing with the current technology. The study aims to develop and improve the processing of bamboo, specifically its drying process. The traditional drying process in the Philippines is sun drying which is a primitive way of drying the bamboo. The drying process presented in this study is the forced convection kiln oven drying. It offers fast drying time and allows the bamboo culm to be enclosed on a system to prevent dirt or other contaminants to accumulate on the culm. The prototype is composed of a blower that would exhibit the forced convection; a base considered to be the system for the bamboo to dry and a heating element that would induce the heat necessary for the drying. The heating source is an electrical component that requires electricity from an AC power source. In order to test the prototype, a fresh bamboo is to be dried inside the system and its moisture content would be monitored with respect to time. The result of the test would provide for the conclusion of the efficiency of the dryer to reduce the moisture content of the bamboo.

1. Introduction

Bamboo is a plant which can be utilized for many applications. Its shoots can be eaten while its culms can be used in the field of construction and furniture crafting. Bamboo culms, the stem part of the plant, are strong and durable which makes it ideal to be used as a construction material. Bamboo, being a grass, grows much faster than trees. Bamboo culms can be harvested within 3-5 years while an oak tree, also a common source for construction materials, can be harvested within 10-12 years. However, much like wood, bamboo is hygroscopic meaning it has the natural tendency to absorb moisture from the surrounding air. Bamboo culms can have a moisture content of more than 150% [1]. The presence of water in the bamboo promotes microbial activity. This microbial activity causes the decomposition of the fibers in the bamboo which effectively reduces its strength as a material. As a result, drying of bamboo culms becomes essential for the preserving and achieving the appropriate structural properties for its further utilization [2].

In the Philippines, the common drying method is open-sun drying which involves stacking the bamboo culms and exposing them to direct sunlight. However, this method is highly dependent on the climatic conditions. The Philippines, being a tropical country and an archipelago, has a naturally humid environment. The drying time decreases due to the fact the bamboo absorbs the moisture from the surrounding air. Other drying methods include forced convection drying, microwave drying, kiln drying, and vacuum-freeze drying. The best aspects of these drying methods have been incorporated into this project in order to determine the most efficient way to dry bamboo. Utilizing a kiln, which is a controlled environment for the bamboo to dry inside, is best suited [3]. A reliable and controllable



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heat source is needed. For this reason, an electric heater was used. Forced convection was utilized to decrease drying time [4]. Multi-directional air flow was used in order to decrease drying defects [2].

In addition to, moisture content was correlated bamboo color. Traditionally, bamboo dryness is determined from the weight of the culms. However, not everyone has access to weighing devices. For this reason, a visual method of determining moisture content was created. This is to allow small bamboo manufacturers, specifically those without access to weighing devices, to accurately determine the dryness of their bamboo.

2. Materials and Methods

The drying system used in this study is seen in figure 1 while the drying system process flow is shown in figure 2. The system takes in atmospheric air through the use of a fan. The fan then directs the air towards the heater and then towards the drying chamber. The drying chamber has a capacity of six 2-foot long bamboo culms. Two trays were used with three culms placed on each tray. The air flows through holes in the wall between the heater and drying chamber. The holes scatter the air flow and distribute the heat within the drying chamber. The door of the oven has a window for viewing the interior and bamboo color. Table 1 shows the materials used in the construction of the oven and were determined using the quantitative material selection [5].

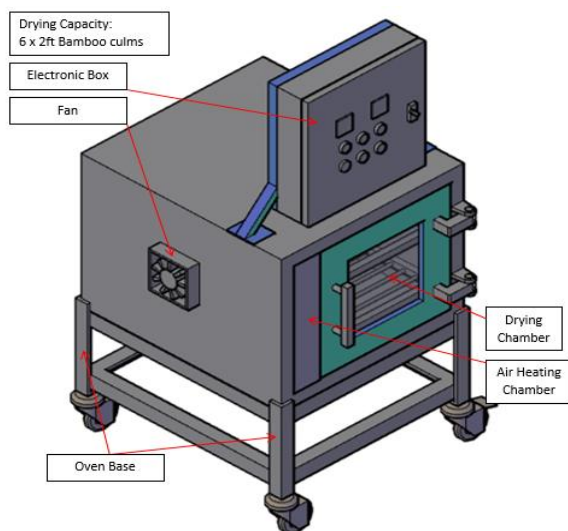


Figure 1. Drying System.

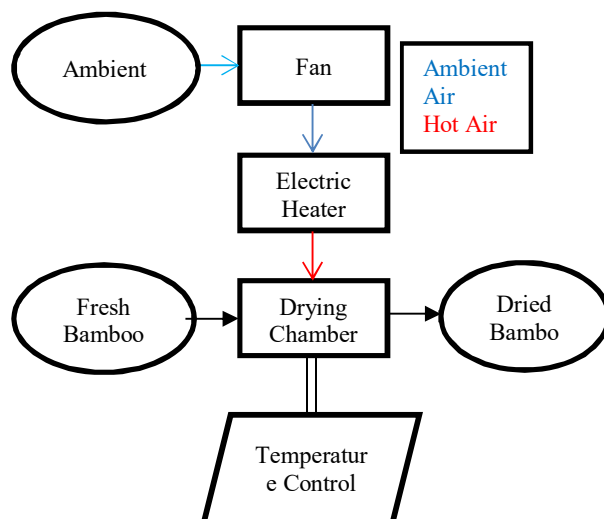


Figure 2. Drying System Process Flow.

Table 1. Oven Material Selection.

Oven Body	Mild Steel Plate
Outer Cover	B.I. Sheet
Drying Tray	Stainless Steel
Glass	Tempered Glass
Insulation	Rockwool
Oven Base	Angle Bar
Wheels	Swivel Caster Wheel

The drying temperature is normally set to an ideal value of 70°C [2]. The drying time is normally set to 2.5 hours. Both drying temperature and drying time can be set to other values. An interface displays the drying temperature and drying time of the oven. Temperature is regulated and controlled by an electronic system. The electronic system controls the electric heater. A thermocouple is used as the temperature sensor. Heater capacity was calculated from the moisture content of bamboo and specific heat capacity of bamboo [6]. Fan speed was calculated using heat transfer equations obtained

from [7]. Theoretical weight loss was calculated using wood moisture calculations by [8] and psychrometric equations. The oven specifications were shown on table 2.

Table 2. Oven Specifications.

Heating Element	Electric Heater
Heater Capacity	1000 W
Fan Speed	1400 rpm; 1.34 m/s
Fan Diameter	115 mm
Temperature Sensor	Thermocouple
Drying Temperature	70°C (adjustable)
Drying Time	2.5 hours (adjustable)
Theoretical Moisture Removed	361

3. Results and Discussion

Upon completion of the fabrication, the prototype was tested. Sample weights were measured using an oven-dry weight basis. This involves measuring the initial weight of the culms and the weight at certain time intervals. Weights of the samples were measured every 30 minutes. This was done by removing them from the oven, weighing them and then putting them back into the oven. A weight sensor was not placed within the oven because of the limitations in the circuitry due to the high temperature. Variation of oven temperature with respect to drying time was also observed. This was done to observe the effect of opening the oven to measure the samples. The set drying temperature of 70°C was reached within 5 minutes. An average weight loss of 5.80 grams per hour was observed and shown in figure 3 and table 3.

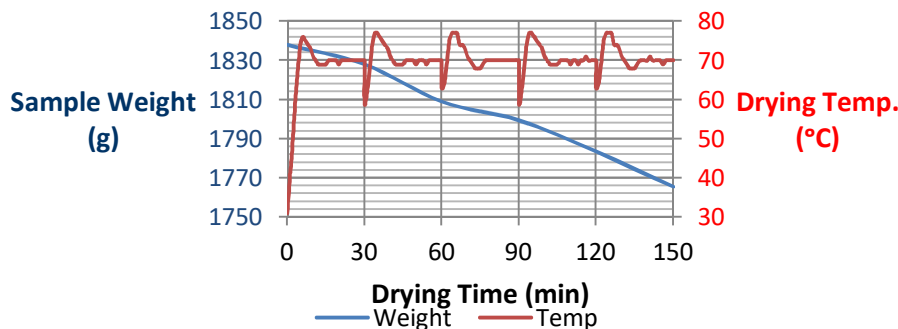


Figure 3. Variation of Sample Weight and Drying Temperature.

Table 3. Weight Loss in Bamboo Samples after 2.5 hours.

Sample No.	Initial Weight (g)	Final Weight (g)	Weight Loss (g)
1	717	638	79
2	606	577	29
3	1183	1149	34
4	853	819	34
5	1168.9	1129	39.9
6	648	620	28
			Average = 40.65
			Total = 243.9

Another test was conducted to compare the drying time of the oven to drying time of traditional open-sun drying. Bamboo samples were left to dry undisturbed within the oven which means the oven was not opened to measure sample weights. Only initial and final weights within the 2.5-hour drying period were measured. The average weight loss was 40.65 grams and the total weight loss was 243.9 grams. Bamboo samples of the same amount were laid out on the ground and exposed to sunlight.

Initial weight was measured. The culms were left to sun-dry for 24 hours. Final weight was measured. On average, the sun-dried culms lost 100 grams seen in table 4.

Table 4. Comparison of Sun-drying to Oven-drying.

Drying Method	Average Weight Loss (g)	Drying Time (hrs)	Drying Speed (g/hr)
Sun-drying	100	24	4.17
Oven-drying	40.65	2.5	16.26

It was found that color values, R-G-B, were somewhat linearly related to moisture ratio [9] referred to figure 4.

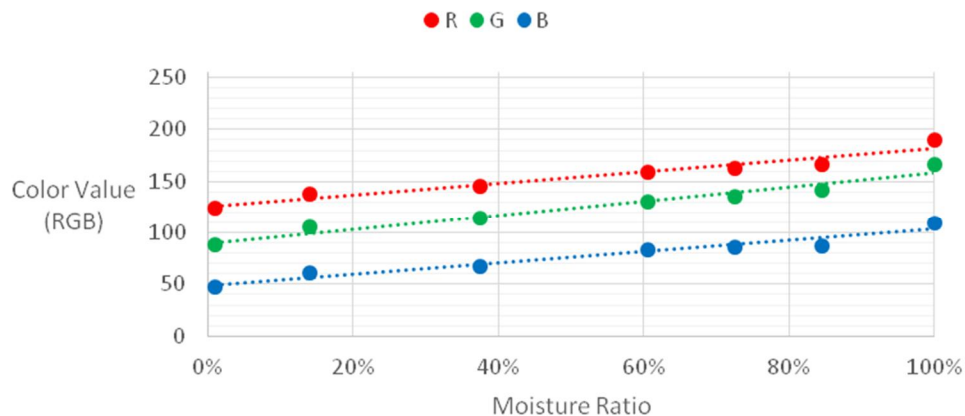






Figure 4. Changes in RGB Values as a Function of Moisture Ratio.

RGB values of various points in the culm were determined using an online image to RGB converter. RGB values were determined for different sample weights. It was found that bamboo changes color from green (fresh) to yellow brown (dried) described in table 5.

Table 5. RGB Values at Various Sample Weights.

Sample Weight (kg)	R	G	B	Color
1.849	43	80	39	
0.853	139	149	73	
0.606	153	158	95	
0.577	190	183	166	

By using a linear relationship between sample weight and color value, equations were created for the color values as a function of sample weight. By plotting straight lines in MATLAB using the established equations as the line color, a color scale was created in figure 5.

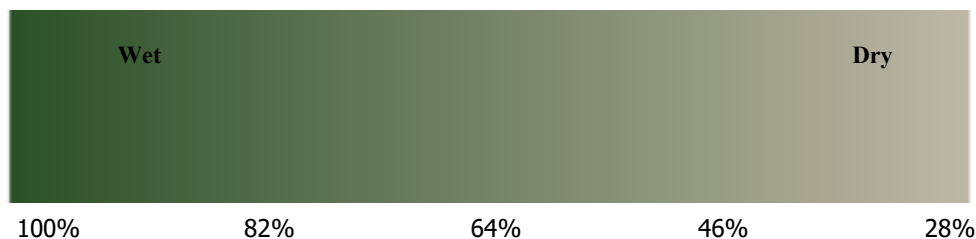


Figure 5. Bamboo Color Scale.

4. Conclusion

As shown in the results of the tests, there is a reduction in the weight of the bamboo signifying a reduction in the moisture content of the bamboo hence becoming dried. The drying speed of the bamboo culms was dependent on their position such that the culms on the top tray dried much faster than the culms at the bottom tray. The bamboo culms closer to the heating chamber also exhibited a faster drying time compared to the other culms. The weight of the culms on average was reduced by 5 percent. This corresponds to a 12 percent reduction in moisture within 2.50 hours. Using the forced convection method in the transferring the heat necessary for the drying process, no visible drying defects were observed on the bamboo culms tested. The forced convection was applied by the installation of a fan that transports air from the surrounding to the oven and by making use of holes that disperses the air flow in multiple directions, ensuring that the heat is spread evenly inside the drying chamber. The results of the tests show that the machine was able to dry the bamboo significantly faster than the sun-drying. The machine having an average rate of 40.65 grams per hour as weight reduction is 4 times faster than the traditional sun drying. The efficiency of the oven was also determined to be 67.56 percent, with an expected total moisture loss of 361 grams and an actual total moisture loss of 243.9 grams. In terms of energy consumption, the oven consumes 3 kWh for every 2.50 hours of drying.

Acknowledgement

The authors would like to thank Malayan Colleges Laguna, A Mapua School for funding the presentation and publication of this research. Likewise, to the Mapua Institute of Technology at Laguna for all the support. Also their family and friends on unparalleled support and motivation.

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