International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Solar driers applied for drying of agricultural and foodproductswitha retrospective study

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Accepted 12 March 2017, Available online 16 March 2017, **Special Issue-7 (March 2017)**

Abstract

Solar drying has several advantages over the traditional drying method and it has been now modernized and developed for drying various agricultural and food products. Solar energy drying which is proven to be an environment friendly and economically viable in the developing countries. The working condition with respective to design of various solar driers with thermal drying factors has been reviewed.

Keywords: *Solar drying; Moisture content, dry basis and wet basis.*

1. Introduction

Agricultural products such as coffee, tobacco, tea, fruit, cocoa beans, rice, nuts, and timber generally require drying through a consistent application of relatively low heat. Nowadays, scientific and technological developments facilitate drying of industrial quantities in a day with preserved organoleptic characteristics (odour, flavour, texture and color) and nutritional quality. Traditionally, crop drying has been accomplished by burning wood and fossil fuels in ovens or open air drying under screened sunlight. Some of the researchers like B.M.A. Amer *et al* worked on a hybrid solar dryer in which uses direct solar energy and a heat exchanger. The dryer consists of solar collector, heat exchanger, reflector, cum heat storage unit and drying chamber. Drying was also carried out at night with stored heat energy in water which was collected during the time of sun-shine and with electric heaters located at water tank. Their research has claimed that The efficiency of the solar dryer was raised by recycling about 65% of the drying air in the solar dryer and exhausting a small amount of it outside the dryer. The colour, aroma and texture of the solar dried products were better than the sun drying products. J. Banout *et al* studied Double Pass solar drier and (DPSD) compared its performances typical cabinet drier (CD) and traditional open sun drier. The drying cost per one kilogram of chilli was 39% lower in case of DPSD (0.077 US$/kg) as compared to CD (0.126 US$/kg). The Double-pass solar drier was found to be technically suitable and economically viable for drying of red chillies in central Vietnam. The Double-pass solar drier was found to be technically suitable and economically viable for drying of red chillies.

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2. Types

2.1 Description of Double-pass solar drier

For each test chilli is weighed and spread out over the all trays and plastic sheet in a single layer. All drying units were loaded at maximum capacity during all experiments, which is having loading density 3.6kg m^{-2}.

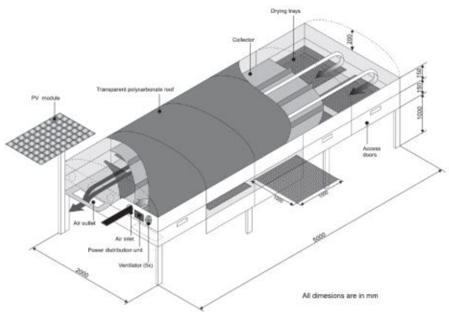

Figure 1: Description of Double-pass solar drier (DPSD)

Weight loss of samples in the DPSD, CD and open-air sun drying were measured during the drying period at 1 h intervals.

Performance calculations for DPSD

Performance of solar drying unit is evaluated and aa methodology proposed by Leon *et al.* The instantaneous moisture content (Mt) on a dry basis at any time can be calculated from the following equation:

$$M_t=[(M_o+1)\,W_t/W_o]-1 \qquad (1)$$

The drying rate can be evaluated by the decrease of the water concentration during the time interval between two subsequent measurements divided by this time interval. The drying rate (DR) equation:

$$DR = M_w/M_{ds} \times t \qquad (2)$$

Drying performance of both solar driers an dopen-air sun drying the overall system drying efficiency (gd),first day drying efficiency (g_{d1}), heat collection efficiency(g_c) and pick-up efficiency (g_p) were calculated. The system efficiency of a solar drier is a measure of how effectively the input energy to the drying system is used in drying product. In case of natural convection solar driers the overall system efficiency can be calculated by the following equation:

$$\eta_d = W * \Delta Hl = I * A * t \qquad (3)$$

Forced convection efficiency of solar driers needs to consider the energy consumed by the fan. The following equation is then used:

$$\eta_d = W * \Delta Hl = I * A * t + P_f \qquad (4)$$

Table:1 Economic evaluation comparison of new designed DPSD and CD

Parameter	DPSD	CD
Dried chilli obtained per annum (kg)	3724	258
Annual cost (US$)	289.1	32.6
Drying cost (US$/kg)	0.077	0.126
Payback period (years)	3.26	2.42
Total drier cost (US$)	2700	160

DPSD – Double-pass solar drier; CD – cabinet drier

2.2 Natural Convection Solar Dryer

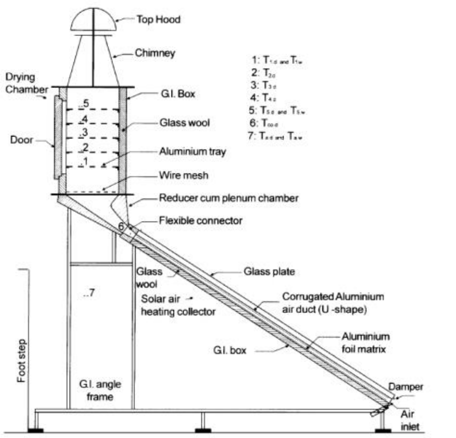

Figure2: Sectional details of natural convection solar dryer

A new natural convection solar dryer consisting of a solar air heater and a drying chamber was developed. This system can be used for drying various fruits and vegetables. In this developed solar drier, grapes were successfully dried. The qualitative analysis showed that the traditional drying, i.e. shade drying and open sun drying, dried the grapes in 15 and 7 days respectively, whereas the solar dryer took only 4 days with better quality raisins.

This type of drier consists of solar flat plate air heater, flexible connector, reducer-cum-plenum chamber with chimney and a supporting stand as shown in Fig. 2. In this solar air heater consists of an absorber (painted matteblack) with fins, glass cover, insulation and frame. The air duct is made from an aluminum sheet (0.5 mm thick and 1.95 m×0.73 m×0.03 m in size) from which air was passed. The U-shaped corrugations (11 in number) are attached with the absorber plate which is parallel to the direction of airflow. Aluminum fins (a matrix foil 0.15mm thick) were fitted to the back of the absorber. At the lower end of the collector (air inlet), shutter plates 4 mm thick and 0.08m×0.4 m in size, were also provided to stop the air flowing during the night. At the upper end(air outlet) of the collector, a flange portion was provided to connect the flexible connector with nuts and bolts. The air duct was made leak-proof with a good quality sealing material. The entire unit was placed in a rectangular box made from a galvanized iron sheet 0.9mm thick. The gap between the bottom of the air duct and the box was filled with glass wool insulation. This entire unit was enclosed in a galvanized iron sheet box of size 0.45 m×0.45m×0.7m and glass wool was filled in between the galvanized iron box and the aluminum box. For loading and unloading of the trays in the drying chamber a door was also provided with locking arrangement. To make it airtight the door was lined with sealing sponge rubber. At the bottom and top ends of the drying chamber Sponge rubber with 6 mm nuts and bolts was used for connecting all the parts. An extended outer rib was provided to connect the reducer-cum-plenum chamber and chimney, respectively. A chimney (Galvanized iron sheet) fitted at the top of the drying chamber. The researcher has found by five days of the experiment, that the rise in air temperature due to the forced air flow rate in the collector is sufficient for drying the grapes. The developed natural convection solar dryer is capable of producing the average temperature up to 55°C, which is considered to be optimum for dehydration of the grapes as well as for most of the agricultural fruits and vegetables. The drying air flow rate increases with increase in ambient temperature by the thermal buoyancy in the collector.

2.3 Cabinet-type natural convection solar dryer

A wooden rectangular box was cut and divided lengthwise into parallel channels of equal width. Solar radiation is transmitted through the single-layered transparent glass at the top and is absorbed on the blackened interior surfaces. The bottom of the dryer is insulated with thermocole sandwiched between an underside commercial board sheet and an inner side blackened metallic sheet. Owing to the trapped energy, the internal temperature increases. Holes are drilled through the base to permit fresh ventilating air to enter the cabinet. As the temperature rises, warm air passes out from the upper area by natural convection, creating somewhat a partial vacuum and suction of fresh air up through the base this in a continuous perceptible flow of air over/through the drying material placed on the perforated trays which were kept in a horizontal position.

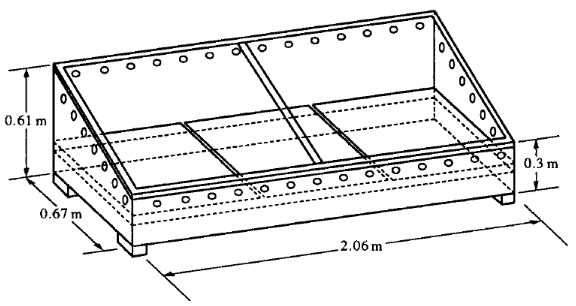

Figure 3 General overview of natural convection cabinet solar dryer

2.4 Multi-stacked natural convection solar dryer

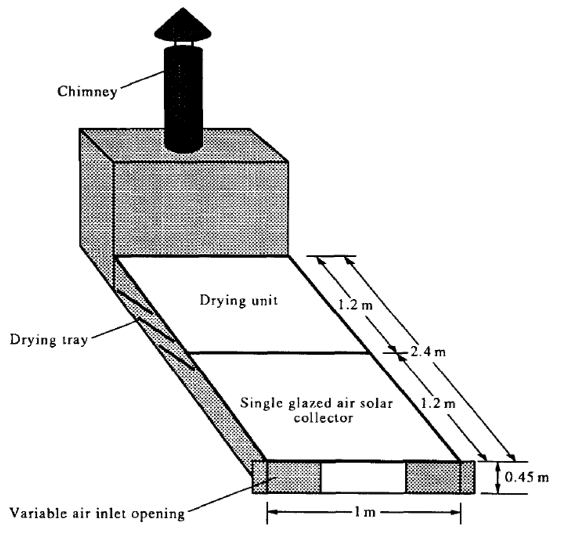

Figure 4: Solar dryer

This is a simple solar-air-collector/solar-dryer housed in a single cubic wooden box. The box has been divided into two halves. The first half is a single glazed solar air collector, whereas the drying unit is in the second half of the complete unit. As shown in Fig. 4, a glazed solar air heater located at the base of the drying chamber provides supplementary heat. Preheated air in the solar collector rises through the second half of the system. An additional chimney is provided at the top of the drying unit. The hot air dehydrates the product and gets exhausted through the chimney. The product to be dried is placed on the moveable trays kept on the metallic frames attached to the drying unit. The system can be operated both in natural as well as in forced convection.

In the natural operation, the flow rate varied by making use of the adjustable inlet opening provided at the inlet section of the solar air heater. In order to operate the system in forced convection, air can be supplied to the air heater at a uniform rate by using an electrically run blower. Also the air flow can be controlled manually by providing an adjustable damper attached to the blower.

2.5 Indirect-type multi-shelf forced convection solar dryer

The system is based on the principle of forced convection. Outlet from the solar air collector is made to pass through thermally and acoustically well-insulated rectangular air ducts. The idea underlying the design of an indirect-type solar dryer (Fig. 5), is to heat a body of air using a solar air collector and then let this air pass through a bed of material placed on trays kept inside an opaque drying chamber connected in series with the solar air collector.

The drying cabinet houses a single column of seven product compartments (each compartment with an area of 0.64 m^2). Each compartment is kept on a frame fixed to the side walls of the drying box. The drying trays can be easily removed to load or to change their position. The compartments are placed 15 cm apart from each other so as to ensure a uniform air circulation under and around the product.

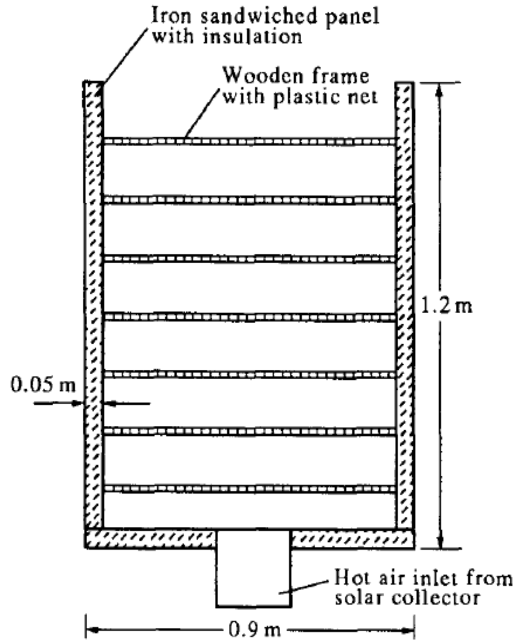

Figure 5: Multishelf (Compartments) solar drying box.

The drying box is well insulated from all four side for minimizing thermal energy losses due to conduction and convection, etc. Connection of the drying box to the solar air collector is given for operating drier at medium temperature. He further stated that the material holding capacity of the drying box depends mainly on the bulk density of the product to be dried and ranges from 75 to 100 kg.

3. Drying principle and theory

3.1 Moisture content

The quantity of moisture present in a material can be expressed either on the wet basis or dry basis and expressed either as decimal or percentage. The moisture content on the wet basis is the weight of moisture present in a product per unit weight of the undried material, represented as,

$$M_{wb} = \frac{W_o - W_d}{W_o} \quad (5)$$

While the moisture content on the dry basis is the weight of moisture present in the product perunit weight of dry matter in the product and represented as,

$$Mdb = \frac{Wo - Wd}{Wd} \quad (6)$$

Percentage Mwb=Mwb × 100 (7)

Percentage Mdb=Mdb × 100 (8)

The moisture contents on the wet and dry bases are inter-related according to the following equations,

$$Mwb = 1 - [\frac{1}{(Mdb+1)}] \quad (9)$$

And

$$Mdb = [\frac{1}{(1-Mwb)}]\text{-}1 \quad (10)$$

The moisture content on the wet basis is normally used for commercial use, while the moisture content on the dry basis has usefulness research designation, because the weight change associated with each percentage point of moisture reduction on the dry basis is constant as against the wet basis where the amount of water involved in a moisture content reduction of one percent changes as drying progresses, because the weight of water and total crop weight change. The relationship between the moisture content on the wet and dry bases is shown in Fig. 6.

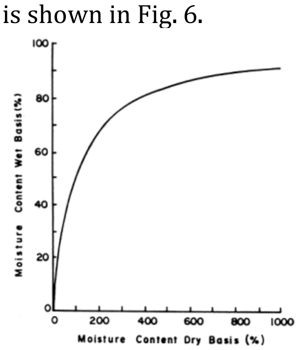

Figure 6: Relationship of moisture content on wet basis and dry basis

4. Result and discussion

The solar insulation, relative humidity, ambient temperature, etc. are counted and analyzed on the days of the experiments and presented in Fig. 7

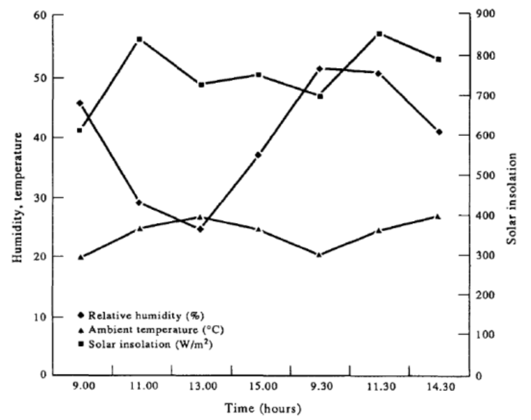

Figure 7: Climatic conditions during 13-14 July 93

Whereas the air temperature inside the different dryers, i.e. the temperature at which the actual drying takes place, is presented in Fig. 8.

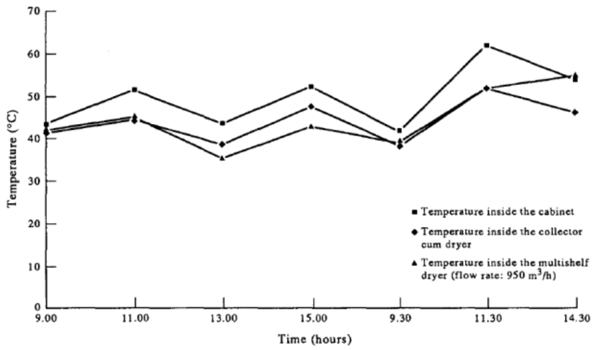

Figure 8: Air temperature inside the different driers, drying test with mushrooms

The initial and final moisture contents of the material dried were determined using the oven method. The total weight losses for different drying materials, measured instantaneously throughout the drying operation, are illustrated in Fig. 9.

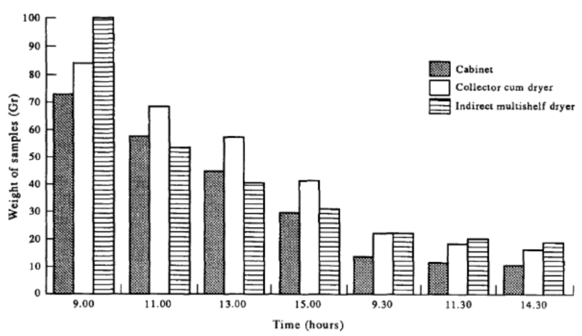

Figure 9: Weight loss of the product, its drying test with mushrooms

To calculate the amount of water evaporated, the products in each experiment were weighed at a regular interval of 2 h using a physical balance It is clear from the curves that the moisture content of the drying sample decreases exponentially with drying time. Solar cabinet dryers undoubtedly demonstrate a faster drying rate than the multi-stacked design, but it is to be noted that they cannot be used to dry a particular product on a large scale. Depending on the bulk density of the material to be dried, this system cannot be used to dry more than 7-10 kg of product. Moreover ,there is no control over the drying temperature which sometimes causes overdrying of the product.

This is especially true on partially cloudy days. On clear sunny days, however, the total drying times to complete the drying operation in all three different dryers were more or less the same. From the experimental results it is obvious that drying is faster in the indirect forced convection solar dryer as compared both with the natural convection cabinet and the multistacked solar dryer. No significant difference in the quality of the dried agricultural product.

Hurdles using solar drier

The type of solar dryerto be used depends on following factors:

(1) Quantity of material which is to be dried;

(2) Drying time to complete the drying operation; and

(3) Availability of resources, electric power and technical skill.

Conclusions

(1) The cabinet-type natural convection solar dryer is very well suited to drying small quantities of fruit and vegetables on the domestic/household scale.
(2) The integrated solar-collector/drying system can be used but for the limited crop quantity on the farm.
(3) The indirect-type multi-shelf dryer is suitable for use on a large scale by industries. From the experiments performed on the system, it is evident that its performance is quite satisfactory and, with slight modification of the existing design, could be improved further.
(4) The developed natural convection solar dryer is capable of producing the average temperature up to 55°C, which has optimum for dehydration of the grapes, fruits and vegetables. This system is capable of generating an adequate flow of hot air toenhance the drying rate. The drying air flow rate increases with increase in ambient temperature by the thermal buoyancy difference inside the collector.
(5) The dependence of the drying on the characteristics of product remains still as a problem, for comparison of drying efficiencies of various driers. The performance evaluation procedure of driers can be simplified by using ''Evaporative Capacity'' concept.
(6) The DPSD performs in the shortest drying time to meet desired moisture content of chilli which is 10% wet basis. This corresponds to the highest drying rate comparing to other methods. The DPSD shows higher performance as well in all measured efficiencies, also the overall drying efficiency is twice more than DPSD compared to CD.

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