COPRA DRYING IN AN IMPROVED SOLAR HYBRID SYSTEM, CRI IMPROVED KILN AND IN THE SUN: A COMPARATIVE STUDY OF DRYING CHARACTERISTICS

T. Thanaraj[1], D. A. N. Dharmasena[2] and U. Samarajeewa[3]

[1] *Division of Agricultural Engineering, Eastern University, Chenkalady, Sri Lanka*
[2] *Dept. of Agricultural Engineering, University of Peradeniya, Peradeniya, Sri Lanka*
[3] *Dept. of Food Science and Technology, University of Peradeniya, Peradeniya, Sri Lanka*

ABSTRACT

Copra is an intermediate product in processing coconut oil. The objective of making copra is to reduce the moisture content of coconut kernel to a safe storage level and thereby prevent microbiological attack and spoilage. Various methods such as sun drying, solar drying, traditional smoke drying, indirect drying, etc. are used to make copra.

A solar hybrid drying system was designed, fabricated and tested, and its drying performance was evaluated. The average drying temperature of this system was 60 °C which falls within the acceptable range. At the end of drying, the RH in the drying chamber was around 30% while ambient RH was around 85%; and the initial kernel moisture content of 50% was reduced to 7%. The drying efficiency of the solar hybrid drying system was 9%.

A CRI improved Ceylon copra kiln was constructed, tested and evaluated according to the Coconut Research Institute (CRI) guidelines. The average drying temperature of this drying system was 75 °C. The RH at the drying bed was reduced to 37% from the ambient level. The average final moisture content of copra was 8%, and the drying efficiency of the system was 16%.

In sun drying, coconut cups, with the inner surface facing the sun, were spread in a single layer on a black polyethylene sheet. The average drying temperature of the inner surface of the cups was 33 °C. The ambient RH was around 78% during the drying period. The average solar insolation was 426 W/m^2 and the moisture content was reduced to around 10% at the end of the sixth day of sun drying. The drying efficiency was 20%; the highest among the systems tested.

INTRODUCTION

Copra is one of the major traditional products processed from coconuts. Traditionally copra is processed by drying the kernels in a kiln or in direct sunlight. Basically, copra manufacture is the reduction of moisture in the kernel from about 50% wet bulb (w.b.) to below 6% (w.b.), as quickly as possible, to reduce its weight, prevent microbiological deterioration and, concentrate the oil while retaining the composition, quality and quantity of oil. On average, five nuts are required to produce 1 kg of copra, but this conversion rate varies (plus or minus 40%) from country to country (Patterson and Pérez, 1981).

The oil is used as a raw material for industrial products and in food processing. Copra cake, the residue after expelling the oil, is a constituent of animal feed. Improperly dried copra results in poor quality oil (Dippon *et al*, 1991).

Grimwood (1975) reported on various techniques utilized in copra drying and their underlying principles. Since the uniformity of drying, labour requirements and quality of the product depends on the technique employed, it was found that there is a paramount need to develop new drying techniques. However, as copra is a low value product sophisticated dryers are not appropriate. Even the use of ventilators, to enable more constant air flow, is not viable due to economic reasons.

Since drying is an important aspect of processing quality copra, the drying characteristics of different techniques like solar hybrid drying, CRI kiln drying and sun drying were studied. It is envisaged the findings will enable the development of better drying techniques and/or improvement of existing drying practices to process quality copra.

METHODOLOGY

Solar hybrid dryer

In designing the solar hybrid dryer factors such as environment, maintenance, reliability, restrictions and costs were considered. The main focus was to produce hygienic, quality white copra, at a low cost of manufacture. In this system, solar energy was used in combination with heat generated from paddy husk so that the drying was continuous. The furnace was operated continuously throughout the drying period. During daytime, solar energy was supplemented with furnace energy, solar energy was collected using clear polyethylene solar collected to maintain a drying temperature of about 60 °C. Figure (1) shows the design of the complete hybrid drying system.

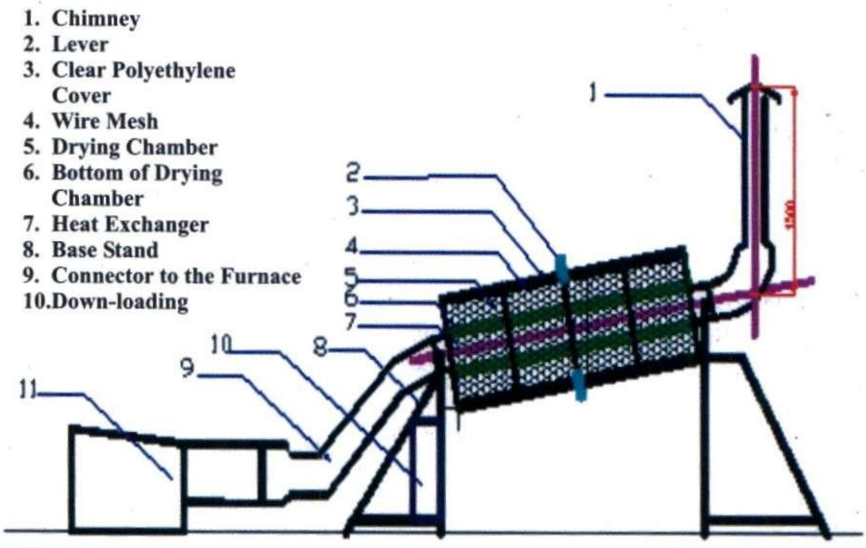

Figure 1: The solar hybrid drying system

The special feature of this design was that the drying chamber could be manually rotated about the heat exchanger, by means of four levers provided at its midpoint. This improved the uniformity of drying and also facilitated loading and unloading.

The performance of the main components of the solar hybrid dryer such as solar collector, drying chamber, heat exchanger and the furnace were evaluated. The nuts were split early in the morning at around 6.00 am and dried in the sun during the day time to remove as much as possible of the free moisture before drying in the chamber.

After sun drying, the cups were loaded into the drying chamber of the solar hybrid dryer. Once the coconut was loaded into the drying chamber, the furnace operation was started, and the kernels dried continuously. The fire was set at the lower end of the steps and paddy husk was fed into the hopper at the rate of 10 kg/h during the night. The temperature in the drying chamber was maintained around 60 °C throughout the drying period. The drying was complete in 24 h.

Samples were taken for determining the moisture content soon after splitting the nuts, and at 6 hourly intervals thereafter until the drying was completed. Solar insolation and the ambient dry and wet bulb temperatures were recorded by sensors connected to the CR10 data logger. Temperature sensors were also fixed in the drying chamber to record the drying temperature.

CRI improved Ceylon copra kiln

A CRI improved Ceylon copra kiln was constructed, according to the Coconut Research Institute (CRI) guidelines, but scaled down to 60% to process 700 nuts per batch (Figure 2). Copra was processed according to CRI recommendations.

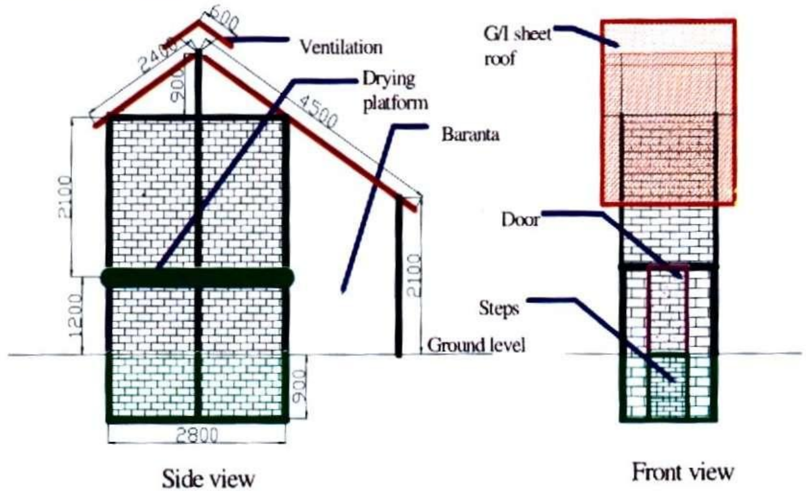

Figure 2: CRI improved Ceylon copra kiln

The average initial moisture content of coconut was determined by the oven method. Moisture content was also determined at the end of each fire and at the beginning of the next fire, and the drying curves were plotted.

Five temperature sensors were fixed along the diagonal length of the drying bed (Figure 3) and connected to the data logger. The first fire lasted six hours and was followed by a four hour rest period, without fire.

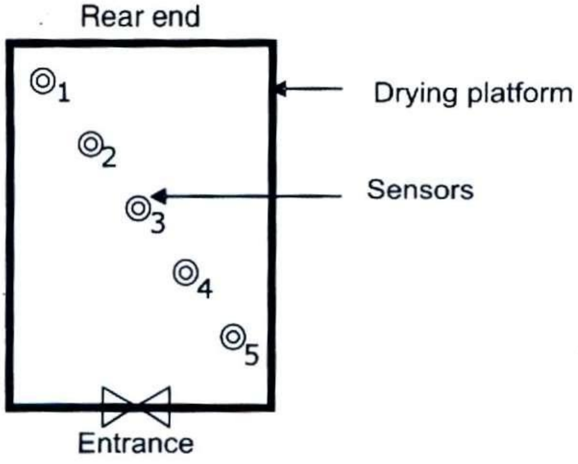

Figure 3: Arrangement of temperature sensors on the drying bed

At the end of the 5th fire, the moisture content of the copra was reduced to the required level.

Sun drying of coconut

Coconut cups, with the inner surface facing the sun, were spread in a single layer on a black polyethylene sheet. The average diameter of a cup was 10cm. Therefore, the space required to dry 700 nuts was about $14m^2$, and a polyethylene sheet 1m x 14m was used for the purpose. During the night and on cloudy and rainy days, the cups were covered completely with polyethylene sheets.

Temperature sensors were fixed on the surface of the drying cups to measure the surface temperature. Samples for moisture determination were taken from 7 cups at a time. The moisture content at the beginning, and in the morning and evening of each day of sun drying was determined.

At the end of the third consecutive day of sun drying, the shells were removed from the cups and coconut kernels were spread on the sheet for further drying. At the end of the sixth day, both visual observations and the moisture determinations indicated that the copra had dried sufficiently. Finally, the copra was graded according to the accepted standards.

The testing and evaluation of all three systems of copra drying were repeated three times.

RESULTS AND DISCUSSION

The main objective of this comparative study was to recommend a reliable drying technique to process good quality copra at a relatively low cost of production. To achieve this goal, the drying performance of the solar hybrid drying system, CRI kiln and sun drying was evaluated and compared to determine the potentially useful applications for small and medium scale operations.

Solar hybrid dryer

Temperature variation in the drying chamber

The variation of temperature in the drying chamber, heated with a combination of solar and furnace energy, is shown in Figure 4. The variations in ambient temperature were compensated by adjusting the feeding rate of paddy husk to maintain the drying temperature around 60 °C. Higher temperatures could cause case hardening and burnt patches while lower temperatures could lead to mould growth, extended drying time, etc.

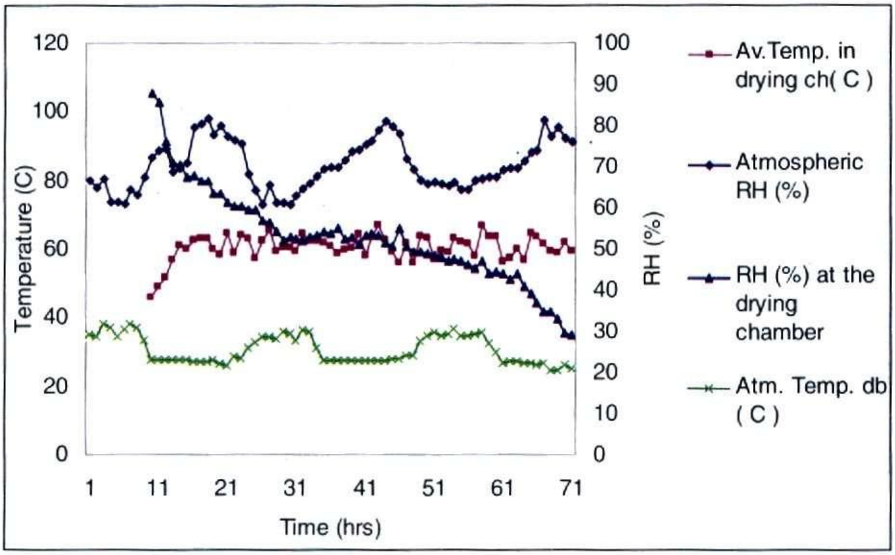

Figure 4: Temperature and relative humidity fluctuations in the atmosphere and drying chamber

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 by 10 °C to 70 °C, the drying time is reduced to 48 h. This phenomenon is due to the increase of the drying power, which has a great influence on the drying rate especially when the moisture content is high. Temperature of the solar hybrid dryer was controlled by manually adjusting the paddy husk feeding rate, and it was sufficient to provide a uniform temperature distribution.

Relative humidity in the drying chamber

Climatic factors such as ambient temperature, relative humidity (RH), solar insolation and wind velocity have a considerable effect on dryer temperature and drying rate. The 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 76% (Figure 4). In the drying chamber, a high RH of around 90% was recorded for about 5 h at the initial stage of drying, from 6.00 p.m to 11.00 p.m, which decreased gradually to about 30% at the end of drying. Supratomo *et al.*(1990) reported that warm dry air could cause considerable damage to copra by hardening its surface. To obtain copra of excellent quality, they suggest using air with a RH of around 35% for the first 12 h and then reducing it to 20% to finish off drying. In this system, the additional air entering the dryer was hotter than the ambient air used in a conventional system.

The solar insolation

Figure 5 illustrates the variation of solar insolation during the daytime. An average solar insolation of 668 W/m^2 was recorded during the drying period. In sun drying *per se*, about 1213 MJ of solar energy was utilized to bring down the moisture content, of a 700 nuts, to around 10%. About 1781 MJ of energy, from coconut shells, was utilized by the CRI kiln to reduce the moisture content of a batch of 700 nuts to 8%.

The drying characteristics of coconut

The initial moisture content of coconut of about 50% was reduced to 7% at the end of drying. The rate of moisture removal, which was high during the initial stage of drying, due to a high rate of moisture migration from the surface layers of coconut, decreased with time. Figure 5 shows the pattern of moisture removal during the trials with the solar hybrid dryer.

Drying efficiency

In each trial, about 147 kg of copra was processed from a batch of 700 nuts. About 115.5 kg of moisture was removed from a batch, and the drying efficiency was 9%. Energy consumed to evaporate 1 kg of water was about 25 MJ.

Bischoff (1996) reported that the thermal efficiency of the modified Kukum copra dryer (indirect dryer) was 12.7% at a specific energy consumption of 19 MJ per kg of evaporated water respectively. In comparison, the drying

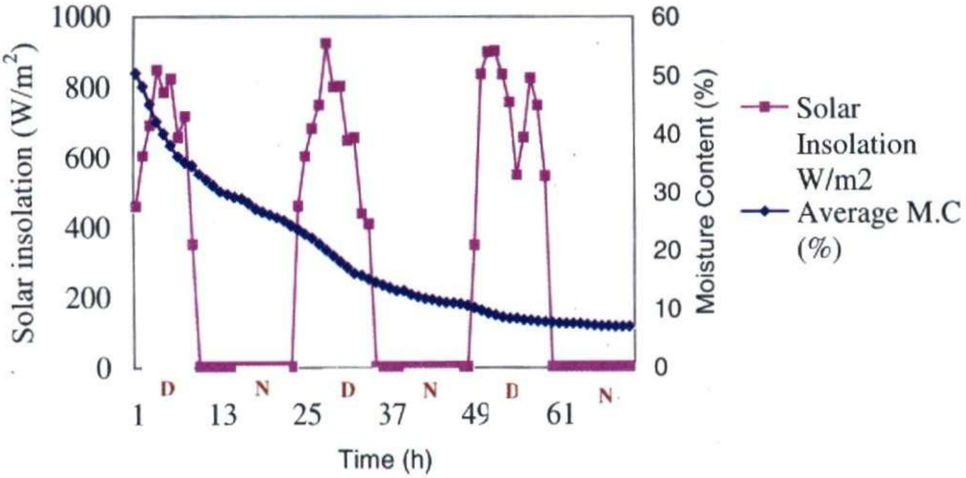

Figure 5: The behavior of solar insolation and moisture removal during the drying period

efficiency of the solar hybrid dryer is low. However, as the final quality of copra is an important consideration; the facility to rotate the drying bed of the solar hybrid dryer and thereby maintain a uniform temperature distribution in the drying chamber, is a positive feature that should not be disregarded in an evaluation.

CRI improved Ceylon copra kiln

Copra was processed according to the drying procedure recommended by the CRI. At the end of fifth fire the copra, which had dried to the required moisture content, was collected from the drying bed. The average moisture content was determined as 8%.

The temperature distribution at the drying bed

The fires are started off at the rear end of the fire pit, and the fire gradually advances towards the entrance. As would be expected, Sensor 1, placed at the rear corner of the drying bed, recorded the highest temperature at the beginning of each firing and progressively declined with time, up to next firing. In similar fashion, the highest temperature reading was observed in 2nd, 3rd, 4th and 5th sensors when the advancing fire point was directly under the sensor, and decreased progressively until the next firing (Table 1).

Table 1: The maximum and minimum average temperatures recorded in different locations of the drying bed

Sensor	Maximum Instantaneous temperature	Minimum Instantaneous temperature	Average temperature
1	115.0	32	60.84
2	105.0	33	64.16
3	117.0	35	74.34
4	104.5	37	75.26
5	105.5	36	74.81

The temperature rise along the diagonal length of the drying bed was due to the advancing flame in the fire pit (Figure 3). After reaching the maximum value the temperature decreased gradually until the next firing. This confirms the observation of Lozada (1991) that traditional smoke kilns do not have any provision to distribute the heat evenly; and some sections of these kilns are hotter resulting in copra with uneven moisture content.

The drying temperature exceeds 80 °C for approximately 50% of the total drying time (Figure 6). High temperatures accelerate the drying but at the expense of quality. Although the average temperature was below 100 °C instantaneous temperatures as high as 100 °C to 115 °C were recorded. The high temperatures affected the quality of copra and oil.

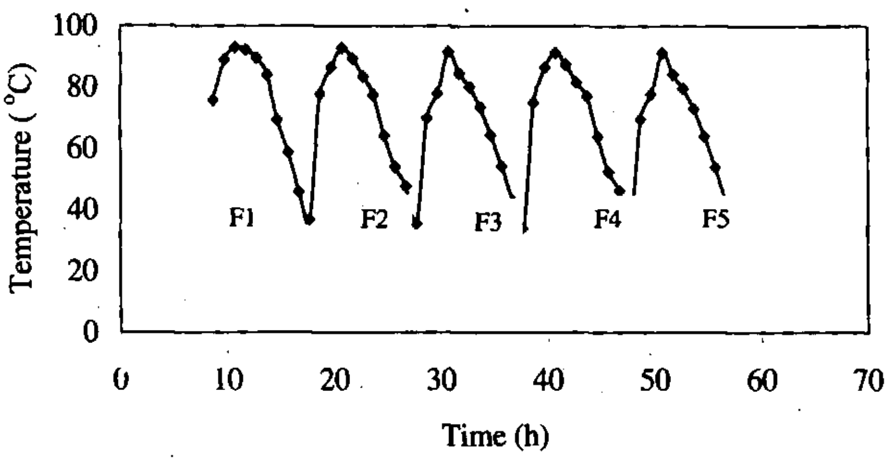

Figure 6: Average temperatures of the drying bed of the Ceylon copra kiln over the entire drying period, from fire 1 to fire 5 [F1 to F5]

The behaviour of relative humidity (RH)

The ambient dry and wet bulb temperatures were recorded continuously throughout the test period and the relative humidity was calculated. The external relative humidity significantly influenced the drying bed relative humidity. Figure 7 illustrates the change of RH at the drying bed with time. RH was high at the beginning of drying and then declined with time to around 37%. The decline of RH is due to the reduction in the rate of moisture removal from cups with time and is not influenced by the external RH.

The solar insolation and drying of copra during initial sun drying

On the first day, coconuts were dried in the sun for about 8 h before feeding to the kiln. The solar insolation and other climatic data were recorded using the data logger. The solar insolation had an average value of 744 W/m^2 since it was a bright sunny day. The relative humidity did not show any regular variation but was within the range of 73 to 77%. Ambient dry bulb temperature was within the range of 26 to 29 °C (Table 2).

During the first day of sun drying in the present study, around 9% of moisture was removed. This is dependent on the solar insolation on the day, and Nathaniel (1966) reported that about 6% of moisture was removed from fresh cups on the first day of sun drying. He further added that the initial sun drying stage achieves a loss of surface moisture from the exposed surface of the kernel from 43% to 38%.

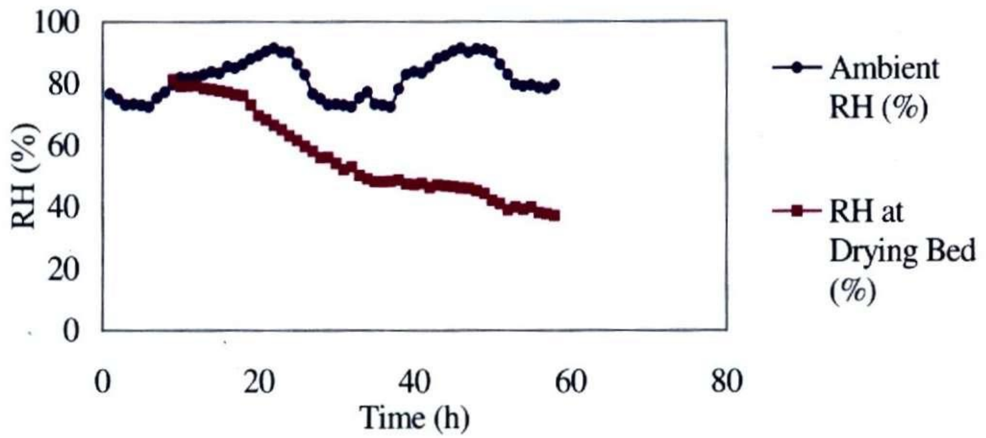

Figure 7: Ambient and drying bed relative humidity

Table 2: Climate data on first day of sun drying

Time	Av. Atmospheric Temperature °C (dry bulb)	Av. Atmospheric Temperature °C (wet bulb)	RH (%)	Solar insolation (W/m^2)
9.00 am	25.8	21.27	77.20	455.7
10.00 am	26.9	23.54	74.90	633.4
11.00 am	28.4	24.60	76.62	756.0
12.00 am	28.1	23.80	74.90	829.1
1.00 pm	28.0	25.00	73.00	738.2
2.00 pm	29.4	24.80	73.20	843.0
3.00 pm	29.0	24.60	75.20	896.1
4.00 pm	27.6	23.00	74.90	800.9

The removal of moisture during kiln drying

After 10 h of sun drying to start with, the cups were loaded in to the kiln for drying. The moisture loss was high during first and second firing and lower in subsequent firings. During the latter stages of drying, moisture gradually migrates from deeper layers to the surface and evaporates. The moisture content of the coconut kernel was reduced from 52% to 8%. Initially, the rate of moisture removal was relatively high. The total drying time was 62 h (Figure 8). Nathaniel (1996) also reported that hot air curing with intermittent cooling established a moisture gradient within the kernel, and moisture gradually migrates from deeper layers to the surface, resulting in uniform dehydration of the kernel.

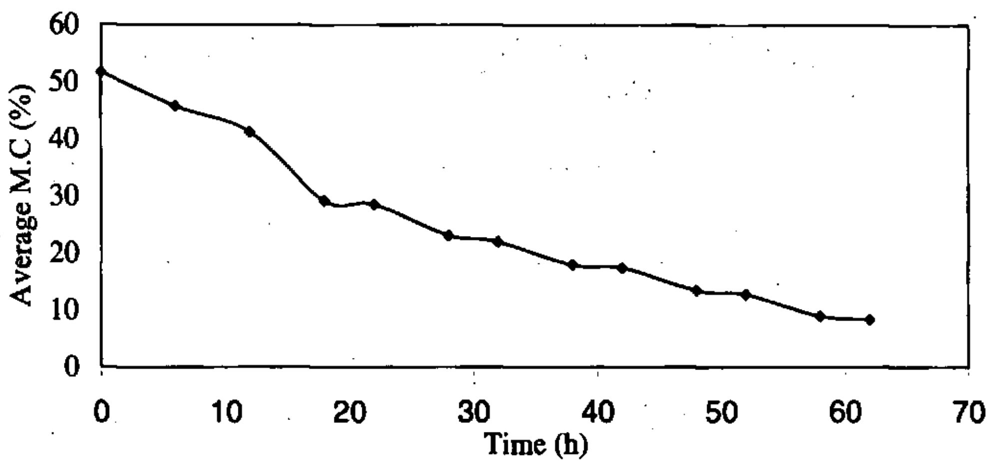

Figure 8:___Drying curve of coconuts in CRI- improved kiln

Thermal efficiency of kiln drying

Kiln drying uses coconut shells as a source of thermal energy. About 145 kg of copra was produced in one batch (700 nuts) in the experiment, consuming 90 kg of shells (910 shells) as fuel. The fuel requirement for drying copra is therefore about 65% of shells and the shell recovery is about 35%. According to the CRI reports about 67% of the shells are used in the drying process. The specific fuel consumption rate also was calculated as 0.62 kg of shells per kg of copra.

Thermal efficiency of drying was 16% which is relatively low. Reviewing the literature it was noted that the thermal efficiency of this copra kiln was half the value reported by Lozada (1991) and a little higher than the value obtained by Bischoff (1996). This points to the need to further improve the efficiency of the CRI kiln.

Sun drying of coconuts

Generally, milling copra is the end product of sun drying coconuts. Rarely, in areas highly suitable for effective sun drying, it is possible to produce edible white copra. Anon (1978) reported that in India, sun drying is very common in the dry season. Alternating sun drying during the day and kiln drying at night is practised in some areas.

As it was bright and sunny during the period of these trials, drying was completed in 6 days. At the end of the 6th day the copra had dried to the required moisture content. Lozada (1991) reported that the sun drying of copra usually takes 7 days. If the moisture content is not reduced to a level that would inhibit the growth of fungi the copra would be of poor quality.

The surface temperature of drying cups

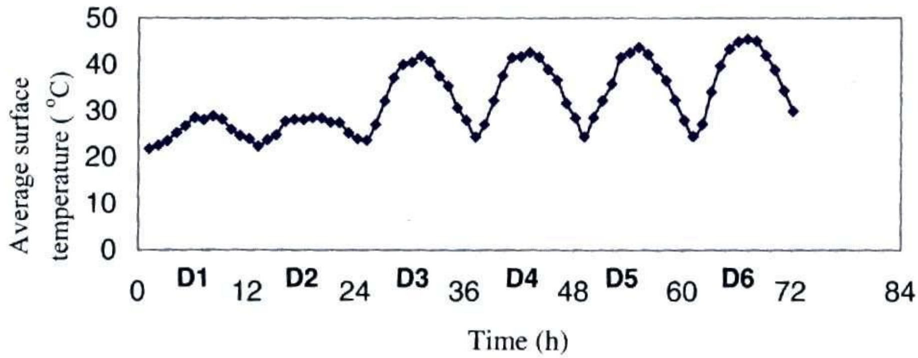

Figure 9: The variation of surface temperature of the drying cups over the six-day sun dying trial.[D1 to D6]

For the first two days, the maximum temperature was below 30 °C and increased thereafter. The presence of surface moisture and the higher moisture migration rate is the likely reason for the lower surface temperature during first two days. The surface temperature of the drying coconut cups varied between 46 °C and 22 °C with a mean value of 33 °C (Figure 9).

Anon (1978) reported that the maximum surface temperature recorded on copra being sun dried in the open air was 40 °C. This is well below the critical temperature of 70 °C, above which copra is inferior in quality. However, a discolouration of kernels possibly due to microbes was observed during the sun drying trials. This was not significant in immature coconuts; their drying rate was relatively low and moisture content high.

Climate parameters during the drying period

The average dry and wet bulb ambient temperatures recorded were 28 °C and 21 °C respectively, and the average relative humidity was 78%. The cup surface temperature was 46 °C; about 16 °C higher than the ambient temperature (Table 3), and marginally higher than the value reported by Thampan (1983).

Table 3: Climate parameters during the drying period (10 to 20 January 2003).

Climate parameter	Highest	Lowest	Average
Ambient Temp. (db) °C			
Ambient Temp. (wb) °C	29	26	28
RH (%)	22	20	21
Solar Insolation (W/m^2)	84	74	78
	834	15	426

The average solar insolation was recorded as 426 W/m^2 and was within the range of 15 W/m^2 to 834 W/m^2. Although the climatic conditions were conducive for sun drying this was not a period of clear sunny days (Figure 10).

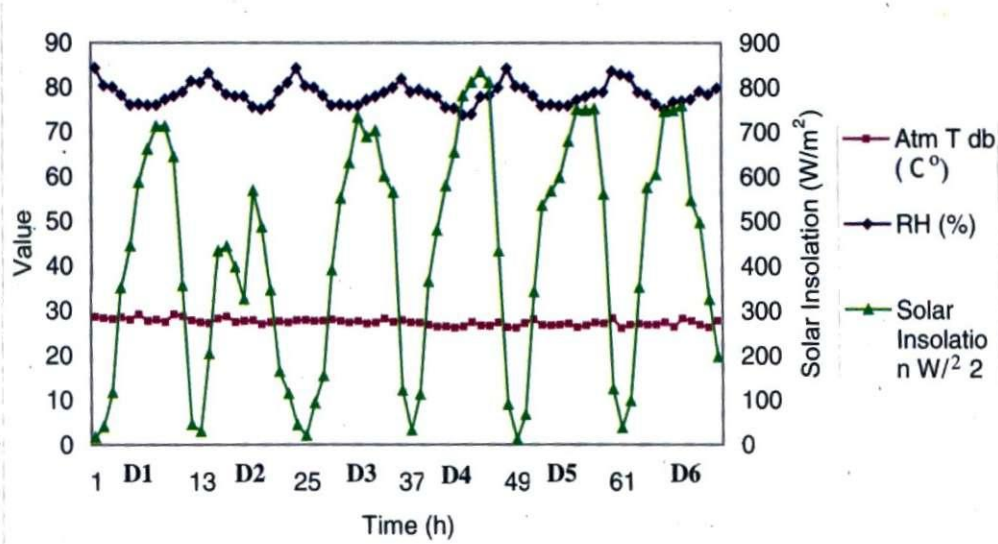

Figure 10: Variation of solar insolation, ambient temperature and RH during the sun drying trial day 1 to day 6 [D1 to D6]

Drying characteristics of coconut under sun drying

The average initial moisture content of coconuts was determined as 50%, and it decreased to 10% at the end of sixth day under direct sun drying (Figure 11). Anon (1981) reported that sun-dried copra has 10-15% moisture, which is too high to avoid deterioration. In some parts of India and Sri Lanka, the moisture content of sun-dried copra is 8-10%, and a further reduction to 5 or 6% takes place during storage. In these areas where the climate is suitable for sun drying, good quality sun dried white copra is produced.

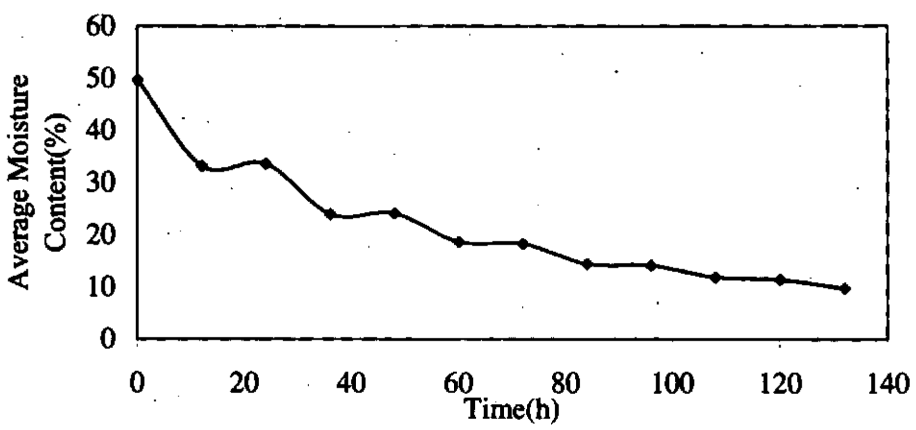

Figure 11: The drying curve of coconut cups under direct sun drying

Drying efficiency of coconut

About 153 kg of copra was produced from 700 nuts weighing about 350 kg of fresh cups, in each of the three sun drying trials. The total quantity of moisture removed per trial was 109 kg. According to Anon (1981), about 1800 kg wet kernel, with a moisture content of 50%, is needed to produce 1000 kg copra with 10% moisture content, after sun drying. The drying efficiency of sun drying was calculated as 20% and was relatively higher than that of solar hybrid drying and CRI improved kiln drying.

CONCLUSIONS

The following conclusions were drawn from testing and evaluating the three systems of copra drying:

1. **Solar hybrid dryer**

   - The average drying temperature of the solar hybrid drying system was 60 °C and within the acceptable range.
   - At the end of drying the RH was reduced to around 30% in the drying chamber while ambient RH was around 76%.
   - The average solar insolation of 668 W/m^2 was recorded during the drying period.
   - The average initial moisture content of coconut was 50% and reduced to 7% at the end of drying.
   - The drying efficiency of the solar hybrid drying system was relatively poor and 9%.

2. CRI Improved Ceylon Copra Kiln

- The average drying temperature of the improved CRI kiln drying system was 75 °C.
- At the end of drying the RH at the drying bed was reduced to 37%
- The average final moisture content of copra was determined as 8%.
- A drying efficiency of 16% was achieved and that was significantly higher than the hybrid dryer and lower than Sun drying.

3. Sun drying

- The average drying temperature of the surface of the cups was 33 °C with a maximum of 46 °C, and that is below the optimum level of 60 °C.
- The ambient RH was around 78% during the drying period.
- The average solar insolation was recorded as 426 W/m^2. However, it was within the range of 15 W/m^2 to 834 W/m^2.
- The moisture content was reduced to around 10 at the end of 6th day of sun drying.
- The highest drying efficiency of 20% was recorded with sun drying.

ACKNOWLEDGMENT

I wish to express my warm gratitude to SEEDS, Sarvodaya for providing a major share of the project funding. My sincere thanks also go to PGIA and CRI for their financial assistance and encouragement to carry out this project successfully.

REFERENCES

Anon. (1981). Chilli drying and vegetable seed drying. Annual report, Central Institute of Agricultural Engineering, Bhopal, India, 132.

Bischoff, J. (1996). Technology transfer and applications in relation to the coconut industry. Proceeding of the 33rd COCOTECH meeting 15–19 (1996), APCC, Malasiya.

Dippon, C. and Rose, V. (1996). Copra dryers and copra drying technologies, proceeding of the XXXIII COCOTECH meeting 15-19 July, 1996, Kuala Lumpur, Malaysia, 79-106.

Grimwood, B. E. (1975). Coconut palm products, FAO publication, Rome, P, 68.

Lozada, E. P. (1991). Copra making and small scale cooking oil production systems, APCC, 320-342.

Nathanael, W. R. N. (1966). Moisture and other quality features in copra. Ceylon coconut quarterly, 17 1-41.

Patterson, G. Perez, P. (1981). Solar drying in the tropics. Santa Monica, USA: Meals for million of freedom from hunger foundation, 13.

Supratomo, L., Daguenet, M., and Elegant. (1990). Technico-economic feasiblity of a partially solar heated dryer for copra production, APCC/QS/23/90, Quarterly supplement, 23-36.

Thampan, P. K. (1981). Food products and commercial products, Handbook on Coconut Palm. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, 195 - 276.