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Thermal Performance Evaluation of Indirect Forced Cabinet Solar Dryer for Cashew Drying

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Abstract: A study was conducted to develop an efficient indirect forced convection solar dryer for the purpose of drying 40 kg of cashews per batch. The system consists of a solar flat plate collector, drying chamber and a blower. Performance test was conducted in active and passive mode on different solar days in the Department of Mechanical Engineering, PRIST University, Puducherry. Dryer performance parameters like moisture content, drying rate, thermal efficiency of collector, system efficiency and dryer efficiency were evaluated based on the experimental data. The performance study indicates that the required moisture reduction from 10% to 5% was achieved within 6 hours in active mode, 10 hours in passive mode and 14 hours in open sun drying. Thermal efficiency of the solar collector varied between 65-70% in active mode and 30-45% in passive mode. The quality evaluation of the products proved that the developed system is suitable for drying of cashew. The dryer can be used to replace electrical and conventional dryer in semi urban and rural areas of India.

Key words*:* Drying efficiency · Drying rate · Moisture content · CNS · Testa · Flat plate collector

INTRODUCTION

India has made a considerable progress in cashew cultivation, processing, import and export, holding a leading position in the world market. At present, India contributes 17.3 and 39.47 percent of the total area and raw cashew production in the world [1]. On an annual average, 7.52 lakh tons of raw cashew nuts are imported mainly from African countries and exporting cashew kernel to USA and UK after processing [2].

Cultivation and processing of cashew promotes rural employment and growth in agricultural sector. Sophisticated dryers are being used for cashew drying as it is considered as a high value product. Normally, drying of cashew is carried out by using steam and electrical drying process. Cashew drying requires a temperature of 65 -70°C around 4-6 hours to reduce the moisture content of the raw kernel from 9% to 3% [3]. Drying of cashew nuts in shell (CNS) for removing testa (the thin skin covering the edible kernel) is the most significant and difficult process.

Considerable efforts have been made to design and develop solar dryers for drying of agricultural products [4-6]. From the review of literature, it was found that many of them were using solar dryer for drying different agricultural product temperature ranging from 45-60°C [7]. Some research is also addressed to enhance the efficiency of drying operation and quality of the product. The amount of moisture content reduced was from 60% to 8% within 6 hours using special mixed mode type dryer [8]. A forced convection solar dryer was designed and developed for drying products like copra [9]. Maximum temperature of 90°C was achieved using a Natural circulation type greenhouse solar dryer when the ambient condition was just 35°C [10].A modified industrial dryer has been developed for drying biomass such as rice husk, sawdust, wheat straw and other light granular materials for energy purposes [11].

The existing literature survey clearly indicated that so far no work has been carried out on solar drying of cashew nut in forced convection mode. Hence to overcome the problems attributed to the cashew nut farmers in the territory, the present study is carried out.

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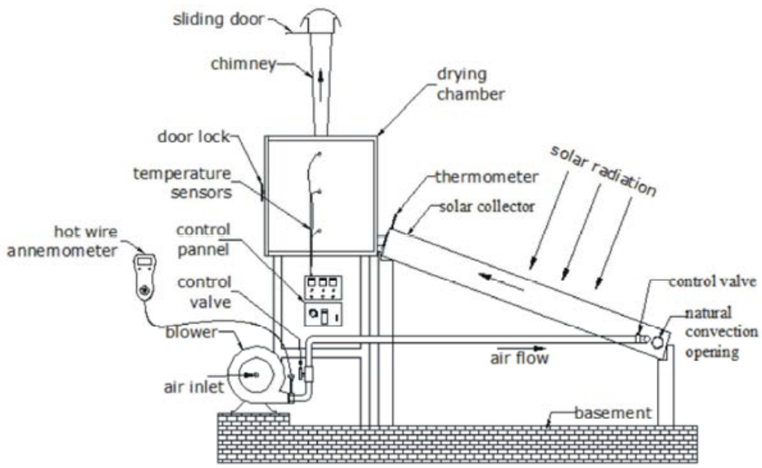

Fig. 1: Description of the components of the solar dryer

The objective of the present work is

- To design and develop a forced convection solar dryer for drying CNS under the meteorological conditions of Puducherry, India.
- To evaluate the performance of forced convection solar dryers so that it could be recommended to farmers for high quality cashew nut production.
- To study the drying characteristic of cashew nut such as drying rate, moisture content, efficiency and quality of the product.

Description of the Indirect Solar Forced Convection Dryer: The indirect forced convection solar dryer consists of a solar air heating collector system, AC blower, drying chamber with chimney and supporting stand. Fig. 1 shows detailed drawing of each part of the solar dryer. The air heating system had dimensions of 2 m length, 1.1 m width and 0.21m depth. It consists of double glass cover, absorber, back plate and insulation.

The entire system was placed in a rectangular box made from a galvanized iron sheet 0.9 mm thick. A 2 mm thick aluminum plate coated with black paint is used as absorber to absorb the incident solar radiation. The toughened two glass plate (4mm thick, 1.78m×1m in size) was fixed on the top of the collector at a distance of 0.04m above the absorber plate to reduce the losses of heat from the top side of the collector. During operation, air flows through the space between absorber plate and back plate (0.08m). These spaces inside the collector are baffled to change the direction of air flow. Two inlet connections are provided at the front end of the collector, one end is connected to the blower through pipe of diameter 0.05m with valve for running the system in forced convection mode and the other end in 0.076m in diameter is open to atmosphere with valve for running the system in free convection mode. One outlet connection is provided at the rear end of the collector which is directly connected to the drying cabinet. The connections are thermally insulated with glass wool. A centrifugal blower with speed up to 2800 rpm is used for the system. Depending on the various drying condition and according to the need of air supply the blower speed is varied. The technical specifications of the system are presented in Table 1.

The drying cabinet consists of four main parts. They are base frame, drying chamber, drying trays and loading door. The drying chamber is made up of mild steel frame and covered by galvanized iron sheet of 1mm thickness with length breadth and height of (0.64×0.6×0.73m) respectively. Inside the drying chamber ten perforated aluminum drying trays are arranged from the base to the top of the drying chamber. They are evenly placed at a distance of 0.05m apart. The frame of each tray was made from an aluminum angle of 0.02m. The entire unit was enclosed in a galvanized iron sheet and glass wool was filled in-between inner and outer shell. A door was provided with locking arrangement for loading and unloading of the product in the drying chamber. Air tight sealing is done in the door by sealing sponge rubber. A funnel with increasing cross section (bottom 0.16m, top0.2m, height0.6m) towards the top with sliding door is incorporated into the system to regulate the air flow and for removing moist air from the dryer. The perspective view of the experimental setup is shown in Fig.2.

(a) Solar dryer (b) drying chamber loaded with cashew kernel

Fig. 2: Perspective view of the solar dryer and drying chamber

Table 1: Technical Specification of the Solar Cabinet Dryer

S.No	Parameter	Description
1	Mode of heating	Indirect
2	Number of glazing	Double
3	Loading provision	Sliding tray
4	Number of trays	10
5	Air outlet provision	Chimney at the top
6	Air circulation	Natural and Forced
7	Collector area	$2.2m^2$
8	Drying capacity	40kg
9	Construction materials	Steel, G.I, Aluminum sheet and Glass wool
10	Glazing slope	20 Degree
11	Thickness of glass	4mm
12	Blower details	0-2800 Rpm; 0.37 kw ; 440 V(A.C)
13	Drying chamber size	0.64×0.6×0.73 m
14	Height of stand	1.2m
15	Size of aluminum trays	0.54×0.51×0.02 m
16	Chimney with increasing cross Section	Bottom-0.16m Top-0.2m Height-0.6m
17	Type of insulation	Glass Wool

MATERIALS AND METHODS

Drying of Cashew Kernel: 80 kg of dried cashew nut shell(CNS) was procured from the local farmer in cuddalore district, tamilnadu, India. A hand cutter is used to obtain kernel (nuts) from the CNS. 40 kg of cashew kernel was used for the drying experiment. Cashew kernel with testa (thin skin covering the edible kernel) is placed uniformly on the trays of the solar dryer. Load density of cashew kernel in the drying chamber is 4 kg per tray. The initial moisture content of the kernel is approximately 9%.After loading of cashew; drying experiment was carried out from 8 a.m to 6 p.m.

Experimental Procedure: Experiments were conducted at an optimum airflow rate of 0.042 Kg/s in forced convection mode under loading condition of 40kg of cashew per batch. During the trial, the temperature of the drying chamber at bottom, middle and top trays are measured every one hour. Experiments were also conducted in natural convection and open sun drying. The experiments results obtained from natural and forced convection mode were compared with the open sun drying.

Instrumentation: The following parameters were measured during the trials: solar insolation, temperature, relative humidity, air velocity, initial and final weight of cashew and energy consumption of the blower. The relative humidity of air at ambient and drying chamber is measured by using thermo hygrometer. Ambient temperature, collector outlet temperature, drying chamber outlet temperature is measured using RTDs. Other results observed are solar intensity by solar power meter, relative humidity by thermo hygrometer. Initial and final weight of

Table 2: Instrumentations used in the experiment

S.No	Parameter	Instruments	Accuracy
1	Temperature	Thermocouple and RTDs	0.05°C
2	Mass	Electronic Balance	0.01g
3	Solar radiation	Solar Power Meter	±5% At 2000W/m²
4	Air velocity	Hot Wire Anemometer	±2.5%
5	Power consumption of blower	Energy Meter	±0.1Kwh
6	Relative humidity	Thermo Hygrometer	±2.5%

the product is measured by using digital weight balance. The flow rate of air is measured by using hotwire anemometer connected between blower and collector inlet. The energy consumption of the blower is also calculated by energy meter. Accuracy of the instruments used in the experiment is listed in Table 2.

Performance and Data Analyses: The system performance and the drying characteristics of cashew nuts (kernel) such as moisture content, drying rate, efficiency were calculated using the following equations.

Moisture Content: The moisture in cashew nuts were determined after each hour of drying. The moisture content after each hour in drying was determined by taking initial weight and weight loss after each hour with the help of electronic balance [12].

$$Me = \frac{m_i - m_d}{m} \times 100 \quad (1)$$

Drying rate (DR) is expressed as the amount of evaporated moisture over time.

$$DR = \frac{m_i - m_d}{t} \quad (2)$$

Thermal efficiency of a solar collector is the ratio of useful heat gain over any time period to the incident solar radiation over same period. It is expressed as [13].

$$\eta_c = \frac{mC_p\,(T_o - T_i)}{I.A} \quad (3)$$

Overall system efficiency η_s is the ratio of the energy required to evaporate moisture from the product to the heat supplied to the dryer. The system drying efficiency is a measure of the overall effectiveness of a drying system. Energy consumed by the blower is taken into account for forced convection mode. System efficiency can be expressed as.

$$\eta_s = \frac{m_w . h_{fg}}{IA.t+E} \text{ (forced convection solar dryer)} \quad (4)$$

$$\eta_s = \frac{m_w . h_{fg}}{IA.t} \text{ (natural convection solar dryer)} \quad (5)$$

Effectiveness factor can be defined as ratio of drying rate in the indirect solar dryer to the drying rate in the open sun drying.

$$\text{Effectvebess}_{\text{factor}} = \frac{\text{drying rate in Indirect solar dryer}}{\text{drying rate in open sun drying}} \quad (6)$$

Pick-up efficiency /drying chamber efficiency determine the efficiency of moisture removal by the drying air from the product. It is used to evaluate actual evaporation of moisture from cashew [14].

RESULTS AND DISCUSSION

Experimental investigation on drying cashew nut kernel has been carried out and tested for varying operating conditions. The results of observations from various operation conditions are explained in the following section.

Temperature Distribution: Fig. 3. shows the variation of solar intensity and temperature in forced convection mode during the experimental period of 8 A.M. to 6 P.M. The ambient air temperature ranged from 28-34°C and solar radiation varied from 600W/m^2- 1000W/m^2 on the typical test day. The average collector outlet temperature was 72°C which was 41°C above the ambient temperature. The average temperature inside the drying chamber remained between 36-67°C. The temperature suitable for drying cashew ranged from 65-70°C. During the time interval, the solar radiation and temperature were fluctuating and varying. However the bottom, middle and top tray temperature inside the drying chamber were almost constant. Maximum temperature difference of 2°C was observed between the bottom, middle and top tray. The rise in air temperature due to the generated air flow rate in the collector is sufficient for the purpose of drying cashew nuts, even when the solar radiation was low. The temperature required for drying cashew is readily obtained in the forced convection dryer.

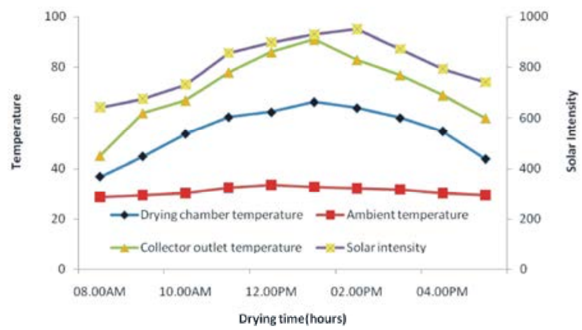

Fig. 3: Variation of ambient, collector outlet, drying chamber temperature and solar insolation in forced convection mode

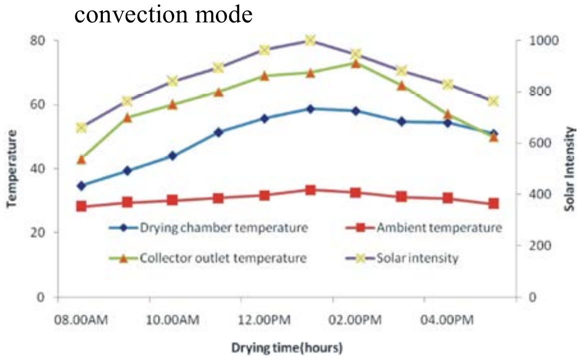

Fig. 4: Variation of ambient, collector outlet, drying chamber temperature and solar insolation in natural convection mode

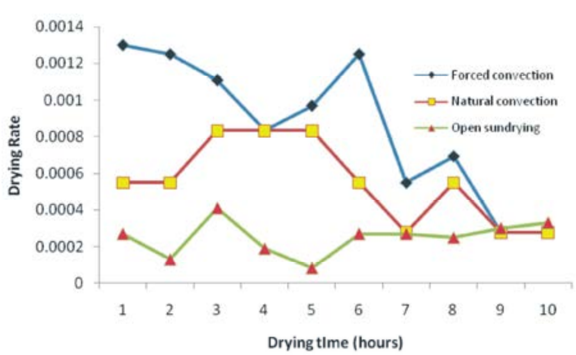

Fig. 5: Variation of drying rate with drying time

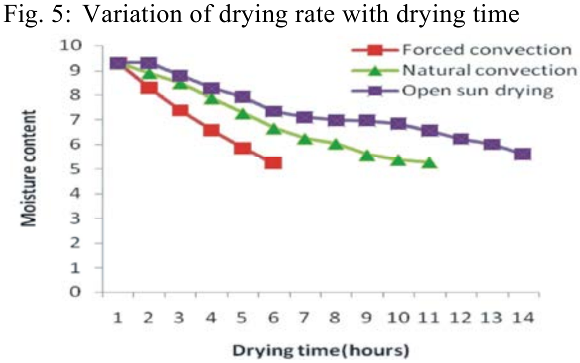

Fig. 6: Variation of drying rate with moisture content at different drying conditions

The variation of solar intensity, ambient temperature, collector outlet and drying chamber temperature for a typical day during drying of cashew in natural convection mode are shown in Fig. 4. Maximum solar intensity recorded was about 1000W/m^2 during peak sunshine hours. The ambient air temperature ranged from 28-34°C. The maximum and minimum drying air temperature recorded at the collector outlet were 43 and 70°C. The maximum and minimum drying chamber temperature recorded were 34 and 58°C. The drying air temperature at collector outlet and inside the drying chamber obtained in this system is comparatively lesser than the temperature obtained in the forced system. Also, the temperature required for drying cashew is marginally attained in the natural convection dryer.

Moisture Content and Drying Rate: The variations of drying rate of cashew in open sun drying, natural convection and forced convection are shown in Fig. 5. It shows that the drying rate of cashew in forced convection mode is higher when compared to the other two methods. Also the cashew nut dried with solar dryer in forced mode showed a variation in drying rate. The drying rate was found to decrease with increase in drying time. Drying rate was higher during the initial stages of drying and becomes very low in the later stages of drying. Drying rate decreases due to decrease in collector outlet air temperature and gets increased due to increase in collector outlet air temperature.

Fig. 6 shows the drying curve for cashew in various modes of drying. It was observed that the drying rate increased due to increase in temperature. The initial moisture content of the Cashew nut was 9.29% (db) and the final moisture content was in the range of 5 to 4% dry basis. The desired moisture content of 5% can be reached within 6 hours of drying in forced convection mode, while it takes 10 hours of drying in natural convection mode and it take more time 14 hours in open sun drying. It was observed that the moisture removal rate is increased by using forced convection as compared to natural convection and open sun drying. Thus, it shows that the time period required for cashew drying is greatly reduced by forced convection solar dryer.Also, the moisture loss rate of cashew nut was uniform and this leads to increased quality of dried product.

Drying Efficiency: Fig. 7. shows variation of collector efficiency with time. It was observed that maximum efficiency of 66% was obtained during the peak sun shine hours and lowest efficiency of 45.4% was obtained during

Table 3: Comparative study of different drying methods for cashew

Type of dryer	Moisture (%) Initial	Moisture (%) Final	Temperature (°C) Ambient	Temperature (°C) Average chamber	Drying time	Collector efficiency (%)	Overall dryer System efficiency (%)	Effectiveness factor
Forced mode solar dryer	9.29	5.22	31.05	54.63	6	59.5	8.89	4.43
Natural mode solar dryer	9.29	5.28	30.73	50.16	10	34.5	5.7	2.9

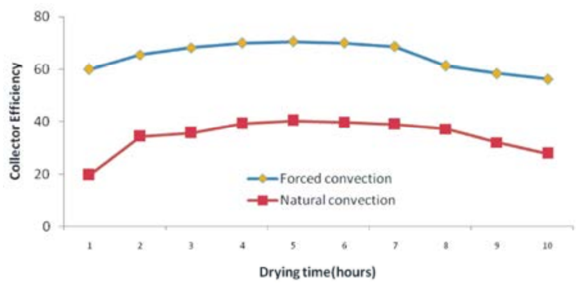

Fig. 7: Variation of drying time with collector efficiency at different drying conditions

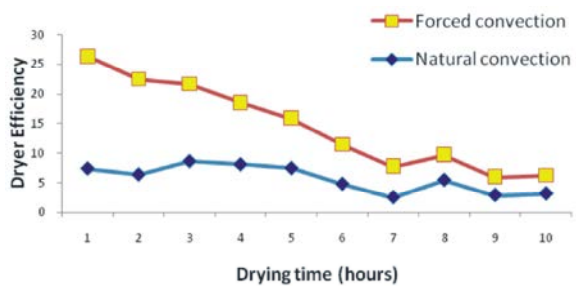

Fig. 8: Variation of drying time with dryer efficiency

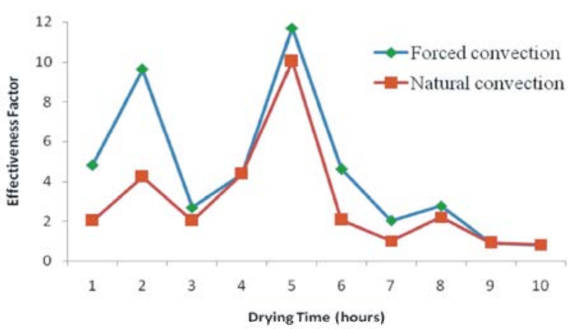

Fig. 9: Variation of drying time with Effectiveness factor

the beginning of the experiment. The collection efficiency was found to increase with increasing mass flow rate and the differences in outlet and inlet air temperature.

The hourly drying efficiency of the system in natural convection varies from 3-7% and in forced convection mode the efficiency of the system varies from 4-26% as shown in Fig. 8. Maximum dryer efficiency of 26% was obtained during the experiment. The drying system efficiency is affected by the properties of the drying materials i.e moisture content, size, shape and geometry as well as ambient conditions.

The variation of drying time versus effectiveness factor is shown in Fig. 9. The maximum effectiveness factor of 11.68 was observed in forced convection mode and 10.03 were observed in natural convection mode. The mean effectiveness factor was little higher for forced convection dryer than natural convection dryer.

DISCUSSION

Comparative result analysis of different drying methods for cashew is listed in Table 3. The average collection efficiency of solar dryer is 59.5%. The overall system efficiency of 9% obtained in this study is acceptable. From the results of table 3, it is reflected that forced mode solar dryer is more efficient and takes less time for drying. The result obtained in this study is consistent with other dryers used for the same application [15]. The system design is acceptable for cashew drying. But one significant drawback of the system is that it can only be used in days of adequate sunlight which limits the production for small scale farmers. The performance of the system can be improved further by altering the design features. Providing parabolic reflectors on both sides of the collector and auxiliary biomass heating arrangements is necessary to enhance the thermal performance of the system.

Quality Analysis of Cashew Nut: It is observed that, the average moisture content of cashew nut kernel is after drying is 5.23%. The epidermis (testa) of the dried cashew nut kernel can be easily removed by hands. Kernels are categorized based on the colour and condition. The kernels looked bright white and clean without black spot or toxin sign. Also the kernel retained its shape and size without any splits and butts. The result showed that the quality of solar dried cashew nut kernel matched with the W 240 level (485-530 per kg) according to the standard of cashew in India.

CONCLUSION

An indirect type forced convection solar dryer has been designed and fabricated for drying of cashew nut. The cashew nut was tested in forced convection solar dryer, natural convection solar dryer and open sun drying. The following conclusions are drawn from the experimental study:

- The hourly variation of drying chamber temperature is much higher than the ambient temperature during the most part of the experimental period.
- The temperature of the drying chamber was almost uniform 60-65°C across the trays with time duration of 6 hours.
- The final moisture content 5% was obtained in the time period of 6 hours in forced convection mode, 10 hours in natural convection mode and 14 hours in open sun drying.
- The present solar system provides the constant heat to the product as well retain its nutritional and organoleptic quality. Uniform drying of cashew was achieved with good quality nuts grade (W240).
- The dryer reduces the cost of energy usage and can be used for drying other agricultural products.
- The proposed forced convection solar dryer is very useful for cashew nut farmers in rural areas of the country.

Nomenclature:

m_i Mass of sample before drying (Kg)
m_d Mass of sample after drying (kg)
M_i Initial moisture content (kg)
M_t Moisture content at a particular time (kg)
m_w Mass of moisture evaporated at a time (t)
m Mass flow rate of air (kg/sec)
t Time of drying (sec)
V Airflow rate (kg/sec) or (m^3/sec)
Cp Constant pressure specific heat (J/kgK)
T_o Collector outlet temperature (°C)
T_i Collector inlet temperature (°C)
I Solar radiation intensity incident on the solar dryer (W/m^2)
A Collector area (m^2)
W Mass of evaporated water from the product (kg) in time of drying ‘t’
t_1 Time of drying in first day (sec)
m_a Mass flow rate of air (kg/sec)
A_p Cross sectional area of pipe connecting to drying chamber (m^2)
h_{fg} Latent heat of vaporization of water for the drying chamber (kJ/kg)
E Energy consumption of blower (kWh)
η_s System drying efficiency (%)
η_c Collector efficiency (%)
M_c Moisture content (%)
DR Drying rate (%)

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