Development and Performance Evaluation of an Indirect Heat Copra Dryer with Phase Changer

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Abstract

In the Philippines, farming communities produce copra using traditional open sun drying method that could be severely affected by heavy rainfall, temperature change, and intermittent sunshine, which could cause high microbial infection to the product. On the other hand, kiln drying may avoid these circumstances. However, smoke deposits in the finished product still cause farmers to have low-quality grade copra. Keeping this in view, an indirect heat copra dryer with phase changer (IHCDPC) was designed, fabricated, and evaluated in the hopes of providing farmers an alternative approach in drying copra, which may yield to producing a high-quality grade product. The developed IHCDPC was able to reduce the moisture content in fresh coconut meat from 57.4% w.b. to about 7.2% w.b. for a drying time of twenty-five hours. The IHCDPC was found out to have a thermal efficiency of 30.87%. The copra produced were graded as 84% MGC1, 13% MGC2, and 3% MGC3.

Keywords: thermal efficiency, solar radiation, moisture content, fired dryer, copra grading

1.0 Introduction

Coconut are among the most widely cultivated crops in the world (Madhiyanon et al., 2009) and significantly contributes to the economy of many countries including the Philippines. One of the major traditional products derived from coconut process is copra (Mohanraj & Chandrasekar, 2008). The Philippines ranks as the second largest coconut-producing country in the world next to Indonesia, with 153,532,000 tons of coconut produced in 2017. One of the major products that is processed from coconut is copra (Thiruchelvam et al., 2007). Both the studies of Swain et al. (2014), and Guarte et al. (1996), reported that to produce good quality copra it is necessary to reduce the moisture content of fresh coconut meat from about 55-57% wet basis (w.b.) to 6-7% w.b. in order to prevent microbiological deterioration, reduce the weight and concentrate the oil content. Copra is produced after drying the coconut meat which is commonly done by either sun drying or direct heat drying using kiln (Thanaraj et al., 2004). One of the reason why the mentioned methods are still the most common method in drying copra is the fact that rural farmers prefer easy-to-use and practical drying system (Chua & Chou, 2003).

However, with kiln drying, both heat and smoke are in direct contact with the coconut meat, resulting in low-quality copra with possible smoke deposits that may form polycyclic aromat`ic hydrocarbons (Thiruchelvam et al., 2007). On the other hand, as reported by Ayyappan and Mayilsamy (2010), in open sun drying, the rate of drying is dependent on parameters such as solar radiation, ambient temperature, initial moisture content, and mass of product per unit of the exposed area. Many disadvantages are present in open sun dryings like degradation by wind-blown debris, animal and human interferences, rain, and infestation by insects which may result in the contamination of the finished product (Fudholi et al., 2009). Jain and Tiwari (2003), in their study regarding the thermal aspects of open sun drying of various crops, mentioned that in open sun drying the product quality and speed of drying is reduced due to intermittent sunshine, over or under drying, and becoming wet due to rain.

It is for the above reasons that studies of the alternative drying process of copra in the form of indirect heat dryers were conducted (e.g. Kadam & Samuel, 2006; Shanmugam & Natarajan, 2006; Ivanova & Andonov, 2001). Moreover, considerable efforts have also been made in the development of solar dryers with/without phase change for drying agricultural products as evident by the works of Leon et al. (2002), Singh et al. (2004), Ayyapan and Mayilsamy (2010), Tyagi et al. (2012), and Singh and Kumar (2012). Several patented technologies were also used as reference for the design of the developed device. One of these patented technologies is a comprehensive ellipsoidal disk-type coconut processing device capable of drying and making coconut oil (China Patent No. CN107616521A, 2017), another technology where the idea for the design of the drying chamber was based on a rolling-drum-type, corncob-grain-drying machine, where the drying chamber was connected to furnace or fuel chamber and an exhaust or chimney (China Patent No. CN201145469Y, 2008).

The main objective of the present work was to develop an indirect heat copra dyer with phase changer (IHCDPC) and to evaluate its performance compared to both sun-drying and kiln-drying methods for copra production. The final product was evaluated using the standard set by the Philippine National Standard as show in Table 1.

Table 1. *Classification Based on Characteristics Quality of Copra (Philippine National Standard)*

Parameters	Grade 1	Grade 2	Grade 3
Moisture content (%)	**[67.9]**	**[810.9]**	**[1113.9]**
Oil (%, min.)	62	60	58
Free fatty acid (as oleic, % max.)	0.5	4.0	5.0
Color of meat	clean, white to pale yellow	brown to dark brown	brown to dark brown
Extraneous matter (% max.)	0.25	0.75	1.0
Aflatoxin level (ppb, max.)	5	20	20
ARM (% max.)	0	10	20
Inferior copra (%, max)	0	10	20
Other specifications	free from smoke and other contaminants		

2.0 Materials and Methods

Using developmental-experimental approach, a prototype design for an indirect heat copra dryer with phase changer (IHCDPC) was made and evaluated with regards to efficiency and effectiveness.

Design and Fabrication

Presented in Figure 1 is the sketch for the prototype's design of the IHCDPC, while shown in Figures 2a and 2b are actual photos of the prototype. The IHCDPC is composed of a parallelepiped-base made of steel plate for higher thermal conductivity and higher strength which was designed to provide enough space for constant air flow, a fuel chamber where coconut shells would be loaded and burnt to produce heat, a triangular basin-shaped drying chamber where the coconut kernels would be loaded through a door located on the topmost part of the chamber, and a chimney that functions as the outlet of excess air thereby providing constant airflow to the drying chamber. Inside said drying chamber is a phase changer that would serve as a stirrer in order to provide equal dryness of the kernels. Said phase changer is made of a shaft that is capable of handling the weight of coconut kernels during the operation. The phase changer could be driven either manually or mechanically by connecting it to a drive motor by a belt and pulley. Lastly, a chute was provided as the outlet for the dried coconut kernel's coming from the drying chamber.

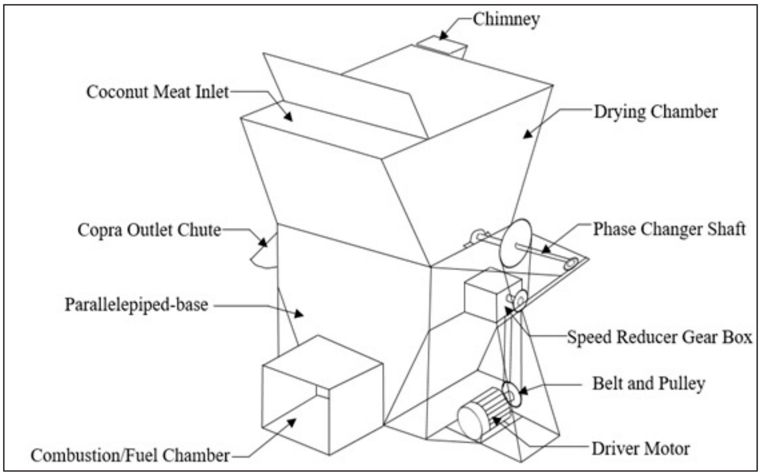
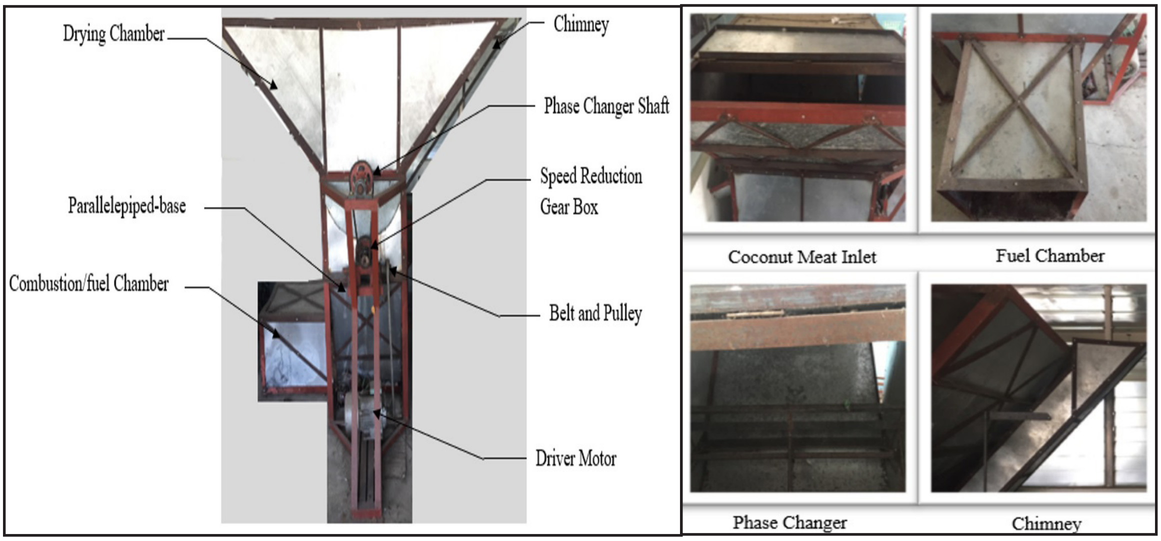


Figure 1. *Schematic Diagram of the Developed Indirect Heat Copra Dryer with Phase Changer (IHCDPC)*



(a) *(b)*

Figure 2. *Actual Photos of the Developed Indirect Heat Copra Dryer with Phase Changer (IHCDPC)*

Testing and Evaluation

The developed prototype was evaluated regarding both its thermal efficiency and effectiveness. The thermal efficiency was evaluated and was compared to the thermal efficiency of kiln drying (using the traditional kiln with coconut shells as fuel for combustion). Both the set-ups were conducted with the same measured parameter, which was the thermal efficiency, and controlled parameters, which were the weight of the coconut kernels to be dried and the amount of fuel used. Thermal efficiency was evaluated using the equation

$$\eta th = Q_A/Q_f \times 100\% \quad (1)$$

where Q_A is the heat available around the coconut meat and, Q_f is the heat supplied by the combustion of fuel. Also, Q_A and Q_f are further calculated using the formulas

$$Q_A = \frac{kA}{x} d \quad (2)$$

$$Q_f = M_f Q_h \quad (3)$$

where k is the thermal conductivity, A is the area occupied, x is the thickness, M_f is mass of fuel used, and Q_h is the heat value.

Another test was conducted to evaluate the effectiveness of the developed prototype by measuring the moisture content of the finished product after the process. The moisture content value of the copra dried using the developed prototype was compared to that of both open sun drying and kiln drying. The measure-content value was calculated in percent w.b. using Equation 4, according to Mohanraj and Chandrasekar (2008)

$$M_{wb} = \frac{(Wi - Wf)}{Wi} \times 100 \quad (4)$$

where M_{wb} is the moisture content in w.b., Wi is the initial mass of the sample, and Wf is the final mass of the sample.

The same weight of coconut kernel was used and converted to copra during the said evaluation. On average, five nuts are required to produced one kilogram of copra however, this varies from country to country by ± 40% (Swain et al., 2014). In this study, a uniform weight of coconut meat already removed from their shell was used for each of the drying methods during the evaluation. The coconut meat was weighed to ensure that each of the drying process evaluated uses the same amount and in this study, 50 kg was utilized.

Experimental Set-up

Kiln Drying

A kiln consists of a bamboo platform raised to a 70-80 cm gap from the ground. The coconut meat that was already removed from their shells were spread on the platform. Coconut shells used as fuel were spread on the ground beneath the bamboo platform and were burned to produce heat where the smoke and burnt gases directly contact the coconut meat on the bamboo platform. Shown in Figure 3 is a schematic diagram of the kiln.

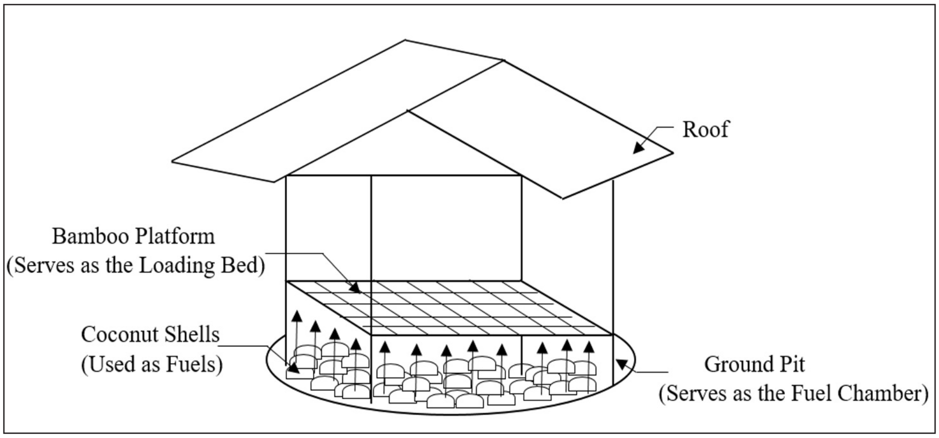


Figure 3. *Schematic Diagram of a Traditional Kiln Dryer*

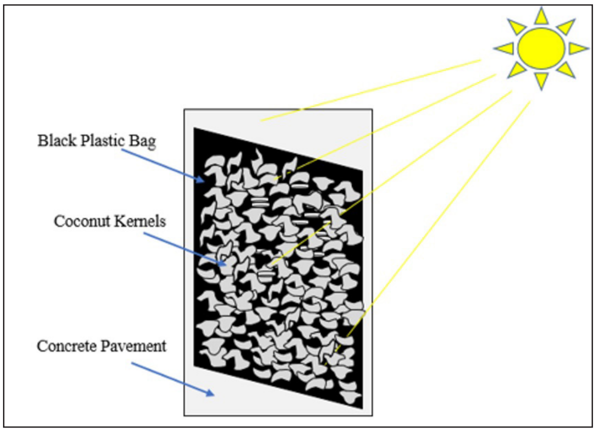


Figure 4. *Schematic Diagram of Sun Drying*

Sun Drying

Fifty kilograms of coconut meat was also used in this drying process. Black plastic sheets were laid on the concretes of an outdoor basketball court, where the coconut meat was spread on the said plastic sheets. Using black plastic sheets would ensure that the area where the coconut meat was spread would absorb the ideal solar radiation needed. During the evaluation, drying time was limited to nine hours, starting from 8:00 AM to 5:00 PM only, which covered most of the solar radiation intensity. After 5:00 PM, the coconut meat was scooped and secured inside sacks and were dried again the next day. The setup is presented in Figure 4.

Drying Using IHCDPC

Figure 5 shows how the coconut was processed using IHCDPC. Coconut meat were grated from their shells manually. Fifty kilograms of freshly grated coconut meat (also known as coconut kernels) that still had high moisture content were loaded to the IHCDPC's drying chamber. Coconut shells that were used as fuel were also loaded to the fuel chamber. Heat from the fuel chamber enveloped the drying chamber thus providing an indirect heating to the kernels. Inside the drying chamber, the coconut kernels were constantly stirred by the phase changer. During the process, the phase changer was activated every hour for the first ten hours and every thirty minutes for the remaining length of the drying time. When the phase changer is activated, it would stir the coconut meat for five minutes before it was turned off. No other setup for IHCDPC was conducted during the testing evaluation. The operator constantly checked the kernels' moisture content until the ideal value for a good quality copra was reached. The dried kernels were unloaded from the drying chamber by opening the chute's cover thus allowing the kernels to pour out.

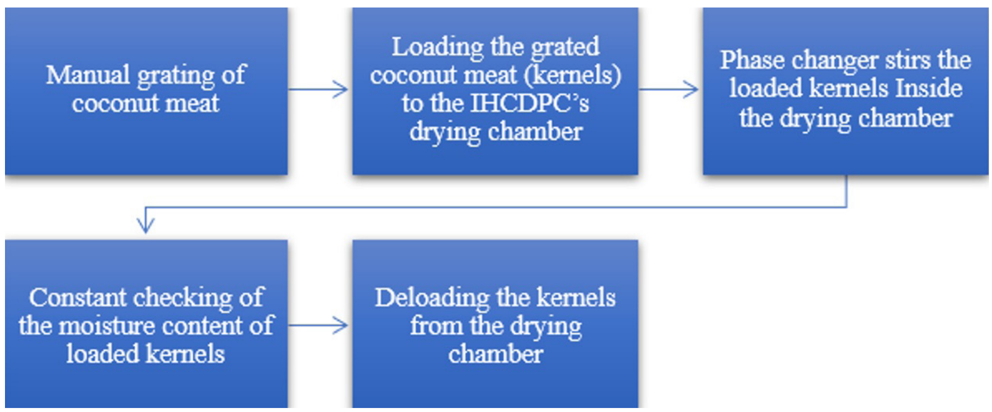


Figure 5. *Flowchart on How the Coconut was Processed Using IHCDPC*

3.0 Results and Discussion

Shown in Figure 6 is the variation of the moisture content with respect to the drying time.

Using the developed IHCDPC, the initial moisture content of the coconut was reduced from 57.4% w.b. to 7.2% w.b. after about twenty-five hours of drying, wherein traditional kiln drying took nineteen hours to reduce the moisture content to 6.8% w.b., while sun drying took forty-two hours to reduce the moisture content to 9.8% w.b. These data imply that the developed IHCDPC has an advantage both in drying time and moisture-content level compared to sun drying. However, it has a disadvantage in both parameters when compared to kiln drying.

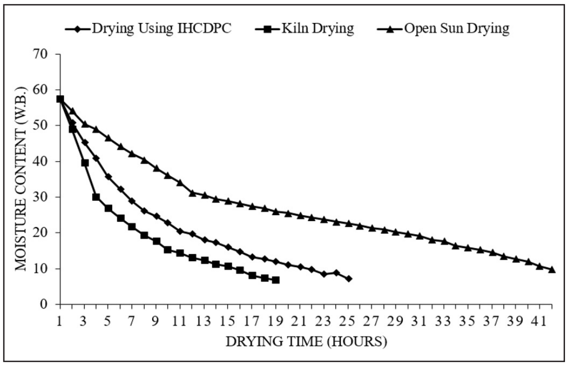


Figure 6. *Moisture Content Variation with Respect to Drying Time*

The average temperature recorded in the drying chamber of the developed IHCDPC varies from 48¬–53°C. Using Equation 1, the thermal efficiency of IHCDPC was found out to be 30.87% compared to a thermal efficiency of 45.75% for kiln drying, giving a 14.88% difference that would explain the difference in their drying time. This simply implies that when it comes to thermal efficiency, kiln drying is still superior to IHCDPC. Since the experimental setups used the same amount of fuel in both kiln drying and IHCDPC drying, the heat supplied by the combustion of fuel (Q_f) was equal. Thus, the only variable that affects the thermal efficiency was the amount of heat measured around the coconut kernels (Q_A). Given the nature of the design of the IHCDPC which utilized the heat through an indirect contact, it was found out that the heat measured around the coconut kernels (Q_A) when using IHCDPC was lesser compared to the heat measured around the coconut kernels (Q_A) when dried using the kiln-drying process.

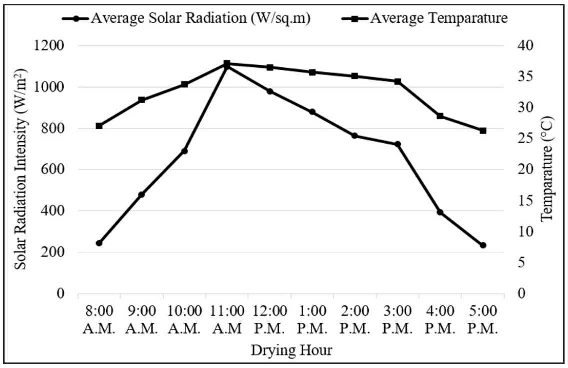


Figure 7. *Solar Radiation Intensity and Average Ambient Temperature Variation with Respect to Drying Time*

In the case of sun drying, the variation of the average ambient temperature and solar radiation during the evaluation process is shown in Figure 7. Data for the solar radiation intensity and drying air temperature were gathered and plotted in a graph showing what particular hours of the day gives off higher air temperature and solar intensity and is therefore ideal for sun drying. During the experimental set-up, a maximum solar radiation intensity of 1098 w/m^2 was observed while the average drying air temperature recorded was 37.1°C during peak sunshine.

Shown in Figure 8 is the different copra-grade level of the product produced by the three methods for copra drying. As can be seen, copra produced by kiln drying has a darker color, with several of the finished products being burnt due to direct heat and smoke contact during the process, as evidenced by the smoke deposits in several of the cups. On the other hand, sun drying produced a pale-yellow-colored copra with several cups having an insect infestation. Using IHCDPC, the copra produced was clean and white in color. However, due to stirring, it is more chopped than the previous two.

Figure 8. *Comparison of the Quality of Finished Copra Product from the Actual Experiment*

Table 2. *Summary of Experiment Outputs*

Drying Method	Drying Time (Hours)	Color of Coconut Meat	Classification of Meat based on (PNS/BAFPS 43:2009)		
			Grade 1	Grade 2	Grade 3
Kiln Drying	19	Majority are brown to dark brown	42%	52%	6 %
Sun Drying	42	Majority are brown to dark brown	71%	22%	7%
Drying Using IHCDPC	25	Majority are clean, white to pale yellow	84%	13%	3%

Table 2 revealed that out of the three drying process involved, using IHCDPC yielded the most copra graded as Milling Copra Grade 1 (MCG1) at 84%, and the remaining graded at 13% MGC2 and 3% MGC3 respectively. The copra was graded based on the parameters and procedures set by the Philippine National Standard (PNS/BAFPS 43:2009) shown in Table 1. Copra produced from kiln drying resulted in the lowest MGC1 grade (42%) among the three drying processes mostly due to smoke formation found in the finished product that was tested. Though no smoke formation was found on the tested samples of the copra produced using open sun drying, due to several contaminants, the copra was graded at 71% MGC1 classification.

4.0 Conclusion and Recommendations

An indirect heat copra dryer with phase changer (IHCDPC) was designed, fabricated, and tested with the objective to produce a higher grade quality of copra than the ones produced through sun drying and kiln drying. Results revealed that by utilizing the principle of indirect heat drying, the developed prototype successfully produced more high-quality grade copra products than both sun drying and kiln drying. However, IHCDPC can still be improved to cope up with kiln drying with respect to the drying time.

Thus, it is recommended to use materials that have far more superior heat-absorption properties to enhance the thermal efficiency of the machine. Also, using microcontrollers can provide the machine automation when it comes to stirring and motor switching.

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