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Design Fabrication and Testing of Indirect Natural Convection Solar Dehydrator for Drying Copra

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Abstract: *Sun drying is traditional method practiced by many people to dry copra before extracting oil. An indirect natural convection solar dehydrator has been designed fabricated and tested for drying copra. Oil was extracted after drying the copra. The dehydrator reduces the moisture contentsuitable for oil extraction. Maximum temperature was obtained on the lowest tray (tray 4) of drying chamber. Drying efficiency, drying rate and final moisture contentwascalculated. faster results were obtained using dehydrator compared to that of conventional solar drying.*
Keywords*: Copra, Conventional solar drying, Solar dehydrator, Drying time, Coconut oil.*

I. Introduction

Coconut is one of the main crops produced in Goa with estimated coconut production of 132,160 thousand nuts in year 2016-17[1]. Coconut and coconut oil have important role in Goancuisine.Coconut oil has many proven medical benefits. Oil is extracted from dried coconut kernel called copra. For producing copra coconut with initial moisture content of about52% (wet basis)is dried and reduced to7%to concentrate the oil content [2].As per BIS standards of grading copra, the best quality copra is obtained at the drying temperature of 70°C [3].

The conventional and widely used method for drying coconut halves is direct sun drying. This method takes about 7days[2]and could even extend more in bad weather conditions. Copra produced by this method is of poor quality as dust particles settles onto coconut halves, birds and rodents eat the coconut kernel. The direct sunlight can cause depletion of nutrients in fruits and vegetables, along with discoloration which is not desirable [4].

In this paper we are going to discuss the design, fabrication and testing of indirect natural convection coconut solar dehydrator. The main objective of the device is toeliminate all the disadvantages of traditional sun drying and reduce the drying time by half compared to traditional drying method.

II. Materials And Methods

The experiments were carried out in western costal state of India, Goa from July 2017 to April 2018.

A. Natural convection indirect solar heater

The device consists of a collector chamber and drying chamber. The collector chamber generated the necessary heat while the drying chamber contained trays which held the coconut halves to be dried.

The collector chamber was 2 m^2. Sufficient gap was provided for the air movement inside the collector chamber. The inclination of collector chamber depends on the latitude of the place where the collector is to be installed. The collector chamber was inclined at 13°with respect to horizontal which is the optimum angle for year-round performance in Goa[4]. Aluminium was used as a heat absorbing material inside the collector chamber after comparingits thermal conductivity and specific heat with pure forms of galvanised iron (GI) (zinc) and copper [5]. Although copper proved to be the best compared to both, the cost and availability were the factors for selection of aluminium. Aluminium mesh was selected over aluminium plate for the better air movement inside collector chamber. To reduce the top losses and to increase the temperature of air due to greenhouse effect an acrylic sheet cover was placed above the collector. Reason for selecting acrylic sheet over low iron glass which is specially designed for solar collectors is the availability of desired size and the chances to break while installing. Since the device is farmer centric afford ability constraints was the reason for selecting the materials which were locally available at low costs. One side of collector was open to atmosphere which formed inlet for air to be heated to enter into the drying chamber while the other end was connected to drying chamber. The inlet vent size was made adjustable to vary the mass flow rate of air entering into the collector chamber by which temperature inside the drying chamber could be controlled. To reduce the side and bottom losses due to convection and radiation both bottom and sides were insulated with standard 4mm aluminium air bubble sheet.

A door was made on one side of drying chamber for loading and unloading the device.Fourtrayswere provided for placing coconut kernel halves. Gap of 10cms was kept in between trays for easy placement and removal of coconut halves on the trays. The trays were made to slide on the guideways so that it could be removed out of the drying chamber through door for cleaning and maintenance work of the device. Trays were made of GI mesh of half square inch gap. Although GI is not food safe it was used as the device was purely made for experimental and not for commercial purpose and with aim to reduce the overall cost of device.

The device was made from class 1 marine plywood as the moisture generated during drying process could spoil the device. The device was painted inside with matte black paint to maximise incident solar radiation absorption that it is mercury and lead free considering the food safety. The stand was fabricated to place the device on it. Four wheels were attached to the base of frame in order to move the device in open surroundings to reduce shading losses and to maximise the use of solar insolation available.Six thermistors were placed at inlet, outlet and at all four trays for data analysis.

Fig.1 Pictorial view of constructed dehydrator

III. Experimental procedure

Device was tested in two phases i.e. for no-loading conditions (without coconuts) and loading conditions (with coconuts). Adjustable inlet vent was kept fully open. Temperature was recorded at every 15 minutes of interval.

No load tests

The purpose of this test was to determine the temperature generated by the collector and to determine collector efficiency. This test was again divided into three stages, without heat absorbing mesh and without insulation, with heat absorbing mesh and without insulation and with heat absorbing mesh and with insulation. During each test temperature at different location was recorded for analysis.

Load test

Matured and good quality coconuts were broken into two halves and weighed after draining all water from it. 54 coconuts making 20kgs were uniformly distributed over all four trays with 5 kg on each tray. Coconuts were weighed at the end of each day. At the end of second day some copra kernels were scooped out of shell and remaining kernels were removed at the end of third day. Than each kernel was cut into 4-6pieces and dried on fourth day. On fifth day kernels were dried for four hours and oil was extracted by cold pressing method.

IV. Data Analysis

For the analysis of solar dehydrator side bottom and leakage losses were neglected. It was assumed that all the energy available inside the collector chamber was fully utilised.

Drying efficiency is the ratio of the energy needed to evaporate moisture from the material to the heat supplied to the dryer [6].

$\eta_d=M_W*LI*As*t*100$

Where,ASis the area of collector plate, "I" is the Insolation, "MW"is the mass of water removed, "L" is the latent heat of vaporization of water at average drying temperature, "t" is the time taken for drying copra.

Drying rate is amount of evaporated moisture over time [6].

$DR=MI-M_Dt$

"MI" is the initial mass of copra, "MD" is the final mass of dried copra.

The final moisture content (Mf) is calculated by [7]

$M_W=(M_I (M_i-M_f))/(1-M_f)$

Where, "Mi" is the initial moisture in copra.

V. Results And Discussions

The graphs for variation of temperature over time for no load described below.

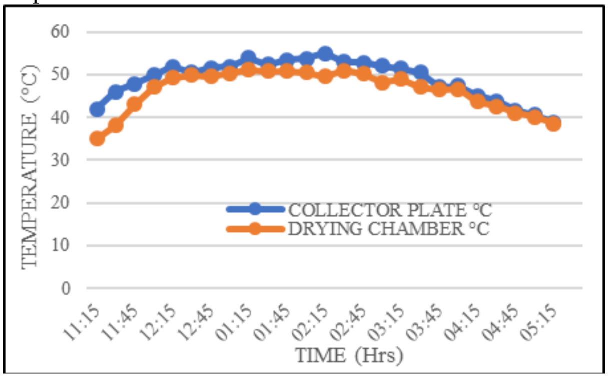

Fig. 2 variation of temperature over time for test

This test was performed without placing heat absorbing mesh and using plywood base of collector as absorbing material. In this test one sensor was placed in drying chamber while one was placed on collector mesh.

The purpose of this test was to obtain the temperatures and plot the graph to see the trend. From this test it was found that the average collectortemperature was 48.95°C and the drying chamber temperature was 46.40°C.

The maximum collector temperature was recorded as 53.9°C and maximum drying chamber temperature was recorded to be 51.1°C.

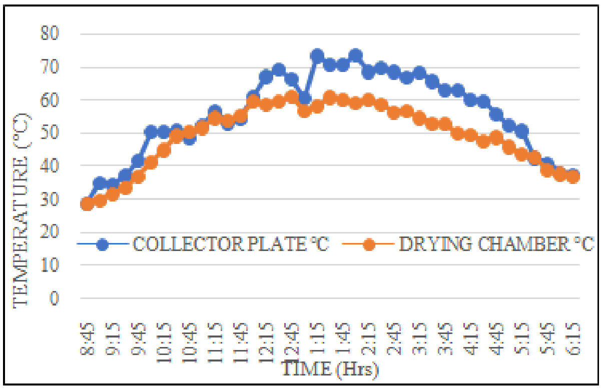

Fig. 3 variation of temperature over time for test 2

This test was performed by placing heat absorbing mesh inside the collector. Two sensors were used to record the data. It was observed that average temperatures were 55.90°C and 49.60°C of collector and drying chamber respectively.

Maximum temperature of collecting mesh was 73.6°C while maximum temperature in drying chamber was 61.1°C.

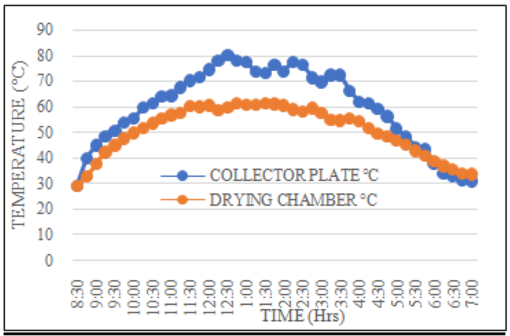

Fig. 4 variation of temperature over time for test 3

Same test was performed again for different weatherconditions and average temperatures were noted to be 59.79°C and 49.40°C of collector plate and drying chamber respectively.
The maximumtemperatures were 80.2°C and 61.3°C of collector mesh and drying chamber.

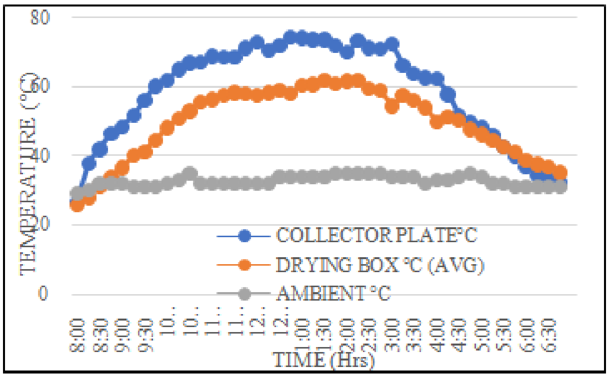

Fig.5 variation of temperature over time for test 4

Now the insulation was placed, and sensors were positioned at inlet to note ambient temperature and on each tray to find average drying chamber temperature. collector plate temperature was recorded as 58.70°C and average drying temperature was 49.80°C while the average inlet temperature was 32.70°C.
maximum collector plate temperature was 74.3°C and maximum average drying chamber temperature was 62°C.

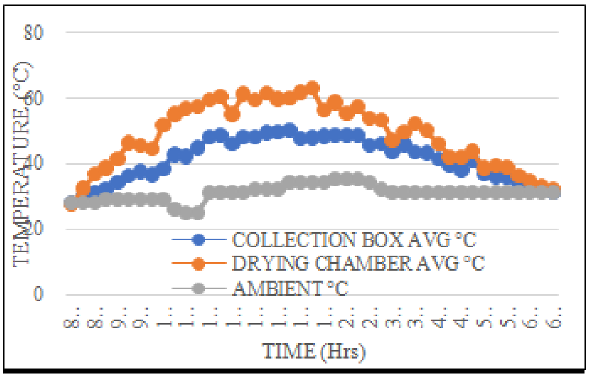

Fig. 6 variation of temperature over time for test 5

This test was performed to get temperature of air inside the collector chamber.
From this test it was observed that the average inlet and outlet of collection chamber was 33.60°C and 49.40°C and average drying chamber temperature was 49.40°C. the average collection chamber temperature was 41.5°C. Maximum averagecollectionchamber temperature was 50.3°C and maximum average drying chamber temperature was 62.8°C. There was noticeable difference in ambient temperature and drying chamber temperature. The difference increased as the day progressed and as the sun set progressed the difference reduced and both temperatures were nearly same. According to the concept of working of dehydrator temperature inside collection chamber should be more than that of drying chamber but practical testing found that the temperature inside drying chamber was more than that of collection chamber. This was because roof and walls of drying chamber was being heated with solar radiation which in turn added heat inside drying chamber.
The graphs for variation of temperature over time for load test is described below.

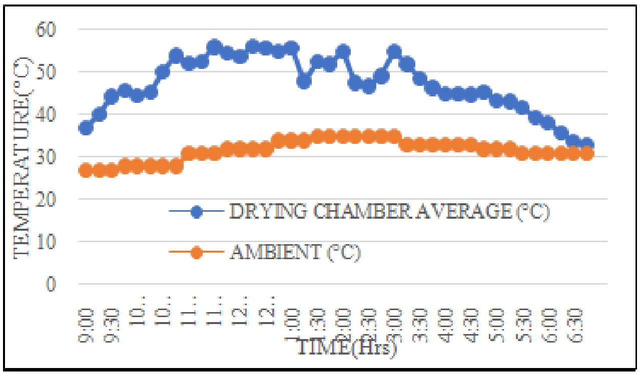

Fig. 7 variation of temperature over time for day 1

The average temperature inside drying chamber on day 1 was 48.16°C while the average ambient temperature was 31.80°C. The maximum drying chamber temperature was recorded to be 56.625°C and maximum ambient temperature was 35°C.

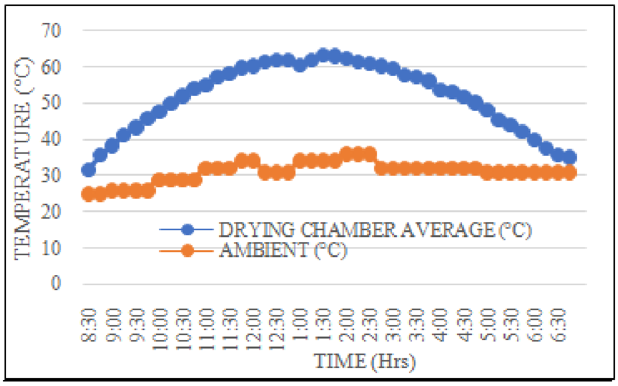

Fig. 8 variation of temperature over time for day 2

The average temperature inside drying chamber was 51.87°C and ambient temperature was31.12°C. The maximum temperature inside drying chamber on day 2 was 63.275°C while the maximum ambient temperature was recorded to be 36°C.

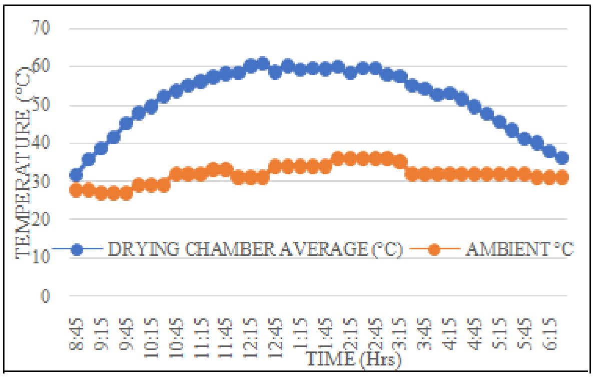

Fig. 9 variation of temperature over time for day 3

The average temperatures on day 3 were 51.60°C in drying chamber while the average ambient temperature was 31.93°C. The maximum temperature inside drying chamber was 60.875°C and maximum ambient temperature was 36°C.

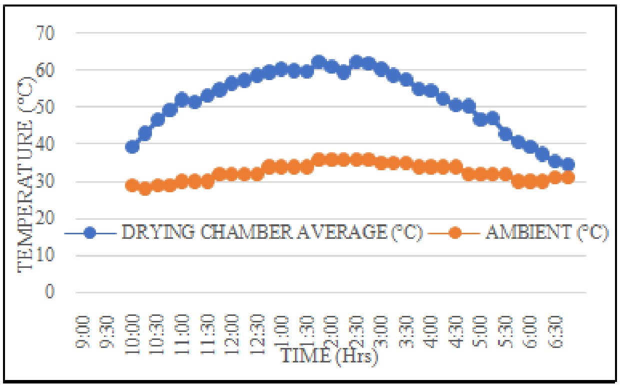

Fig. 10 variation of temperature over time for day 4

day 4 the average temperature inside, drying chamber was recorded as 51.98°C and average ambient temperature as 32.5°C while the maximum temperature inside drying chamber was 62.15°C and maximum ambient temperature was 36°C.

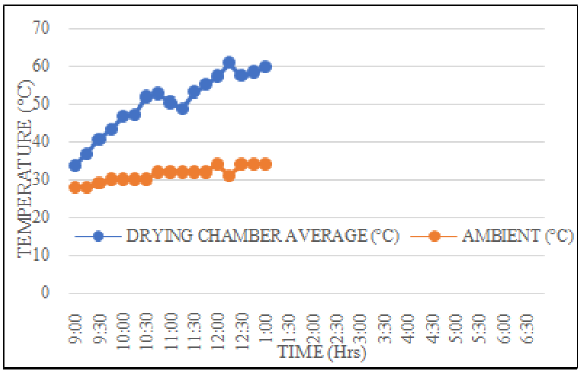

Fig. 11 variation of temperature over time for day 5

The average temperatures on day 5 were 50.22°C in drying chamber while the average ambient temperature was 31.30°C. The maximum temperature inside drying chamber was 60.775°C and maximum ambient temperature was 34°C.

Table below shows the reduction in weight along the trays for all days. From table it can be seen that the weight on tray 2, 3 and 4 increases on day 3 because the weight subtracted from day 1 and 2 is weight of shells after drying for two days whereas the initial moisture content was more because of the moisture content in shells. Also, some shells were not separated from kernel on second day from tray 2, 3 and 4 and were dried in dehydrator on third day which resulted in increase of weight on third day.

Table I Weight Distributionof Copra Along The Trays

	Tray 1 (in Kg)	**Tray 2 (in Kg)**	**Tray 3 (in Kg)**	**Tray 4 (in Kg)**	**Total (in Kg)**
Day1 (morning)	3.335	3.390	3.360	3.300	13.385
Day 1 (evening)	2.785	2.815	2.755	2.780	11.135
Day 2 (evening)	2.360	2.380	2.290	2.375	9.405
Day 3(evening)	2.285	2.610	2.355	2.735	9.985
Day 4 (evening)	2.010	2.055	1.865	2.050	7.980
Day 5 (afternoon)	1.960	1.980	1.825	1.935	7.700
Coconutshellweight	1.755	1.745	1.645	1.710	6.855

The pictures below show the dried copra along all trays.

Fig. 11 Dried sample of tray 1

Fig. 12 Dried sample of tray 2

Fig. 13 Dried sample of tray 3

Fig. 14 Dried sample of tray 4

The oil was extracted al local milling machine on fifth day.

Fig. 15 Oil extracted on day 5

VI. Conclusions

Coconut is cultivated throughout the southern cost of India. Coconuts are widely consumed by the people of tropical regions across the world. It is important for coconut farmers to realise adequate crop returns and minimise losses. This research was an attempt to minimise wastage as well as preserve nutrients and extract oil.

An indirect natural convection coconut solar dehydrator was successfully designed, fabricated and tested. The materials used were locally available. The dehydrator was portable easy to move and handle. But big size of the dehydrator made it slight bulkier in weight.

Under no load conditions, the average temperature inside collection chamber reached to 41.5°C and that of drying chamber reached to 49.40°C while the average ambient temperature was 30.90°C. For loading conditions, the average temperature inside collection chamber reached to 43.745°C and that of drying chamber reached to 50.80°C while the average ambient temperature was 31.73°C.During the drying test the temperatures in peak sunshine hours reached up to 70°C on bottommost tray(tray4) which resulted in some amount of damaged copra. Thus, peak temperatures of drying were obtained and any further increase in temperature would spoil(burn) the copra. The performance of the dehydrator was evaluated in which the moisture content in coconuts was reduced from 52% w.b. to 16.56% w.b. in 4.5 days i.e. 42.5 sunshine hours. The drying efficiency was 6.232%.About 7.700 kg of dried copra was obtained from 20kg of fresh coconut kernel halves. Unlike sun drying, the copra produced was free from dust, bird and rodents damage. The natural convection indirect solar dehydrator is suitable for producing high quality of copra for small to medium holders. Drying rate was calculated as 0.13376kg/hr. Since the roof of dehydrator was painted in black, it helped in increasing temperature inside drying chamber. Increase in the cloud cover decreased the temperature inside the dehydrator.

The device can also be used to dry other crops like chilies, raw mangoes, banana, tomatoes and many more which can be stored and used for months. The device can also be used to dry fish which is also other main occupation in Goa. Some modifications can also be made for the device to dry clothes. The device can also be equipped with thermal storage material so that it can be used during non-sunshine hours.

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