Tropical Agriculture Research Vol 16 : 305 - 315 (2004)

Development of a Rotary Solar Hybrid Dryer for Small Scale Copra Processing

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ABSTRACT. *The main objective of this study was to design and develop a solar hybrid copra drying technique suitable for small holders. Three components; solar collector, furnace and heat exchanger were evaluated separately. It was found that the efficiency of the drum type solar collector was only 4%. The drum shape drying chamber of coconut cups was designed as the solar collector as well. The drying chamber was designed to rotate manually around the axis of the heat exchanger. The maximum-recorded temperature in the drying chamber due to solar insolation was 50 °C during the test period. The furnace was fired with paddy husk at different feeding rates. The average drying chamber temperatures recorded at the husk feeding rates of 3 kg/h, 5 kg/h and 10 kg/h were 43 °C, 53 °C and 62 °C and the furnace efficiencies were 43%, 48% and 70%, respectively. The furnace efficiency increased with increasing husk feeding rate. The performance of the rotary drum solar hybrid drier was evaluated and compared against sun drying and Coconut Research Institute (CRI) Improved copra kiln drying. White copra was dried to a moisture content of 7% using the hybrid drier. The copra was graded as 73% white copra, 21% MO G11 (brown) and the balance 6% into MO G111 (dusty copra). About 70 h of continuous drying was needed to complete the drying process at the overall thermal efficiency of 10%. Although the thermal efficiency is not that satisfactory, the dryer was found to be economical in comparison to other methods due to the quality of the final product and the ability to perform under adverse environmental conditions.*

INTRODUCTION

Copra is one of the major traditional products processed from coconuts. Traditionally drying is performed either using a direct fired kiln or under direct sun to reduce moisture content of the coconut meat from about 50% to 6% (wet basis) in order to reduce the weight, prevent microbiological deterioration and concentrate oil (Patterson *et al.*, 1981). Grimwood (1975) has reported various techniques utilized in copra drying. He evaluated the performance in terms of uniformity of drying, labour requirements and quality of product. However, copra being a low value product sophisticated dryers are not appropriate under local conditions. Therefore, a new drying technique is importance for the small-scale rural farmers.

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The hybrid system of drying was known to increase the system efficiency. The combination of solar energy with the furnace carries the advantage of continuous drying even during nights or in cloudy rainy days. Even though an extra cost is involved with a furnace, it is expected to provide benefits of reducing the drying time, labour cost and improving the final quality. The objective of this study was to designed votary hybrid dryer for the farmer as an alternative to traditional drying. This dryer was designed to provide the farmer an alternative to traditional drying.

METERIAL & METHODS

Design of the solar hybrid dryer

The solar hybrid dryer was designed considering certain key factors such as environment, maintenance, reliability, product hygiene and costs. Therefore, design mainly focused on producing hygienic, high quality white copra at a relatively low manufacturing cost.

Design of the drying chamber

The drying chamber was designed to have a cylindrical shape and was divided into two equal longitudinal halves by inserting a horizontal platform across the diagonal (Fig.1) to eliminate the coir dust contamination on kernel during drum rotation, which leads to discolouration of copra.

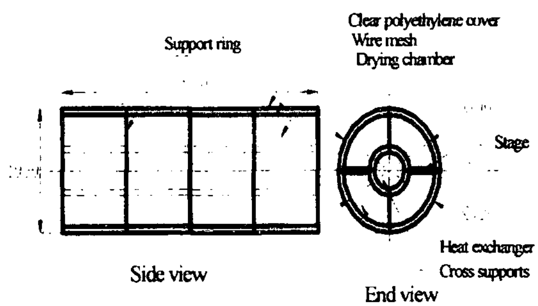


Fig. 1. Solar drier, drying chamber and heat exchanger (all dimensions in mm).

It was designed to dry 175 kg of fresh coconut (350 nuts/batch) per batch in one compartment, assuming the loose bulk random packing arrangement of cups in the drying compartment of the chamber at 500 kg/m^3 bulk density of fresh coconut cups.

Design of the solar collector

The drying chamber was modified as the solar collector and it was cylindrical in shape to facilitate rotation and mixing for uniform drying (Fig. 1). A 22 gauge clear polyethylene was used as the transparent cover for the solar collector. The horizontal projected area of the solar collector was 2.5 m^2, which was the effective area on which solar insolation falls on at a given time.

Slope of the collector

According to Brewer *et al.* (1979), the optimum tilt angle for a fixed installation should equal the latitude if energy needs are constant throughout the year. Therefore, to satisfy all the requirements, it was kept at 10° to the horizontal facing South in order to maximize the efficiency of the heat exchanger and facilitate the loading and unloading operations (Fig. 2).

Fabrication of the heat exchanger

A cylindrical shape heat exchanger was designed and fabricated using a 20 gauge metal sheet. Baffles were made inside the heat exchanger to increase the internal contact area of hot air to maximize heat transfer.

Design of the step grate furnace

Cast iron fire bars were fixed as steps to withstand high temperatures with a 3.5 cm gap. High Alumina Concrete (HAC 52) was used to construct the fire tube. HAC 52 concrete has the ability to withstand high temperature while acting as an effective insulator. Furnace walls were constructed using normal bricks, clay and cement. Fire bars were fixed to the sidewalls at an angle of 45° to the horizontal.

Design of the chimney

A 1.5 m cylindrical shape chimney was fabricated using a 20 gauge metal sheet. According to Brenndorfer *et al.*, (1987), the height of the chimney was 1 m in the natural convection dryers at the average wind velocity of 0.7 m/s. Since the average wind velocity was 0.5 m/s at the experimental site, height of the chimney was 1.5 m to develop a sufficient natural draught (Fig. 2).

Instrumentation

The operational parameters i.e. temperature, relative humidity, wind velocity and solar insolation were recorded and monitored continuously at 10 s intervals, and averaged at every five minutes. Data recording was done by using temperature and RH sensors coupled to a CR 10 data logger.

Determination of moisture content

Copra pieces were taken from randomly selected seven cups, they were chopped into small pieces and mixed well. Three representative samples of 10 g were drawn and kept in a Precision Laboratory Mechanical Convection Oven (Model 26) at 105 °C until it reaches a constant weight.

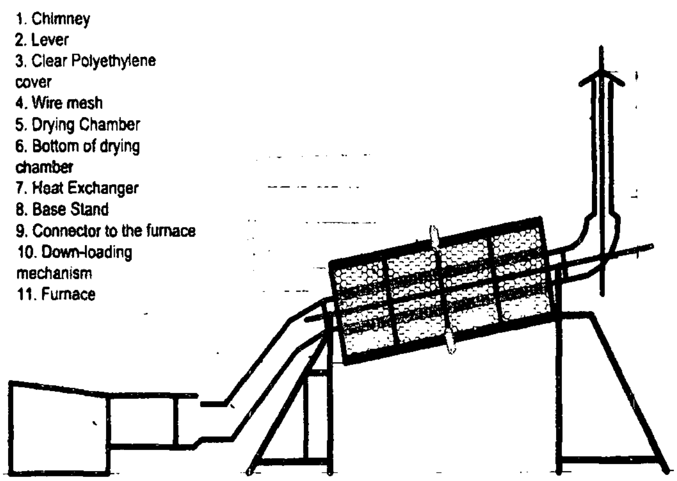


Fig. 2. Complete system of the solar hybrid

Grading of copra

Based on the standards, grading is the sorting out of copra as white copra, coloured copra, burnt copra, mouldy copra, *etc.* At the end of each drying, copra was graded according to Sri Lanka Standards, SLS 612:1983. Different grades were given as percentages of weight.

Testing and evaluation of the solar hybrid dryer

The main components of the solar hybrid dryer; solar collector (drying chamber), heat exchanger and the furnace were evaluated for their performances.

Efficiencies of components were estimated using the following equations.

$$\text{Efficiency of the solar collector (\%)} = \frac{V \times \rho \times \Delta T \times Cp}{Ac \times Ic} \times 100 \qquad \text{----(1)}$$

where, V = Volumetric air flow rate, ρ = Density of drying air, ΔT = Temperature rise in the solar collector (°K), Cp = Specific heat of air, Ac = Projected area, and Ic = Solar insolation.

$$\text{Efficiency of the furnace (Et)} = \frac{Esp}{Es} \times 100\% \qquad \text{----(2)}$$

where, Esp = Actual energy resulted from furnace or energy prepared for drying.

Es = Theoretical energy resulted from burning of paddy husk.

$$\text{Overall efficiency of the heat exchanger system } (\eta) = \frac{Q_a}{Q_e} \times 100 \qquad \text{----(3)}$$

where, Q_a = Energy absorbed by the cold fluid, Q_e = Energy emitted from the hot fluid, η = Overall efficiency for the system (%).

$$\text{Thermal Efficiency } (\eta_t) = \frac{\varphi \lambda (M_o - M_f)}{WC(100 - M_o)} \times 100 \qquad \text{----(4)}$$

Where, Mo = Initial moisture content of coconut (%, wet basis), M_f = Final moisture content of coconut (%, wet basis), φ = Quantity of the final dried product at M_f moisture content (kg), λ = Latent heat of vaporization of water in k.cal/kg, W = Quantity of fuel used (kg), and C = Calorific value of fuel used (k.cal/kg) (Sing *et al.*, 1999)

The system performance and the quality of the final product were evaluated to determine the potential use of the dryer under local conditions. The quality and cost comparisons were made with Sun drying and with kiln drying that are the most common traditional techniques used in Sri Lanka.

RESULTS AND DISCUSSION

Testing and evaluation of the solar hybrid dryer

Solar collector was evaluated at the average solar insolation of about 708 W/m^2. The recorded average temperature in the collector was 50 °C. The collector efficiency (Equation 1) varied between 3 to 5% with an average of about 4%. This is about 10% of the efficiency of a flat plate collector. However, this was expected since the structural design did not permit to include an inbuilt efficient collector.

Since there was a need to increase the temperature up to 60 °C and maintain it throughout the drying period, supplement furnace heat was provided by burning paddy husk at a feeding rate of 3 kg/h during the daytime. According to Paul (1989) different experiments showed that good quality copra could be obtained by drying nuts at an average air temperature of 60 °C, above which the quality of copra may decline. The dried copra is expected to maintain moisture content not exceeding 6% for maximum shelf life.

The furnace was evaluated (Equation 2) at the feeding rate of 3 kg/h, the average temperature recorded in the drying chamber was 43 °C and the furnace efficiency was 43%. Since the temperature was not enough to maintain the dying temperature of 60 °C, the furnace was evaluated at the feeding rate of 5 kg/h and the average temperature in the drying chamber was 53 °C and the furnace efficiency was 48%. It was observed that the increase of feeding rate from 3 kg to 5 kg increased the efficiency of the furnace by 5%. This may be due to the improvements of combustion and the development of a proper flame with increased temperature. However, the average temperature in the drying chamber was not at the optimum of 60 °C.

When the furnace was evaluated at the feeding rate of 10 kg/h, the average temperature was recorded at the outlet of the furnace and the drying chamber were around 207 °C and 62 °C, respectively. The average furnace efficiency was 70%. It was observed that the efficiency of the furnace increased by 27% when the feeding rate was increased from 3 kg/h to 10 kg/h (Fig. 3).

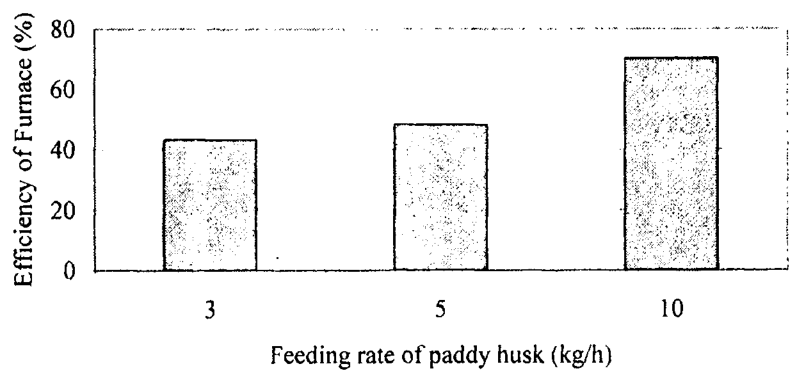


Fig. 3. Efficiency of furnace at different feeding rates of paddy husk.

Since the temperature at the dying chamber was recorded around 60 °C at 10 kg/h, it was decided to run the trials at this feeding rate whenever the solar energy is not available.

The heat exchanger was evaluated (Equation 3) at the feeding rate of 10 kg/h and the average heat transfer from the exchanger was found to be 5 kJ/s. The average overall efficiency of the heat exchanger system was about 32%. Thampan (1981) reported that the average efficiency of the tube heat exchangers used in indirect copra dryers were around 20 to 25%, but it may be higher in the heat exchangers used in water heating. However, the efficiency of this heat exchanger is higher than the values reported by Thampan (1981). The higher efficiency might be due to the baffle like internal structure of the heat exchanger.

Temperature in the dying chamber

The variation in ambient temperature definitely could cause some effects on the drying chamber temperature but it was compensated by the feeding rate of paddy husk to maintain the drying temperature around 60 °C (Fig. 4). High temperatures may cause case hardening and burnt patches while low temperatures may help mould growth due to extended drying time. Supratomo *et al.* (1990) reported that higher the temperature, shorter the drying time. At 60 °C, it takes 55 h to dry copra to a final moisture content of 6%. If the temperature is increased to 70 °C, the drying time reduced to 43 h. This phenomenon is due to the increase of the drying power drying air which has a high influence on the drying rate, especially at high moisture content levels.

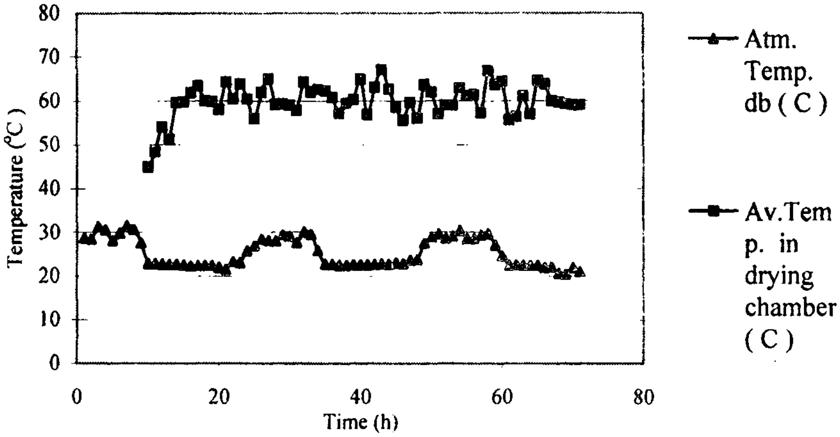


Fig. 4. Variation of drying chamber temperature with time.

Temperature was controlled by adjusting the manual feeding rate of paddy husk to the furnace and it was sufficient to maintain a uniform internal temperature. Anon (1981) reported that the temperature was controlled manually by adding or removing fuel to regulate the fire and to make copra with the safe moisture content of 6-8%, the drying process should take 24-30 h.

The relative humidity in the drying chamber

Average dry and wet bulb ambient temperatures were recorded as 25°C and 22°C throughout the drying period. The average ambient RH throughout the drying period was 84% (Fig. 5).

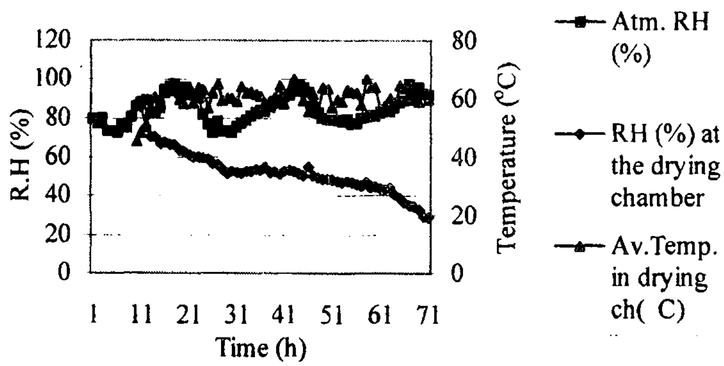


Fig. 5. Behavior of ambient and drying chamber relative humidity

In the drying chamber, high RH of around 90% was recorded for about 5 h at the initial stage of drying and then it reduced to about 30% at the end of drying. The air velocity was recorded as 0.6 m/s under natural convection. Eventhough, the lower RH favoured the dying rate, high moisture removal rate and the low air velocity may be the reasons for the RH around 90% at the initial stage of drying. Supratomo *et al.*,(1990) also reported that in a convectional drier, a mean RH of 35% corresponds to an air speed of 0.9 m/s. In this system, the additional air entering the drier was hotter than the ambient air used in a convectional system.

The solar insolation

Figure 6 illustrates the variation of daytime solar insolation during the drying period. The average solar insolation of 668 W/m^2 was recorded during the drying period. It was found that the solar insolation contributes a considerable amount of energy into the drying chamber reducing the feeding rate of paddy husk from 10 kg/h to 3 kg/h.

The drying characteristics of coconut

The average initial moisture content of coconut was 50% and it was reduced to 7% at the end of drying. Moisture removal rate from the coconut was high during the initial stage of drying because of high moisture migration rate from the surface layers and then the rate reduced with time (Fig. 6).

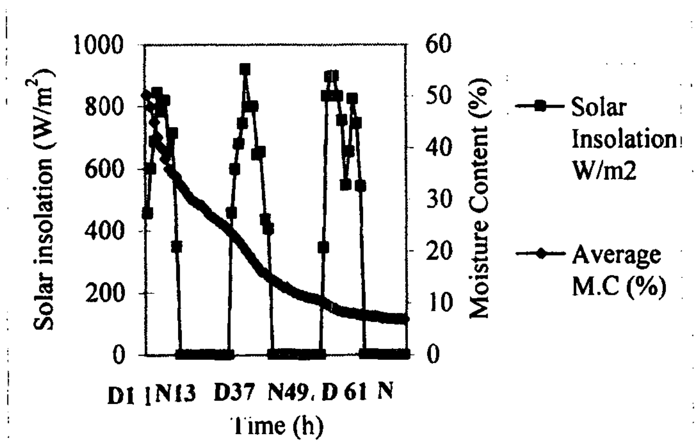


Fig. 6. The behaviour of solar insolation during the drying period (D–day time).

Drying efficiency

The overall thermal efficiency calculated using Equation (4) was 10%. The energy consumed to evaporate 1 kg of water was 25 MJ. Bischoff (1996) reported that the thermal efficiencies of modified *Kukum* copra dryers (indirect dryers) was 13% at a specific energy consumption of 10 to 19 MJ per kg of evaporated water. The thermal efficiency of the new dryer is relatively lower than similar systems. However, the dryer had the facility to rotate the drying bed manually to improve the drying uniformity. The efficiency could be further improved by increasing internal airflow rate of the drying chamber and reducing the heat loss especially from the furnace.

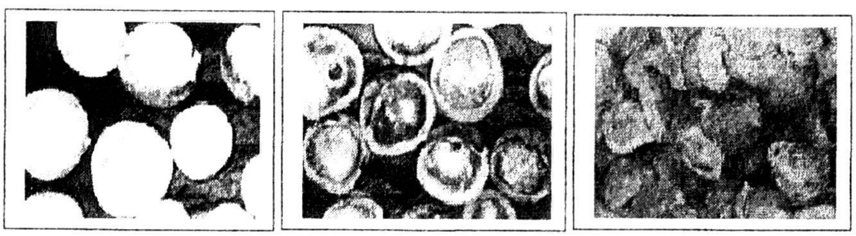
Copra grades

The dried copra consisted of 73% white copra, 21% brown coloured copra and the rest 6% dusty copra when graded based on SLS 612: 1983 (Table 1: Fig. 7). High percentage of white copra produced by the drier is one of the major achievements though the thermal efficiency is relatively low.

The percentage of high grade copra was more than what was reported in a survey conducted in Philippines, where about 60% of white edible copra was processed in the large-scale indirect copra dryers. They also reported high initial and operational costs. Problem of low thermal efficiency and high cost have been reported in other studies where improvement of copra quality has been obtained using indirect dryers (Escalante *et al.*, 1977).

Table 1. Different grades of copra produced using the solar hybrid dryer.

Grade of copra	Trial-1 (%)	Trail-2 (%)	Trial-3 (%)	Average (%)
1. White copra	65	71	82	73
2. M O Gr-II (Brown copra)	26	23	14	21
3. M O Gr-III (Dusty cups)	9	6	4	6



(a) White copra (b) Brown copra (c) Dusty copra

Fig. 7. Different grades of copra processed in solar hybrid drying.

CONCLUSIONS

The solar hybrid drying technique is found to be a good option for processing of high quality white copra especially under Sri Lankan conditions. The following conclusions could be drawn from the series of evaluations conducted with the solar hybrid dryer.

The solar hybrid dryer operates at the average drying temperature of 60°C and produce a higher percentage of (73%) white copra with the best quality.The average efficiency of the drum type solar collector was poor compared to flat plate collectors and it is 4%. The average overall efficiency of the heat exchanger system was at a satisfactory level of 32%. The average efficiency of the furnace at higher feeding rates of husk was as high as 70% but the efficiency declined with the reduction of husk feeding rates. The thermal efficiency of the solar hybrid drying system is about 10%.

ACKNOWLEDGEMENTS

We express our sincere appreciation to Sarvodaya Economic Enterprise Development Services (Gte) Ltd., for granting funds for this study. The Postgraduate Institute of Agriculture, Peradeniya and the Coconut Research Institute, Lunuwila are also greatly acknowledged for providing test material, partial funding and other technical assistance for the study.

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