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Comparison of drying characteristics and quality of copra obtained in a forced convection solar drier and sun drying

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An indirect forced convection solar drier integrated with sensible heat storage material has been fabricated and tested for copra drying. It reduces moisture content (wet basis) from 52% to 7.8% and 9.5% in 66 h for trays at bottom and top respectively. System pickup efficiency varies between 45% and 13%. Copra obtained was graded as 76% milling copra grade1 (MCG1), 18% MCG2 and 6% MCG3. Specific moisture extraction rate was estimated to be 0.84 kg/kWh. In sun drying, moisture content reduced from 52.3% (wet basis) to about 9.2% in 7 days. Copra obtained was graded as 53% MCG1, 24% MCG2 and 23% MCG3. Average drier thermal efficiency of sun drying was estimated to be about 21%.

Keywords*:* Copra, Heat storage materials, Solar drier, Sun drying

Introduction

India, third largest coconut producing country in the world, annually produces 12.59 billion nuts[1]. Copra (dried kernel) is the richest source of oil (70%). In India, kiln and sun drying, produces poor quality copra. In kiln drying, smoke will be in direct contact with coconut cups; hence, high quality copra could not be produced due to formation of high acid content and polycyclic aromatic hydrocarbons in copra[2]. Sun drying that requires more space and time (6-8 days) is labor intensive, and allows quality deterioration due to deposition of dirt and dust on wet kernel[3].

Several experimental studies are reported for drying of agricultural materials using solar drier[4]. Forced convection solar driers improve product quality considerably[5-7] and seem to be an advantage over traditional methods. Common sensible heat storage materials used to store sensible heat are water, gravel, sand, clay, concrete etc.[8]. Solar drying can be carried out only during sunshine hours and to extend the periods of drying during off sunshine hours, whereas thermal storage systems are employed to store the heat, which includes sensible and latent heat storage[9-11].

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This paper presents development of a forced convection solar drier integrated with heat storage material (gravel) for copra drying to improve its quality.

Materials and Methods

Experiments were conducted during January 2007 to April 2007 at coconut farm nearby Pollachi, Tamil Nadu, India.

Forced Convection Solar Drier

Solar drier contains flat plate solar air heater (SAH) connected with drying chamber (Fig. 1). SAH (area 2 m^2) has copper absorber plate (2 mm thick) coated with black paint. A glass cover (5 mm thick) was used to reduce losses from topside of collector. A gap (25 mm) between glass and absorber surface was maintained air circulation. One side of collector was connected to blower using reducer and other side was attached with drier cabin. A 100 mm gap between absorber and insulation was filled with gavel to store heat during sunshine hours and to obtain hot air during off sunshine hours. Drying chamber (1m × 1m × 1.5m) is made up of galvanized iron sheet (2 mm thick) and insulated with glass wool (10 mm thick). SAH was tilted to an optimal angle of 25° with respect to horizontal, and oriented to face south to maximize solar radiation.

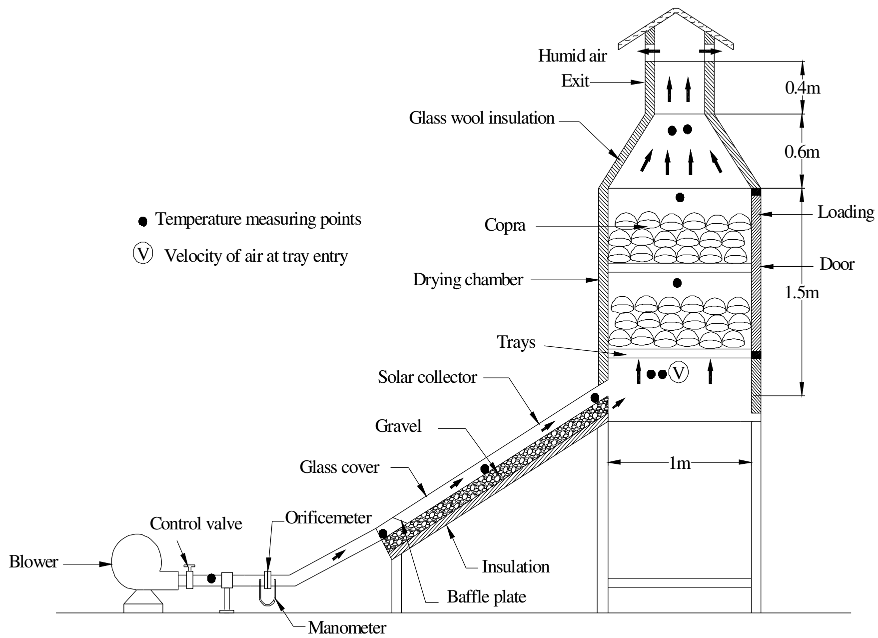

Fig. 1—Schematic view of solar drier

Six calibrated thermocouples (Pt 100) with ±0.5°C accuracy were fixed at different locations (Fig. 1) of solar drier to measure temperature of drying air through digital scanner having 0.1°C resolution connected with rotary selector switch. Relative humidity (RH) of ambient air was calculated from measured wet and dry bulb temperatures using mercury thermometers (sensitivity 0.5°C) covered with wetted cloth. RH of air at entry and exit of dryer cabin were measured by the same method by using four (Pt-100) thermocouples connected with digital scanner having 0.1°C resolution. Energy consumption of blower was measured with an energy meter having ±0.5% accuracy. A solar intensity meter with accuracy ±1 W/m^2 was used to measure instantaneous solar isolation. A U tube manometer was fixed in path of air circuit to measure velocity of air entering the drier. Air velocity at inlet of tray was measured using vane type anemometer (accuracy ± 0.01 m/s). A digital electronic balance (capacity 1 kg, accuracy ±0.001 g) was used to weigh samples.

Experimental Procedure

Matured and good quality nuts were split into two halves in crosswise manner to remove coconut water. Initial moisture content was calculated by taking five different samples. Broken coconuts along with shell were loaded over trays (porosity 90%) of drier chamber. Then, air blower is switched on and airflow rate[11] through solar flat plate air heater was adjusted to 0.025 kg/m^{2}s. During sunshine hours, air flows over absorber plate to drying chamber for drying product, and simultaneously gravel packed in collector stores solar energy. In off sunshine hours, flow was diverted to pass through gravel packed below the absorber plate. Temperature at various locations in solar collector and drying chamber were measured for every 1 h interval. After attaining about 40% moisture content, copra kernels were scooped from shells and dried further.

In sun drying, cups were spread over an open surface in a single layer directly facing the sun. Average initial moisture content (wet basis) of coconut was measured as 52% from randomly selected five cups. During off sunshine periods and nights, cups were covered by polyethylene sheet to avoid desorption of moisture. After second day, cups were removed from shells manually and dried for another five days. Moisture content of copra was determined at every 2 h interval.

Data Analysis

Samples (10 g each) were chopped from randomly selected five cups and kept in a convective electrical oven, maintained at 105 ± 1°C for 4 h. Initial (W_0) and final mass (W_t) of samples at time t were recorded using electronic balance and repeated every 1 h interval till the end of drying. Moisture content on wet basis (M_{wb}) was calculated as

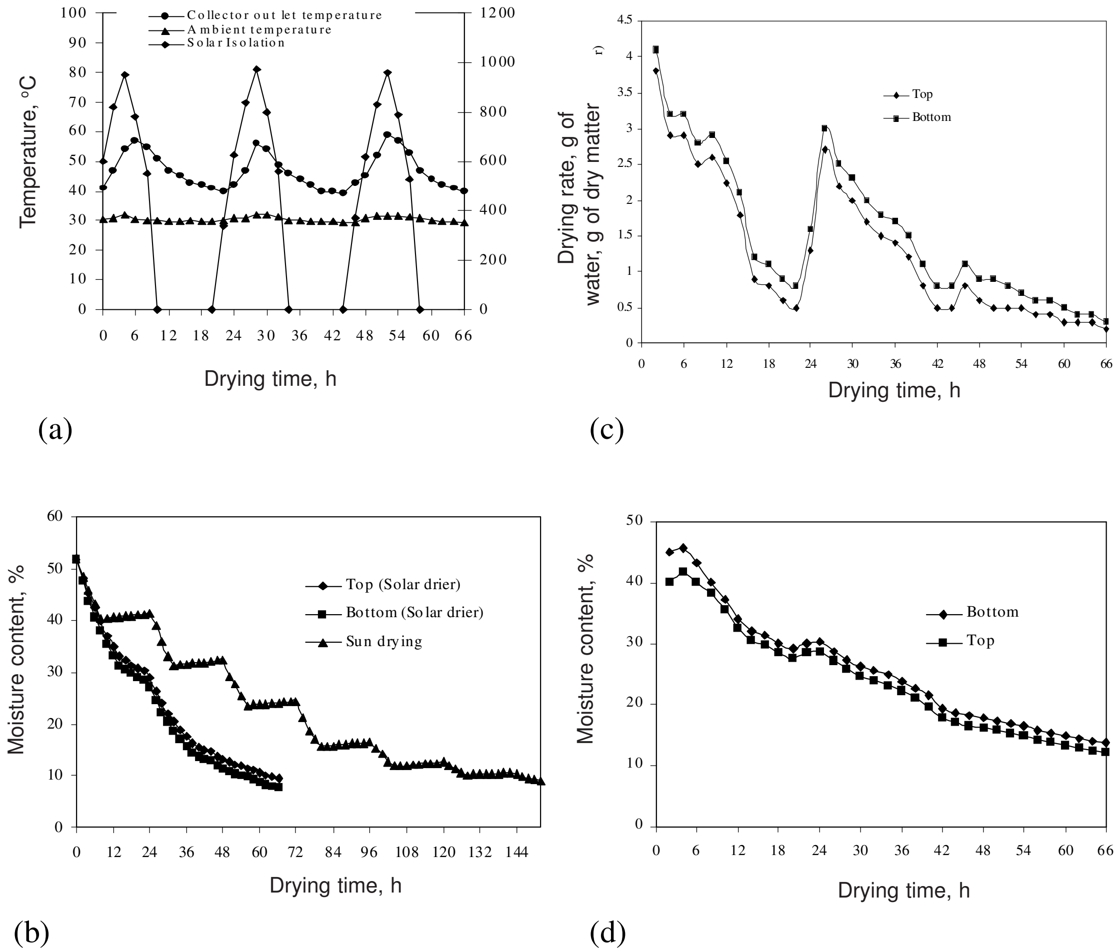

Fig. 2—Variation with drying time of: a) Ambient temperature, collector outlet temperature and solar isolation; b) Moisture content; c) Drying rate; d) Pickup efficiency

$$M_{wb} = \frac{(W_0 - W_t)}{W_0} \times 100 \qquad \ldots(1)$$

Drying rate (DR) should be proportional to the difference in moisture content between material to be dried and equilibrium moisture content (M_e) and calculated as[12]

$$DR = \frac{dM}{dt} = -k(M_t - M_e) \qquad \ldots(2)$$

Specific moisture extraction rate (SMER), which is energy required for removing one kg of water, is calculated as

$$\mathrm{SMER} = \frac{\mathrm{m_d}}{\mathrm{P_{bl}}} \qquad \ldots(3)$$

where m_d is amount of moisture extracted from maternal and P_{bl} is energy consumption of blower.

Pickup efficiency[13] (η_P), used to evaluate actual evaporation of moisture from copra, was estimated as

$$\eta_P = \frac{W_0 - W_t}{m_a A t (h_{as} - h_i)} \times 100 \qquad \ldots(4)$$

where m_a =mass flow rate of air (kg/sec), A =cross section area of pipe connecting drying chamber (m^2), h_{as} =absolute saturation humidity of air entering chamber (kg water / kg dry air), and h_i=absolute humidity of air entering chamber (kg water/kg dry air).

Thermal efficiency (η_{th}) of sun drying was estimated as[14]

$$\eta_{th} = \frac{m_f h_{fg}(M_o - M_f)}{E(100 - M_o)} \times 100 \quad \ldots(5)$$

where M_o is initial moisture content of coconut on wet basis, M_f is final moisture content of coconut on wet basis, m_f is mass of product dried (kg), h_{fg} is latent heat of vaporization of water (kJ/kg) and E is energy absorbed from sun.

Grading

Grading of copra was done after drying according to BIS: 6220-1971 by selecting 100 cups randomly (Table 1). Chips in bulk sample were separated and weighed (% by wt). Wrinkled cups were separated and calculated their number as percentage of cups constituting bulk sample. Number of mouldy and black cups were counted and reported as percentage.

Results and Discussion

Forced Convection Solar Drier

Average drying air temperature recorded at inlet of drier was about 46°C (Fig. 2a). Maximum drying air temperature recorded was about 59°C during peak sunshine hours and temperature was reduced to about 39°C during off sunshine hours and nights. Maximum solar intensity recorded was about 975 W/m^2. Average ambient dry and wet bulb temperatures recorded were 31°C and 26°C respectively. In drying chamber outlet, a high RH (85%) was recorded during initial stages of drying and gradually reduced to about 32% at the end of drying.

Average moisture content of coconut was reduced from about 52% to 7.8% and 9.5% in bottom and top tray respectively after 66 h (Fig. 2b). Moisture reduction during first and second day of drying was found to be about 33% and 20% respectively. Higher moisture reduction during first day was observed due to evaporation of free moisture migration from outer surface layers and then gets reduced due to internal migration of moisture from inner layers to the surface. This results in a process of uniform dehydration of wet kernel. Reduction in moisture content of copra at bottom tray was about 5-8% higher than that of top tray.

Temperature inside drier was higher than ambient temperature and corresponding RH in drier was lower than ambient RH. As a result, drying rate of copra in force convection drier was found to be higher than that of open sun drying. High drying rate (4.2 g of water/g of dry matter. h) was observed during initial stage of drying. Drying rate gets decreased with increase in drying time. Drying occurs in the falling rate period with steep fall in moisture content in initial stages of drying and becomes very slow in the later stages. The reason for sudden increase in drying rate during second day is due to increase in collector out let temperature. During off sunshine hours and nights, drier utilizes the heat stored in heat storage materials. Drying rate decreases due to decrease in collector outlet air temperature and gets increased due to increase in collector outlet air temperature.

Pickup efficiency varies between 45% and 14% for bottom tray and between 40% and 12% respectively for top tray. Increase in pickup efficiency observed during initial stages of drying due to faster evaporation of free moisture in outer surface and also due to increase in collector outlet temperature. Pickup efficiency gets decreased due to internal moisture migration. In this

Table 1 —Grading of milling copra according to BIS: 6220-1971

S No	Characteristic	Requirements		
		MC Grade 1	MC Grade 2	MC Grade 3
1	Impurities, % by wt, *Max*	0.5	1	2
2	Mouldy cups, % by count, *Max*	4	8	10
3	Black cups, % by count, *Max*	5	10	15
4	Wrinkled cups, % by count	5	10	15
5	Chips, % by wt, *Max*	5	10	15
6	Moisture content % by wt, Max	6	6	6
7	Oil content (on moisture free basis), % by wt, *Min*	70	68	66
8	Acid value of extracted oil, *Max*	2	4	10
9	Grades of copra			
	Solar drier, %	76	18	6
	Sun drying, %	53	24	23

drier, energy is obtained from blower work, solar radiation and through heat storage material.

About 51 kg of moisture was removed from 300 nuts to obtain about 60 kg of copra in one batch. Specific moisture extraction rate was estimated to be about 0.84 kg/kWh by using Eq. (4). In solar drier, about 60 kg of copra was produced from 300 coconuts (Table 1). Copra obtained was graded as 76% MCG1 copra, 18% MCG2 and 6% MCG3.

Sun Drying

Average initial moisture content was determined as 52.3% at beginning of sun drying, which was reduced to 9.2% at the end of 7th day under direct sun drying (Fig. 2b). During first and second day of drying, moisture content was reduced to 41.2% and 32.76% respectively. However, moisture content of copra was increased by 0.1-1% due to desorption during off sunshine hours. Average ambient temperature during drying period was 35°C. Drying rate was found to be very slow as compared to solar drier due to lower heat and mass transfer coefficients.

About 170 kg of moisture was removed from 1000 nuts to obtain about 180 kg of copra (Table 1). Copra obtained was graded as 53% MCG1 copra, 24% MCG2 and 23% MCG3. Nearly 25% of copra produced was affected by bacterial infection due to prolonged heating. Thermal efficiency of the drier was estimated to be about 21% using Eq. (5).

Comparison of Drying Techniques

Forced convection solar drier reduces moisture from 52% to 7.5% in 66 h. Copra produced (75% of high quality) was free from dust, birds and rodents attacks. Operating cost per kg of copra was about Rs 2.50 and Re 1.00 for solar drier and sun drying respectively (Table 1). Revenue obtained from 100 kg of copra obtained in a solar drier and sun drying was Rs 3504.00 and Rs 3322.00 respectively. Quality of copra obtained in solar drier was better compared to sun drying.

Conclusions

Indirect forced convection solar drier dried product to final moisture content of about 7.8% and 9.5% in 66 h for trays at bottom and top respectively. SMER of solar drier was estimated to be about 0.84 kg/kWh. Pickup efficiency varies between about 45% and 13%. In sun drying, moisture content was reduced from 52.3% to 9.2% in 7 days. Average thermal efficiency of sun drying was estimated to be about 21% respectively. Poor quality copra was obtained in sun drying mainly due to its exposure to open atmosphere, exposing it dust, birds, insects and rodents attack etc, which may induce formation of carcinogenic substance in copra. Forced convection solar drier is more suitable than sun drying for producing high quality copra for small holders.

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