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Solar Cabinet Drying of Copra using Flat Aluminium sheet Reflector Assisted Evacuated Tube Solar Air Collector

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Abstract

Drying of copra is one of the important steps in the coconut to coconut oil extraction from copra. Traditionally copra is dried by sun drying, smoke drying or kiln drying and indirect hot air drying including solar drying, which improves quality of dried copra and considerable energy saving when it is coupled with other hybrid systems of drying. The objective of this study is to develop a forced convection solar dryer for copra using evacuated tube air collector and study its performance. The designed solar dryer consists of a cabinet drying chamber, evacuated tube with flat Aluminium reflector sheet assisted air collector, blower, and a chimney. The Drying parameters of moisture ratio (MR), moisture content (MC) and drying rate (DR) are calculated and their performance is compared with natural sun drying. The results of the study show that the Evacuated tube assisted solar dryer Collector temperature developed between 38^{o}C to 80.2^{o}C and efficiency varied from 36.15% to 64.69%.The moisture content of copra in solar dryer is reduced from 52.61% to 8.48%in 22 hours as compared to 40 hours in natural sun drying. In this solar dryer, the products are uniformly dried, and the MC of the copra is controlled. Both sun dried and solar dried copra is tested for its Potassium, Calcium, Magnesium and Phosphorus besides oil content, it is found that solar dried copra using evacuated tube with flat aluminium sheet assisted solar dryer retained Potassium and Phosphorous of 7.7% and 3.38% lower than sun dried copra. The solar dried copra retained Calcium and

Magnesium of 7.34% and 23.11% higher than sundried copra. The solar dried Copra contained 14.18% more oil than sun dried copra.

Keywords: Evacuated tube solar Collector, solar drying, Copra drying, open sun drying, Moisture ratio, Moisture content, Drying rate, Oil content of Copra, Mineral content of Copra

1. Introduction

India is one of the largest coconut producing countries in the world. Copra is one of the major traditional products processed from coconut. Copra is obtained by drying the meat, or kernel, of the coconut used to extract coconut oil. Mohanraj M and Chandrasekar P [1] conducted an experiment on copra drying and in the experiment the moisture content of copra was reduced from about 52% to 8% in order to concentrate the oil content. The traditional methods followed in India are sun and kiln drying. Both sun drying and kiln drying produce poor-quality copra and are time consuming. Thiruchelvam Thanaraj et al., [2] designed a kiln drying for copra in which smoke is in direct contact with the coconut cups results in low quality copra and smoke deposits forms polycyclic aromatic hydrocarbons in the copra. In open sun drying the drying rate of copra depends on solar radiation intensity, ambient temperature, wind velocity, relative humidity, and mass of the product per unit exposed area. The open sun drying has many disadvantages like degradation by wind-blown debris, insect infestation, rain, human and animal interference results in product contamination. The open sun drying of copra is labour intensive and there can be deteriorations in quality from deposits of dirt and dust and growth of microorganisms can increase the acid content, cause rancidity and reduce the amount of extractable oil resulting in low-quality coconut oil. Ayyappan S and Mayilsamy K [3] conducted experiment on drying copra in solar tunnel dryer and observed that in solar tunnel drying results in 85% good quality copra whereas open sun drying it is 53%. Solar drying can be coupled with kiln drying, will result in energy saving as well as drying can be continued which suits copra drying. Rajagopal S et al [4] designed evacuated tube indirect forced convection solar drier for copra and compared with natural sun drying, in which experimentally concluded that solar drying requires less time and results in improved quality. Mohanraj M [5] designed a solar ambient heat pump drier for copra drying and dried copra in indirect forced convection of 52% moisture content to 9.2% to 9.8% in 40 hours. It is reported in the literature that some hybrid driers also been tried one of them being solar drier with heat pump. Sachidananda Swain et al [6] designed biomass fired copra drier and dried copra using coconut shell as biomass heat source in which the moisture reduction of 57.4% to 6.8% is achieved in 22 hours with 81% milling grade I copra in climatic conditions of Andaman Islands. Arun S et al [7] designed a solar greenhouse natural circulation solar tunnel drier with biomass backup heater for copra drying and compared the drying time obtained practically and predicted mathematically the drying curves with page equation. Satter M A [8] designed a natural convection biomass fired portable drier and dried effectively and economically copra as a 50 kg batches. Udna H.K [9] studied the factors affecting the good quality copra in drying and concluded that temperature upto 70^{o}C and velocity of air are the parameters in determining the clean white copra in drying. Hii C.L et al [10] advocated solar drying in their book, Solar Drying: Fundamentals, Applications and innovations, advocated that the solar cabinet drying of Copra was found to be fastest drying method as compared to sun drying results in best quality. Asish D Choudhary et al [11] reviewed the solar drying technologies under direct solar drying, indirect solar drying, and mixed mode solar drying used for drying agricultural and industrial products. El-Sebaii et al [12] reviewed the description, fundamentals of solar driers and solar air heaters for direct and mixed modes of solar dryers. Sadodin S, and Kashani T.T [13] numerically simulated copra drying and found that the simulated drying curve reasonably matched with solar tunnel greenhouse drying of copra. Arun S et al [14] compared the drying of copra in solar greenhouse drying and natural drying and concluded that the solar greenhouse drying resulted better quality copra. Coconut and it's by products are available in different forms like coconut cream, spray dried coconut milk powder/skim milk powder, virgin coconut oil, coconut chips, desiccated coconut, vinegar, packed tender coconut water, shell charcoal, shell powder, activated carbon, coconut jaggery (sugar), Coconut Chips etc.

Solar dryers have been used in all parts of globe and extensive research has been carried out, aiming at the improvement of these systems. From the literature, it is found that most of these solar drying systems use flat plate air collectors of various designs and only a few of them considered a different type of collectors, One of them being natural and forced convection solar tunnel driers. Solar collectors with evacuated tubes are a special type, offering significant advantages compared to flat-plate collectors, such as higher efficiencies. Evacuated tube collectors, flat-plate ones alike, are classified into two broad categories, water and air-collectors, based on their heat transfer fluid. Vishal Dabra et al., [15] analysed the performance of air heater in radiator type arrangement of tubes using evacuated tube with the tilt angle of 30^o to 45^o and concluded that the performance of the evacuated tube with or without reflector is better at the tilt angle of 30^o and proved that beyond 30^o inclination of evacuated tubes had no positive effect on thermosyphon phenomenon inside the evacuated tubes and hence the performance. Liangdong Ma et al., [16] analysed the performance of evacuated tube with 'U' tube with and without copper ring fin between inner absorber tube and 'U' tube and concluded both experimentally and analytically that the copper ring fin increases the efficiency of the evacuated tube with 'U' tube collector. Siddharth Arora et al., [17] analysed the performance of evacuated tube with heat pipe assisted evacuated tube solar collector to supply heat to refrigeration through water as working medium and concluded that the air gap between the heat pipe inner tube and collector tube plays important role in the performance. Ashish Kumar et al., [18] studied the performance of evacuated tube assisted solar air heater as direct heating of the air in the glass tubes with and without reflector at different mass flow rate and concluded that with reflector assisted arrangement the outlet temperature and efficiency is maximum. Pin-Yang Wang et al., [19] conducted an experiment on 10 linked evacuated tube solar air heater with concentrating parabolic reflector with 'U' shaped copper tube and concluded that the system has high thermal performance, and the air gains heat gradually and proved through simulation that the outlet temperature of air can reach 200^{o}C. Selvakumar P et al., [20] conducted an experiment on evacuated tube evacuated tube solar collector using therminol D-12 as heat transfer fluid coupled with parabolic trough for water heating and concluded that the efficiency of therminol based evacuated tube collector coupled with parabolic trough is 40% more efficient than that of water based evacuated tube collector coupled with parabolic trough. Lamnatou Chr et al., [21] analysed the thermodynamic performance analysis of a solar tunnel dryer with an evacuated tube collector in which air heated directly in evacuated tubes and suggested same arrangement can be extended to industrial scale. Rabindranath Ramsaroop and Prakash Persad [22] determined the heat transfer coefficient and thermal conductivity for coconut kernels using an inverse method. Zhen-Hua Liu et al [23] studied the performance of copper oxide based Nano fluid using concentrating parabolic reflector assisted evacuated tube solar collector and noted that the outlet temperature can attain moderate to as high temperature as 170^{o}C at the air flow rate of 7.6 m^{3}/hr in winter period.

The major contents of copra are oil and proteins besides minerals of Calcium, magnesium, potassium, and phosphorus. In this experimental study, a novel forced convection solar active dryer with four trays is designed and developed with an evacuated tube air collector with Aluminium reflector to enhance the performance, and its performance is studied on copra and compared with natural sun drying. The mineral contents of both natural drying and solar drying are compared.

2. Experimental Setup

The solar drying system mainly consists of a drying chamber, evacuated tube collector with Aluminium reflector, a blower, and a chimney. The experimental setup is as shown in Figure -1. The size of the drying chamber used for the study is 460 mm x 460 mm x 535 mm which is made of stainless steel sheets of thickness 5mm and insulated on all sides with fiberglass insulation of thickness 50mm to prevent the loss of heat. The chamber consists of four Aluminium perforated trays to place the product for drying. A 125 mm diameter and 2250 mm length pipe is concentrically placed in the 300 mm diameter and 2250 length tube with 30 number of 12.7 mm GI pipes connected and is inserted in Evacuated Tubes to a length of 1300 mm. The collector header is divided into two parts, in first fifteen numbers of tubes the air flows in downward direction in the GI pipes and upward direction in the remaining fifteen numbers of tubes. The flat Aluminium sheets are placed below the evacuated tubes to enhance performance of the collector. The 300 mm diameter tube is insulated with 50 mm fiberglass insulation. The twin glass evacuated tube collector is made of borosilicate of 1.6mm thickness, and the gap between the glass tubes is evacuated. The inner tube of the collector is coated with a three-layer magnetron sputter coating. Heat loss due to convection, conduction, and radiation is minimized, and it can with stand high temperature. The length, inner diameter, and outer diameter of each tube are 1500 mm, 38 mm, and 48mm, respectively. The Collector has a dimension of 2250 mm X 1500 mm. The collector is placed at optimum tilt in accordance with the latitude and longitude of Chennai (13.084^{o}N, 80.27^{o}E) Tamilnadu, India along North-South direction, facing south so as to track maximum solar radiation throughout the day. This collector which is used as a heat source is connected to the drying chamber with the help of GI pipes and the pipes are insulated. A blower motor of 0.375 KW, with three speed regulator to control the rate of flow of air is attached at the inlet of the solar collector to blow air into the collector. A chimney of height 50 cm made of Standard wire gauge Galvanized sheet is used at the top of the chamber which increases the air flow rate inside the chamber due to convection. Temperature at different locations inlet and outlet temperatures of the collector, temperature of inlet, outlet of Drying chamber and four trays is measured with the help of k – type thermocouple (8 nos.) connected to 12 point data logger and display unit, besides a hygrometer is attached to measure relative humidity. The ambient temperature, relative humidity, and wind velocity are measured using a digital anemometer (Lutron AM 4201). Solar insolation is measured using a solar power meter (TENMARS-TM207). Air flow rate is measured at the exit of the collector with an orifice and 'U' manometer. A digital electronic balance is used for weighing the samples. The accuracy of instruments used in this experimental study is tabulated in the table-1.

Figure – 1 Experimental Setup

Table 1 Accuracies of the Measurements

Sr.No	Measuring Parameter	Accuracy
1	Temperature	±0.1^{o}C
2	Solar Intensity	± 10 W/m^2
3	Weight	± 0.1 g
4	Air flow rate-U tube manometer	±1 mm of water column
5	Relative Humidity	±1
6	Wind Velocity of air	±0.1 m/sec

Solar drying and natural sun drying experiments are carried out for copra. Fresh copra nut is broken into two parts; shell removed from copra and the initial moisture content is measured by oven-drying method, maintained at a temperature of 105°C for 24 hours by taking 624 grams as sample. Total of 11360 grams of copra is spread uniformly white portion facing downward on the trays for solar drying equally in all four trays (Figure - 2) and 1600 grams of copra was spread on a plate for sun drying. The blower motor is then switched on. The air that is passed through the evacuated tube collector gets heated up and is made to flow into the drying chamber, where copra is loaded in four trays. During the experiment, ambient temperature, relative humidity and wind velocity, solar insolation, inlet and outlet temperatures of the collector, and temperature of all the trays inside the chamber, temperature of the chimney are recorded (Table -2) on hourly basis from 8.30 am to 4.30 pm in the first week of December 2014 being a winter month.

Figure – 2 Drying of Copra in the Cabinet Dryer

Table –2 Hourly Variations of Relative Humidity and Wind Velocity during Copra Drying

Day/Time		8.30 A.M	9.30 A.M	10.30 A.M	11.30 A.M	12.30 P.M	1.30 P.M	2.30 P.M	3.30 P.M	4.30 P.M
Day-1	RH	77	59	59.5	54	47	47.5	49	48	55
	Wind Velocity m/sec	3.2	0.2	2.1	2	0.5	1.2	4	1.3	4.7
Day-2	RH	78.5	67.5	51	47	41.5	42.5	41.5	45.5	56
	Wind Velocity m/sec	3.4	1.5	0.7	3.7	1	1	4.3	1.5	0.3
Day-3	RH	80	75	69	68.5	56	55.5	52.5	56	72.5
	Wind Velocity m/sec	3.2	4.6	3.6	2.5	0.6	2.4	4.3	2.8	1.2

During the experiment, all the drying trays are weighed on hourly basis until the product acquires constant weight, that is, equilibrium moisture content. Every time after weighing the trays position is changed for uniform drying. The solar dried Copra (Figure - 3) and sun dried Copra (Figure - 4) is obtained after drying. The solar dried and sun dried samples of copra was tested (Table - 3) for its oil content, Phosphorous, Potassium, Magnesium and Calcium content at Chennai Testing Laboratory Pvt. Ltd, Chennai, a National Accreditation Board for Testing and Calibration Laboratories (NABL) approved Laboratory.

Figure – 3 Solar Dried Copra

Figure – 4 Sun Dried Copra

Table –3 Laboratory Analysis of Dried Copra

Name of the mineral/ Nutrient	Oil Content g/100g	Potassium mg/100 g	Calcium mg/100 g	Magnesium mg/100 g	Phosphorus mg/100 g
Solar Drying	63.45	851.91	113.38	103.19	202.06
Sun drying	55.57	922.56	105.63	83.82	209.12

3. Data Analysis

3.1 Determination of Moisture Content

The initial mass (m_i) and the final mass (m_f) of the sample are recorded at an interval of every one hour till the end of drying using the balance. The moisture content on wet basis (M_{wb}) is given as

$$\text{Moisture content } M_{wb} = \frac{m_i - m_f}{m_i} \qquad (1)$$

3.2 Determination of Moisture Ratio (MR)

The instantaneous moisture (M) at one hour interval is calculated from the drying data, the initial moisture content (M_o), and equilibrium moisture content (M_e) are calculated from the drying data. Then the moisture ratio at any time interval is given by

$$\text{Moisture Ratio MR} = \frac{M - M_e}{M_o - M_e} \qquad (2)$$

3.3 Determination of Drying Rate (DR)

The instantaneous dried mass per kg (m_t and $m_{t+\Delta t}$) at one hour interval (Δt) is calculated from the drying data. Then the drying rate at any time interval is given by

$$\text{Drying Rate DR} = \frac{m_t - m_{t+\Delta t}}{\Delta t} \qquad (3)$$

3.4 Determination of Efficiency of the Evacuated Tube Collector

The inlet temperature (T_{in}) and outlet temperature (T_{out}) of the Evacuated tube collector are recorded at one hour time interval. The mass flow rate (m_c) of the air is recorded. The solar insolation (I) is recorded at one hour time interval. With aperture area (A_p = 2 x L x D, L= Length of the evacuated tubes and D = Diameter of the Evacuated tubes), Specific heat of air (C_{pc}) and number of Evacuated Tubes (N) are known; the efficiency of the evacuated tube is given by

$$\text{Evacuated tube collector efficiency} = \frac{m_c\, C_{pc}\,(T_{out} - T_{in})}{N A_p I} \qquad (4)$$

4. Results and Discussion

4.1 Experimental Evaluation of Collector Performance

For the evaluation of Evacuated tube with flat Aluminium sheet reflector assisted collector performance, the measurements were taken for three different flow rates of 170 kg/hr, 190kg/hr, and 205 kg/hr during the dry run and 205 kg/hr is selected for actual drying experiment according to the need of the copra drying. It is observed from table-2 that the ambient temperature of the air varied from a minimum of 25.9°C and the maximum of 30.5°C .The relative humidity of air varied from a minimum of 41.5% to a maximum of 80%. The ambient air temperature increases from 8.30 A.M to 2.30 P.M and decreases from 2.30 P.M to 4.30 P.M. The relative humidity almost follows the similar pattern with ambient air temperature. The wind velocity varied from 0.2 m/sec to 4.6 m/sec. The wind velocity do not have any correlation either with ambient temperature or with relative humidity. The inlet temperature of air to the collector varied from 28.5°C to 35°C (Figure 5). The exit temperature of the collector varied from 47.4°C to 80.2°C. The inlet temperature increases from 8.30 A.M to 1.30 P.M. and decreases from 1.30 P.M to 4.30 P.M. The exit temperature of the collector increases from 8.30A.M to 12.30P.M and decreases from 12.30P.M to 4.30P.M. This trend is almost followed in all the three days of drying.

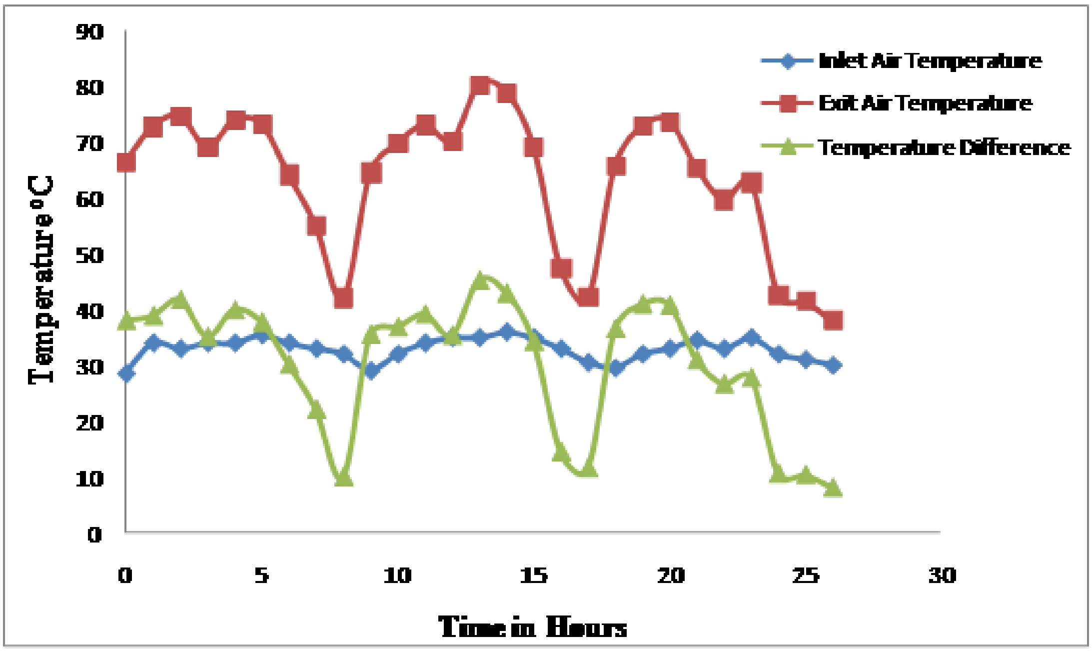

Figure – 5 Variation of Air Inlet, Exit Temperatures and Temperature Difference

The solar radiation varied from 240 W/m^2 to 1295W/m^2 during drying period of three days (Figure 6). The radiation intensity gradually increases from 8.30 A.M and peaks at 12.30 P.M. then gradually decreases till 4.30 P.M and it reaches minimum at 4.30 P.M. Almost a similar pattern is observed for all the three days. The Figure -7 shows the variation of collector efficiency during the three days of drying period. The collector efficiency varied from a minimum of 36.15% and a maximum of 64.69%. The collector efficiency increases with increase in solar radiation and it attains a maximum of 64.07% at end of the day one of drying and the same pattern followed in the subsequent days. Vishal Dabra et al [15] have noted an efficiency of similar nature in their analysis of evacuated tubes air heater.

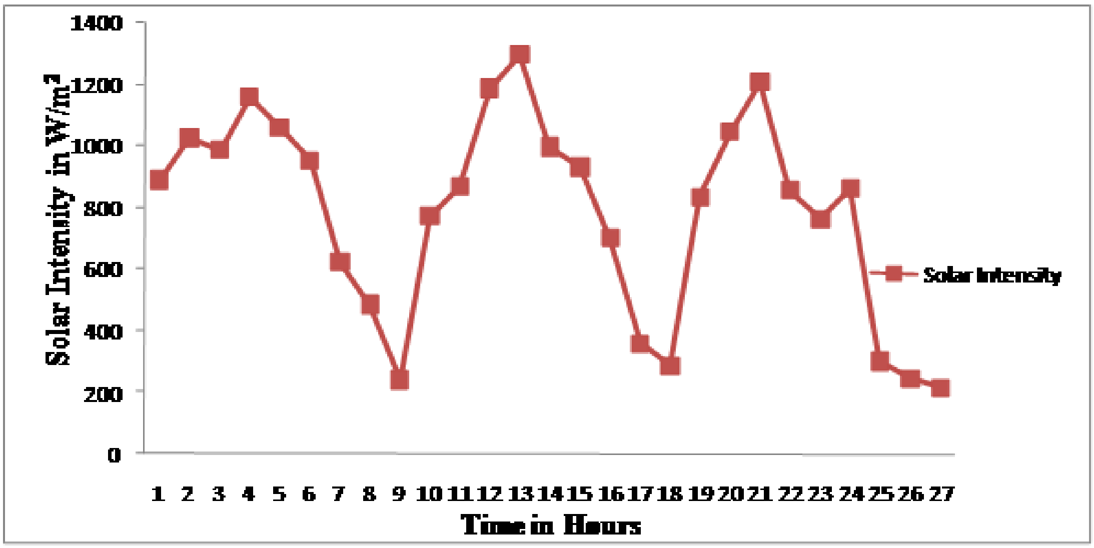

Figure – 6 Variation of Solar Intensity for three days during Copra Drying

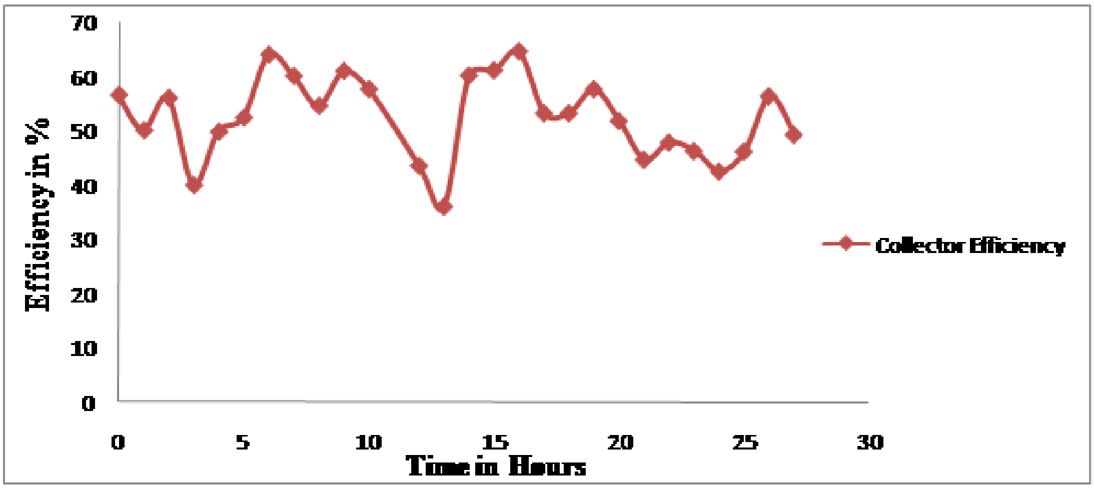

Figure – 7 Variation of Evacuated Tube Collector Efficiency three days during Copra Drying

4.2 Thin Layer drying of Agriculture Products

The temperature rises that can be obtained with this Evacuated Tube with flat Aluminium sheet assisted solar collector are appropriate for agriculture product drying. The Evacuated Tube Solar Collector connected to a Cabinet drying chamber. The drying chamber consists of four trays which are loaded with copra for drying. Some 1600 grams of copra was spread on a plate for sun drying. The dried products of solar drying and sun drying are obtained after 22 hours and 40 hours respectively.

4.3 Copra Drying

The product loaded was copra having an initial moisture content of 52.61% (wb). The final moisture content of 8.48% is obtained in 22 hours of solar drying, whereas sun drying took 40 hours. The experimental conditions of copra are shown in Table -2, while the variation of moisture content (MC) (Figure 8) and moisture ratio (MR) (Figure 9) are illustrated. It is observed that the moisture removal is high initially and then gets reduced exponentially; this may be because of surface moisture is removed first from the copra surface and followed by the bound moisture from internal part of product to its surface. This can be correctly observed Figure -8 and Figure -9 in solar drying the slope of the curve during 7^{th} hour to 8^{th} hour of drying is less, whereas from 8^{th} hour to 9^{th} hour slope of the curve is higher. This because of at the end of the 8^{th} hour the drying stopped and the copra was preserved in plastic covers, during night time the diffusion of moisture to upper layers resulted in higher slope during 8^{th} hour and 9^{th} hour. The same pattern is repeated during next day 16^{th} and 17^{th} hour of drying. It is observed that after 22 hours solar drying and 40 hours of sun drying the slope is flat, this shows the copra obtained equilibrium moisture content.

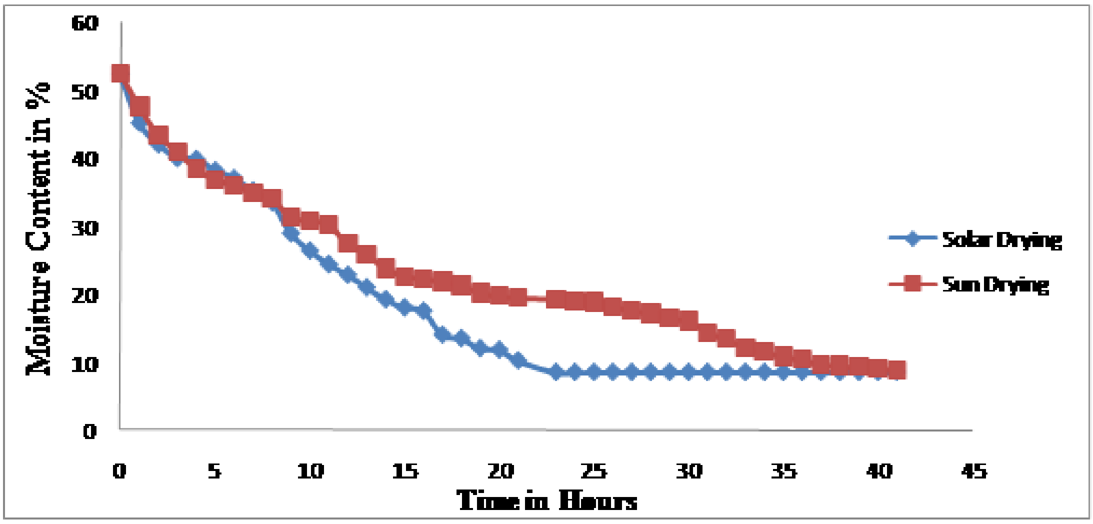

Figure – 8 Variation of Moisture Content in Copra Drying

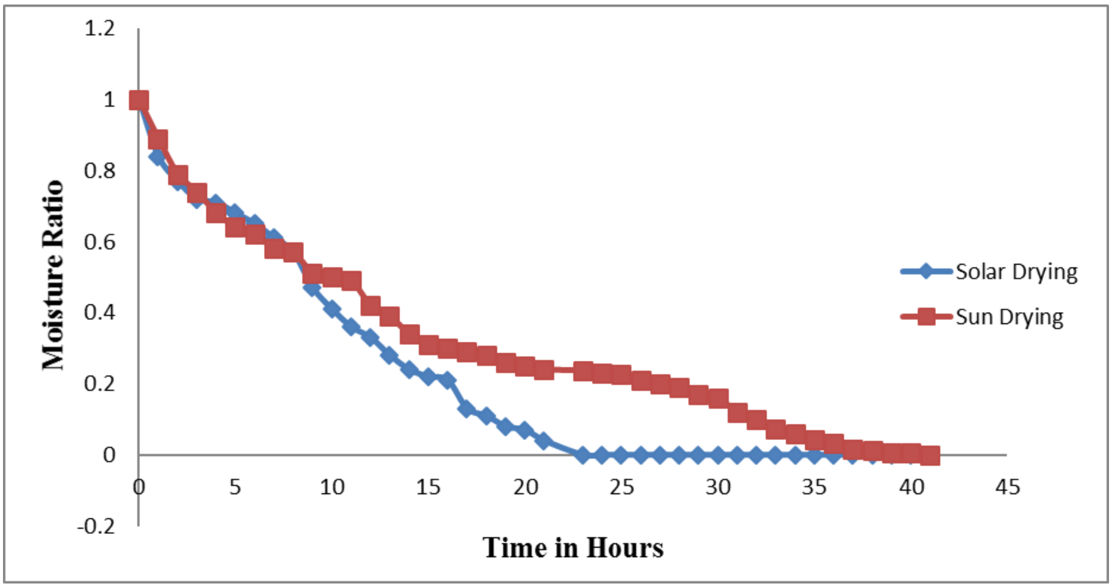

Figure –9 Variation of Moisture Ratio in Copra Drying

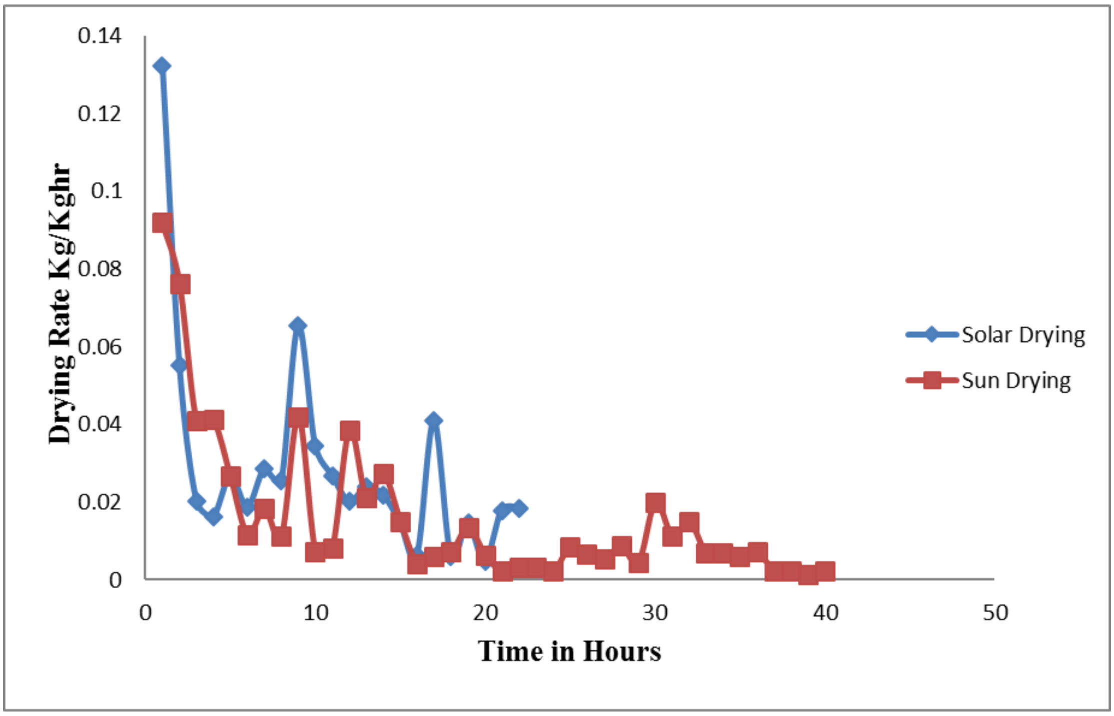

Figure -10 Variation of Drying Rate in Copra Drying

Figure -10 shows drying rate (DR) for both sun drying and solar drying. A similar observation as above is absolved in solar drying that the drying rate is maximum in the initial hours and first hour of day-2 and day-3 that is from 8^{th} to 9^{th}

and 16th to 17th hour of drying rate is more. Figure-3 and Figure -4 shows the solar dehydrated copra was excellent in colour, flavour and good in texture compared to sundried copra. Evacuated tube with flat aluminium sheet assisted solar dried product retained the minerals (Table -3) of phosphorous and potassium of 3.38% and 7.7% lower than sun dried copra. This may be due to sun drying is at a lower temperature than solar drying .The Solar dried copra retained minerals of calcium and magnesium of 7.34% and 23.11% more than sundried copra. The higher calcium and magnesium retention may due to shorter drying time. The evacuated tube with flat aluminium sheet assisted solar dried copra retained 14.18% more oil than natural sundried copra. The lower oil content of sundried copra may due to fungi of Rhizopus sporangia, Aspergillus niger, Aspergillus flavus, and penicillium glaucum at different moisture contents during non-drying hours of storage.

5. Conclusion

The Evacuated Tube collector with Aluminium sheet assisted dryer used in the present study reduces the drying period of copra considerably. Solar drying of copra takes nearly half the time as compared to natural sun drying. The minimum drying period of 22 hours is required for copra to achieve equilibrium moisture in evacuated tube solar dryer, whereas the time taken by sun drying is 40 hours. It is observed that copra drying requires two day and a night for continuous drying, which is the requirement in copra drying. The evacuated tube with aluminium sheet assisted solar drier may be coupled with some hybrid driers, so that the drying cost is reduced considerably. The Evacuated tube solar drier collector efficiency varied from 36.15% to 64.69%. The drying process is controlled in evacuated tube solar drying. The most important advantage of using evacuated tube solar dryer is that it can be used to dry products even during winter season. In this dryer the wind velocity has no effect on evacuated tube collector performance, since it makes use of evacuated tube collector. The evacuated tube with flat aluminium sheet assisted solar dried copra contained 14.18% more oil than sun dried copra. The lower oil content of sundried copra may due to fungi of Rhizopus sporangia, Aspergillus niger, Aspergillus flavus, and penicillium glaucum at different moisture contents during non-drying hours of storage. Evacuated tube with flat aluminium sheet assisted solar dried product retained the minerals of phosphorous and potassium of 3.38% and 7.7% lower than sun dried copra. The lower phosphorous and potassium retention may be due to higher temperature at which the solar drying takes place than sun drying. The Solar dried copra retained minerals of calcium and magnesium of 7.34% and 23.11% more than sundried copra. The higher calcium and magnesium retention may be due to shorter drying time in solar drying than natural sun drying.

References

1. Mohanraj M, and Chandrasekar P, Drying of copra in a forced convection solar drier, 2008, Bio Systems Engineering, 99: 604 – 607

2. Thiruchelvam Thanaraj, Nimal D.A. Dharmasena, and Upali Samarajeewa, Comparison of quality and yield of copra processed in CRI improved kiln drying and sun drying, 2007, Journal of Food Engineering, 78:1446-1451.
3. Ayyappan S and Mayilsamy K, Experimental Investigation on a Solar tunnel dryer for copra drying, 2010, Journal of Scientific and Industrial Research, 69:635-638.
4. Rajagopal T, Sivakumar.S, and Manivel R, Development of Solar Dryer Incorporated With Evacuated Tube Collector, 2014, International Journal of Innovative Research in Science, Engineering and Technology, 3(3): 2655-2658.
5. Mohanraj M, Performance of a solar-ambient hybrid source heat pump drier for copra drying under hot-humid weather conditions, 2014, Energy for Sustainable Development, 23.165-169.
6. Swain, S., Din, M., Chandrika, R., Sahoo, G. P., & Roy S. D, Performance Evaluation of Biomass Fired Dryer for Copra Drying: A Comparison with Traditional Drying in Subtropical Climate, 2014, Journal of Food Process Technology, 5(1): 1-5
7. Arun, S., K. Velmurugan, and S. Shankar Balaji, Experimental Studies on Drying Characteristics of Coconuts in a Solar Tunnel Greenhouse Dryer, 2014, International Journal of Innovative Technology and Exploring Engineering, 4(5): 51-55
8. Satter, M. A, Design and Development of a Portable Copra Dryer, 2003, International Conference on Mechanical Engineering, 1-5
9. Udana, Hewapathage Kasun, Study the factors affecting the production of good quality copra, 2012, University of Moratuwa.
10. Hii C.L, Jangam S.V, Ong S.P and Mujumdar A.S, Solar Drying: Fundamentals, Applications and Innovations, 2012, ISBN: 978-981-07-3336-0.
11. Chaudhari, Ashish D., and Sanjay P. Salve, A Review of Solar Dryer Technologies, 2014, International Journal of Research in Advent Technology, 2.2: 218-232.
12. El-Sebaii, A. A., and S. M. Shalaby, Solar drying of agricultural products: a review, 2012, Renewable and Sustainable Energy Reviews, 16(1):37-43.
13. Sadodin, S., and T. T. Kashani, Numerical investigation of a solar greenhouse tunnel drier for drying of copra, 2011, *arXiv*:1102.4522
14. Arun, S., S. Ayyappan, and V. V. Sreenarayanan, Mathematical Modeling of Solar Tunnel Greenhouse Dryer for Describing the Drying Kinetics of Copra, 2014, International Journal of Innovative Technology and Exploring Engineering, 4(5):61-67
15. Vishal Dabra, Laxmikant Yadav, and Avadhesh Yadav, The effect of tilt angle on the performance of evacuated tube solar air collector: Experimental Analysis, 2013, International Journal of Engineering, Science and Technology, 5(4): 100-110

16. Liangdong Ma, Zhen Lu, Jili Zhang, and Ruobing Liang, Thermal performance analysis of the glass evacuated tube solar collector with U-tube, 2010, Building and Environment, 45: 959-1967.
17. Siddharth Arora, Shobhit Chitkara, R. Udayakumar and Muhammad Ali, Thermal analysis of evacuated solar tube collectors, 2011, Journal of Petroleum and Gas Engineering, 2(4): 74-82.
18. Ashish Kumar, Sanjeev Kumar, Utkarsh Nagar, and Avadhesh Yadav, Experimental Study of Thermal Performance of One-Ended Evacuated Tubes for Producing Hot Air, 2013, Journal of Solar Energy, (Hindawi Publications), Article ID 524715.
19. Wang, P. Y., Guan, H. Y., Liu, Z. H., Wang, G. S., Zhao, F., & Xiao, H. S, High temperature collecting performance of a new all-glass evacuated tubular solar air heater with U-shaped tube heat exchanger, 2014, Energy Conversion and Management, 77: 315-323.
20. Selvakumar P , Somasundaram P, and Thangavel P, An Experimental Study on Evacuated Tube Solar Collector using Therminol D-12 as Heat Transfer Fluid Coupled with Parabolic Trough, 2014, International Journal of Engineering and Technology, 6.1: 110-117
21. Lamnatou Chr, Papanicolaou E, Belessiotis V, Kyriakis N, Experimental investigation and thermodynamic performance analysis of a solar dryer using an evacuated-tube air collector, 2012, Applied Energy, 94: 232-243
22. Ramsaroop, Rabindranath, and Prakash Persad, Determination of the heat transfer coefficient and thermal conductivity for coconut kernels using an inverse method with a developed hemispherical shell model, 2012, Journal of Food Engineering, 110(1): 141-157.
23. Liu, Z. H., Hu, R. L., Lu, L., Zhao, F., & Xiao, H. S, Thermal performance of an open thermosyphon using nanofluid for evacuated tubular high temperature air solar collector, 2013, Energy Conversion and Management, 73: 135-143.