International Journal of Engineering Applied Sciences and Technology, 2020
Vol. 4, Issue 9, ISSN No. 2455-2143, Pages 294-298
Published Online January 2020 in IJEAST (http://www.ijeast.com)

FIELD BASED COMPARATIVE ANALYSIS OF A DIRECT TYPE, NATURAL CONVECTION SOLAR BOX DRYER

Shribalaji Shenbagaraj
Masters in Energy Systems, University of Petroleum and Energy Studies
Dehradun, Uttarakhand, India

Abstract— **The dehydrating temperature for most of the agricultural and food products range between 55˚C - 65˚C. This work deals with the experimental investigation of a direct type, natural convection solar box dryer typically working between the temperature ranges of 40˚C - 80˚C. The dryer was designed and fabricated to work at a latitude of 10.7560˚N and longitude of 78.6513˚E. The dryer consists of a stainless steel Flat plate collector - FPC (Area - 0.3 m²) placed at an angle of 20.7905˚N. Evenly sliced pieces of pineapple were used as sample to investigate the drying performance on the basis of certain specific drying parameters such as: % reduction in moisture, amount of evaporated water, mass shrinkage ratio and drying rate of the sample. The results were compared with a simultaneous Open Sun Drying (OSD) as well as Electric Oven Drying (OTG oven at 80˚C). Practical Examinations of the dryer revealed that, pineapple which was initially at a mass of 100 g was reduced to a mass of 16.1 g after 7 hours of drying by the developed setup, removing 83.9 % of moisture content from the sample in % - wet basis. Whereas in case of OSD and Oven Drying 83.9 % and 84.1 % of moisture content was removed from the sample in a time span of 12 hours and 7 hours respectively. It has been practically observed that the absorber plate reaches an average temperature of 79.5˚C during the peak working hour when the solar Irradiance value reaches a peak value of 1128 W/m².**

Keywords— **dehydrating; Natural Convection; FPC; solar dryer; glazing; Irradiance.**

I. INTRODUCTION

Solar energy is one the most important renewable source of energy and is globally preferred over other conventional sources of energy such as fossil wood, coal, natural gas, diesel, and petroleum etc, Banwal et al (2008). This is so because it is available in abundant, inexhaustible, cheap and environment friendly, Tiwari (2002). On an average the earth receives about 4,000 trillion kWh of energy every day in the form of electromagnetic radiations from the sun, Gupta (1999). Thus, the use of solar energy would prove to be quite feasible in tropical regions where at least six hours of clear sunshine may be received everyday with an average solar irradiance of 500-900 W/m².

India, being a tropical nation located between 7˚N and 37˚N latitude receives more than the required amount of sunshine. In majority of parts of the country the average daily solar radiation varies between 5 to 7 kWh/m². There is an average of 200 to 300 clear sunny days in a year and hence it receives about 5,000 trillion KWh of solar energy per year, Banwal (2014). This excessive amount of solar energy can harnessed and converted into thermal applications especially for drying of crops and food products. In most of the rural areas of the nation, there is massive scope for the application of various solar drying techniques due to the lack of affordable fuel facilities. It will also lead to the mitigation of CO_2 emissions by saving the amount of fossil fuels consumed for similar drying applications, Kumar el al (2005).

Solar drying is a process of removing the moisture content from a wet material by evaporation for preservation purposes. In usual case of solar drying, heat is transferred from a high temperature medium (Absorber Plate) to the air above the plate, thereby increasing the temperature of air and this heat from the air is further transferred to the outer surface of the product to be dried making the outer surface hot. A part of this heat energy enters into the interior of the product thereby causing a rise in its temperature which leads to the formation of water vapour at the surface of the product. The remaining part of the heat is utilized in evaporating the water vapour surface which is carried away in the form of natural convection or forced convection.

A. Modes of Solar Drying

The mode of drying, in the presence of solar energy, depends upon the method of solar energy collection and its conversion to useful thermal energy. Generally solar drying can be categorized into three major modes (i) open sun, (ii) direct and (iii) indirect modes, Barnwal et al (2008).

Open Sun Drying (OSD): In case of OSD the product to be dried is openly exposed to solar radiation for a number of hours or days in order to achieve the desired reduction in the moisture level of the product. OSD is quite popularly used in places where there is scarcity of adequate amount of fuel supply and lack of resources.

International Journal of Engineering Applied Sciences and Technology, 2020
Vol. 4, Issue 9, ISSN No. 2455-2143, Pages 294-298
Published Online January 2020 in IJEAST (http://www.ijeast.com)

However, in case of OSD the products are exposed to deteriorating conditions such as Climatic changes, sedimentation of dust and other particles, contaminations from rodents and insects etc. which tend to reduce the quality of the product.

Direct Solar Dryers (DSD): DSD are simple box type dryers which are extremely easy to design and fabricate. These are also referred to as cabinet dryers in which the solar radiation is directly absorbed by the product kept in trays inside the box or cabinet. Holes may be provided in order ensure the inlet and outlet circulation of air by natural convection phenomena, Kamble (2016). Air vents may also be provided to permit the discharge of evaporated matter from the system. DSD's are the most feasible and sought after technique for drying products at temperatures below 100˚C.

Indirect Solar Dryers (ISD): Indirect solar dryers generally comprises of two different parts.

A solar collector and a separate drying chamber with a chimney or air exhaust, Aggarwal (2018).

Note that the solar collector is same as that in case of DSD without the trays.

Since a separate drying chamber is provided, the hot air from the collector is blown inside the chamber by forced convection or natural convection, where the trays are placed for the drying process.

The drying time in case of ISD is more as compared to DSD since the products are not directly exposed to the solar radiation, however drying rate can be improved by employing a forced convection model.

The developed solar dryer for the present work is a direct type, natural convection box solar dryer.

The dryer consists of stainless steel (SS) flat plate collector without any heat absorbing coating.

The main reason behind eliminating the idea of special surface coating was the fact that SS naturally possesses a reflective shiny surface which can effectively reflect majority of the shorter wavelength solar radiations (Higher Temperature).

Consequently increasing the temperature of the air space provided between absorber plate and glass top, since this temperature is retained inside the drying cabinet by trapping the heat with the help a simple glass top which serves as glazing.

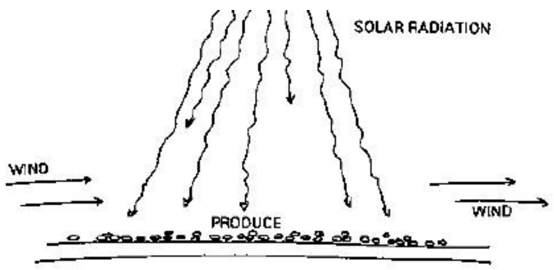

Fig. 1. Open sun drying

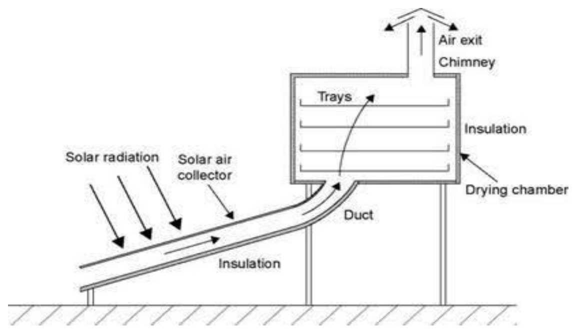

Fig. 2. Indirect solar drying

II. MATERIALS AND METHODS

The experimental setup is a typical flat Plate collector with a wooden outer case and stainless steel absorber plate. The collector top is glazed using simple clear glass of thickness 4mm. Holes of 12.5mm each have been drilled at the top and bottom along the side phases of the collector casing to permit the inward and outward flow of air through natural convection.

Fig: 3 represents a pictorial view of the developed box type solar dryer. The calculated base insulation thickness was 3cm. Certain assumptions and considerations were made in order to over the practical constrains, these are as follows.

- Mass flow rate of air is assumed to be constant i.e. $\dot{m}$ = 2.85 Kg/s
- Initial mass of the sample (M_i) = 100 g
- Latent heat of fusion for pineapple,(H_{fg}) =289 KJ/Kg (ASHRAE Handbook, 2006).
- Specific heat capacity of pineapple (C_p) = 3.85 KJ/Kg ºK (ASHRAE Handbook, 2006).
- % Moisture Content present (Wet Basis) = 86.50 % (ASHRAE Handbook, 2006)

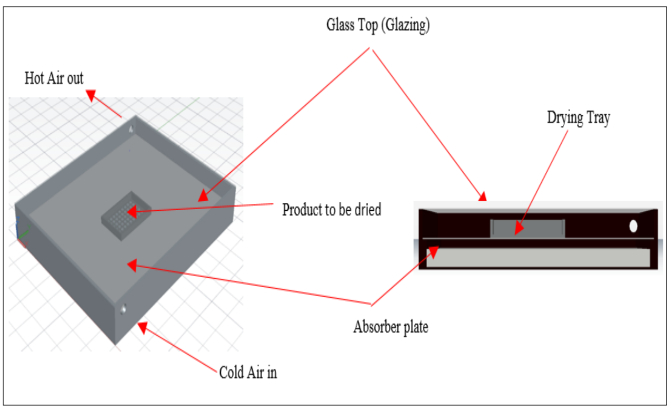

Fig. 3. Developed Solar Box Dryer

B. Procedure

Evenly sliced pieces of pineapple, rinsed thoroughly in water, were taken for the experimental investigation. Three such batches of sample weighing 100 grams each were taken and three separate modes of drying were employed in order to examine the variations in drying parameters and to obtain comparison curves under various boundary conditions.
Surface temperature measuring sensors (Surface Thermocouples) were used to monitor the change in the surface temperature of the absorber plate with respect to the change in time (per hour), ambient temperature (˚C) and irradiance (W/m²)
The change in the ambient temperature were observed using a simple alcohol filled hygrometer by examining change in the wet bulb and dry bulb temperatures with respect to time.
All the three batches of samples were loaded in the solar dryer, OSD and OTG oven respectively at 9:30 am in the morning simultaneously.
The main reason behind simultaneous loading of samples was to determine the instantaneous change in mass of the samples at every 60 minutes of drying for all three modes of drying in order to ease the comparison.
Periodic solar irradiance and the corresponding wind speed was monitored in a time range of every 60 minutes using a pyranometer.

C. Mathematical Equations Employed

Mass Flow Rate of Air (ṁ): The determination of mass flow rate of air into the collector/system plays a vital role to examine the drying parameters in case of natural convection flow. It is the product of density of air kg/m³ (ρa) under standard conditions, the collector area m² (Ac) and the periodic wind speed m/s (Vw)

$$M_{wb} = \frac{M_i - M_t}{M_i} \tag{2}$$

Mass Shrinkage Ratio (SR): It determines the amount by which shrinkage had occurred during drying the sample. It is the ratio of Instantaneous mass (M_t) of the sample at every time interval of 60 minutes to the Initial mass of the sample (M_i)

$$SR = \frac{M_t}{M_t} \tag{3}$$

Mass of Evaporated Water (Mw): There are many approaches to determine the mass of evaporated with the help of Fick's law of diffusion which may involve various mathematical models but a more simpler and easier way of determining is by the difference between the reduction in masses at every time interval of 60 minutes. It may be noted that 0.1 kg of sample was reduced to mass of 0.0161 kg after 7 hours of drying in the developed dryer which clearly indicates that 0.0839 kg of water was removed from the sample in the due course of time.

Drying Rate (k): Drying rate is the rate of reduction in moisture content of the sample (% Mwb) with respect to drying time taken (t) in hours.

$$K = \frac{M_{wb}}{t_d} \tag{4}$$

D. Technical Specifications of the system

TABLE I
TECHICAL SPECIFICATIONS

Component Description	Material	Area/ Specifications
Collector outer case	Ply Wood	0.3 m^2
Absorber Plate	SS AISI-304	0.57m x 0.47m x 0.0002m
Glazing	Simple Glass (Clear)	0.0004m Thick
Base Insulation	PU Foam	0.03m Thick
Hygrometer	-	Alcohol Filled
Temperature Sensors	-	Surface type
Temperature Indicator	-	Digital Type
Drying Tray	GI and AL	
Sample	Pineapple (3 batches)	Less than 0.0005m Thick

TABLE II
TECHNICAL SPECIFICATION OF OVEN

Product	Bajaj, Oven, Toaster, Griller
Wattage	1200 Watts
Voltage	230 Volts – 50 Hz
Capacity	16 litres
Net Quantity	One unit

III. EXPERIMENTAL RESULTS AND DISCUSSIONS

A. Comparison Plots

The comparison results were represented in a graphical form. The comparison curves indicate the change in various drying parameters such as, Instantaneous mass, % reduction in moisture content of the sample, Mass of evaporated water vapour, Mass shrinkage ratio and drying rate with respect to the change in time in all three modes of drying.

Fig. 5. Represents the comparison curves of % reduction in moisture content of the sample with respect to the change in time in all three modes of drying.

International Journal of Engineering Applied Sciences and Technology, 2020
Vol. 4, Issue 9, ISSN No. 2455-2143, Pages 294-298
Published Online January 2020 in IJEAST (http://www.ijeast.com)

It can be noted the curves corresponding to Oven drying and solar drying coincide with each other at various occasions.

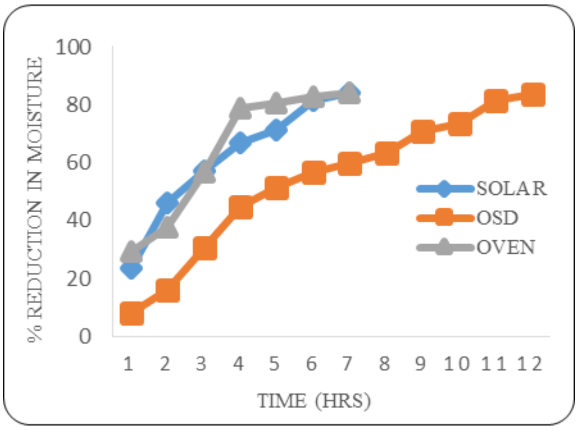

Fig. 5. Time VS % reduction in moisture

Fig. 6. Represents the comparison curves of Instantaneous mass of the samples with respect to the change in time in all three modes of drying. It must be noted that instantaneous mass of the sample is the measure of reduction in mass at a time span of 60 minutes each. The rate of reduction in mass of the sample in case of solar drying and oven drying appears to be more or less similar.

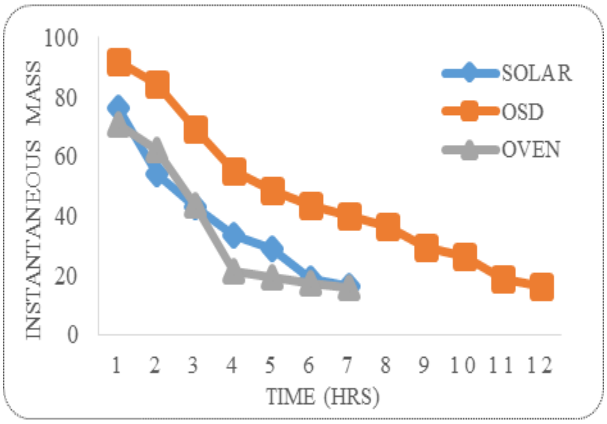

Fig. 6. Time VS Instantaneous mass

Fig. 7. Represents the Comparison curves of the mass of evaporated water from the samples in all three modes of drying. From the below curves it can be observed that the amount of water evaporated from the samples in case of solar drying is fairly similar to that in case of oven drying.
From the analysis below it can be absorbed that the pattern at which the evaporation of moisture takes place in case of oven drying is random in nature, whereas that in case of solar drying is considerably steady in nature, this may enhance the quality of drying.

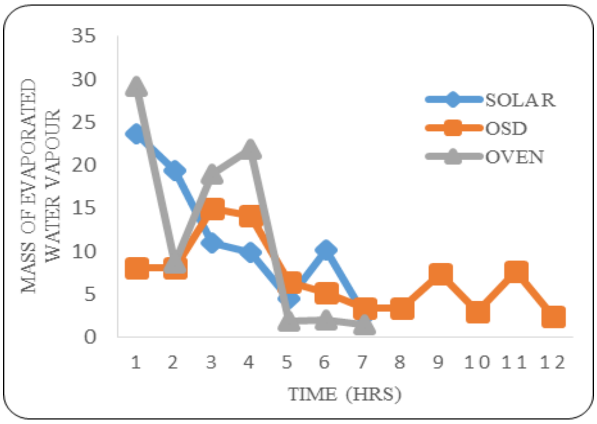

Fig. 7. Time VS Mass of evaporated water vapour

Fig. 8. Represents the comparison curves of mass shrinkage ratio of the samples in all three modes of drying. In the above case also, considerable similarities can be observed between the curves of solar drying and oven drying.

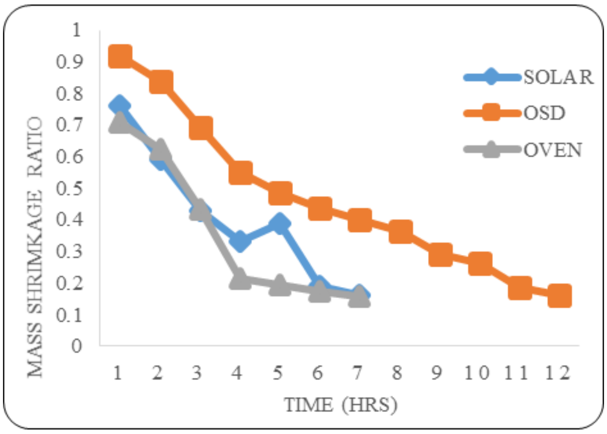

Fig. 8. Time VS Shrinkage Ratio

Fig. 9. Represents the comparison curves of drying rates in all three modes drying. The graph reveals that the characteristics of the curves in case solar drying and oven drying appears to similar to each other.

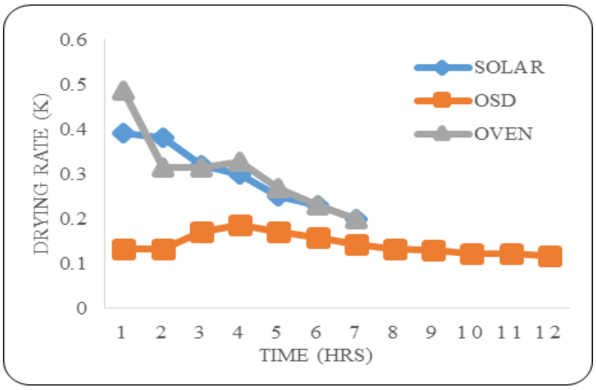

Fig. 9. Time VS Drying rate

TABLE III
NOMENCLATURE

Abbreviation	Descriptions
M_{wb}	% Reduction in moisture (Wet basis)
$\dot{m}$	Mass flow rate of air (Kg/s)
SR	Shrinkage Ratio
ρ_a	Density of Air (Kg/m^3)
A_c	Area of Collector (m^2)
V_m	Wind velocity (m/s)
M_i	Initial mass of sample (g)
M_t	Instantaneous mass of sample (g)
M_w	Mass of evaporated water vapour (g)
M_f	Final mass of sample (g)
I_n	Solar Irradiance (W/m^2)
t_d	Drying time (hours)
K	Drying Rate

B. Experimental Samples

METHOD	BEFORE DRYING	AFTER DRYING
Solar Dryer		
Open Sun Drying		
Oven Drying		

IV. CONCLUSION

The experimental and comparative analysis of various modes of drying revealed that the comparison curves involving the change in drying parameters such as, M_t, M_{wb}, SR, M_w and K with respect to time share a similar modulation in the case of developed solar box drying and oven drying. Whereas the characteristics of the curves differ significantly in the case of open sun drying. There was also a significant similarity in the drying time between solar drying and oven drying as compared to OSD. Thus, it had been concluded from the observations that solar box drying and Oven drying have similar drying characteristics and therefore solar box can be employed as an effective alternative for dehydrating desired products in domestic, Agricultural as well as in small scale industries. It may prove to be cost saving in regions where there is a scarcity of adequate fuel supply. It can be used for remote small scale farm produce drying with a minimal construction cost.

V. REFERENCE

[1] Barnwal P. and Tiwari A. 2008. Design, Construction and Testing of Hybrid Photovoltaic Integrated Greenhouse Dryer. *International Journal of Agricultural Research*, 3 (2), 272-301, (Pg.653-697).
[2] Kumar A. and Kandpal T.C. 2005. Solar Drying and CO2 Emissions Mitigation: Potential for Selected Cash Crops in India. *Solar Energy*, 78(2), 492-514.
[3] Gupta P.K 1999. Renewable Energy Sources-A long way to go in India. *Renewable Energy*, 16 (1-4), (Pg.318-342).
[4] Tiwari, G.N. 2002. Solar Energy: Fundamentals, Design, Delhi, Modelling and Applications. *Narosa Publishing House*, New Delhi, (Pg.303-317)
[5] Pradyuman Bamwal and G.N. Tiwari 2014, Solar Energy Technology For Drying Applications, 30th *National Conventions of Mechanical Engineers, Conference Paper*, (Pg.377-441).
[6] R.K. Aggarwal 2018, Review of Solar Drying Technology for Agricultural Crops, 7(1), (Pg.891-918)
[7] A.K. Kamble 2016, Thermal Performance of Natural Convection Air Heater with Thermal Storage for Drying Agricultural Produce, *IJPRET*, 5(2), (Pg.840-858)
[8] C. Phadke et al, 2015, Direct Type Natural Convection Solar Dryer: A review, *IJARSE*, 4(2), 2319-8354.
[9] Anil Motiram Patel et al, 2015, Theoretical model of circular solar collector for close water open air (CWOA) heated humidification and dehumidification, *International Journal of Renewable Energy and Environmental Engineering*, 3(1), 2348-0157, (Pg.256-262).
[10] Romdhane Ben Slama, 2009, Experimental investigation of Solar Drying for orange peels by forced convection, *International Symposium on heat and mass transfer in Sustainable energy*, Tunisia.
[11] Varun et al, 2012, Construction and Performance analysis of an Indirect solar Air Dryer integrated with solar Air Heater, *ICMOC*, (pp.3260-3269).
[12] Daniel Maisnam et al, 2016, Recent advances in Conventional drying of food, *J Food Technol Pres*, 1(1), (Pg.25-34).