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Construction and Performance Analysis of an Indirect Solar Dryer Integrated with Solar Air Heater

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Abstract

The use of conventional sources of energy for drying agricultural product is an expensive process in developing countries. Therefore, an appropriate technology for drying of agricultural produce has been developed and its performance for the drying of tomatoes was evaluated. An indirect type natural convection solar dryer was developed. The aim of this study is to evaluate dryer performance under natural and forced convection modes of drying. In natural and forced convection, air mass flow rates of 0.00653 kg/s and 0.019 kg/s respectively were obtained. Hot air reached an average drying temperature of 45°C in natural convection and 40°C in forced convection. The results obtained from natural and forced convection modes of drying were also compared with open sun drying. The colour, flavour and time required for drying is favorable in solar drying as compared to sun drying.

Keywords: Indirect solar dryer; Natural and Forced convection; Solar air heater; Solar drying performance study

Nomenclature

η_c	Efficiency of collector
η_d	Efficiency of Drying Chamber
T_o	Temperature at collector outlet, °C
T_i	Temperature at collector inlet, °C

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C_{pa}	Specific heat of air, kJ/kg K
A_c	Area of collector, m^2
I	Intensity of solar radiation, W/m^2
h_L	Latent heat of water in tomato, kJ/kg
$\dot{m}$	Mass flow rate of air, kg/s
m_w	Mass of evaporated moisture, kg
m_p	Initial mass of product, kg
M_i	Initial moisture content, % wet basis
M_f	Final moisture content, % wet basis
t	Time in second

1. Introduction

Drying of agricultural products after harvesting had always been of great importance for preservation of the products for longer period due to their increased shelf-life. The process of drying removes the moisture from the product being dried and prevents the growth and reproduction of micro-organism when the product is stored for longer period. Solar drying is not only a process, but it is a technology that helps to obtain products that are better in colour, flavour and nutrient content than the open sun dried products. Using this technology farmer can fetch better price for their products, because the solar dried products are at par with the international standard of market in quality. Drying brings about substantial reduction in mass and volume, minimizing packing, storage and transportation cost and enables storability of the product under ambient temperature [1]. Solar drying helps to overcome the inherent disadvantage of open sun drying i.e. it protects the product from unpredicted rain, wind-borne dirt and dust, infestation by insects, rodents etc. Currently hot air drying is the most widely used method in post harvest technology of agricultural products. Using this method, a more uniform, hygienic and attractively coloured dried product can be obtained rapidly [2]. However, it is an energy consuming operation, so more emphasis is given on using solar energy source due to the high prices and shortage of fossil fuels. Solar dryers are now increasingly used since they are a better and more energy efficient operation. The solar dryer could be an alternative to the hot air and open sun drying methods, especially in location with good sunshine during the harvest season [3]. Using a solar dryer, the drying time can be shortened by about 65% compared to open sun drying because, inside the dryer it is warmer than outside, the quality of the dried product can be improved in term of hygienic, cleanliness, safe moisture content, colour and taste; the product is also completely protected from rain, dust, insects, and its payback period ranges from 2 to 4 years depending on the rate of utilization [4].

Several successful attempts for developing natural and forced convection solar dryer have been investigated over the years. Dilip R. Pangavhane carried out a comparative study of drying performance of natural convection solar dryer with traditional grape drying method [5]. E. Kavak Akpinar investigated thin-layer drying characteristics using mint-leaves [6]. EL-Amin Omda Mohamed Akoy et al. describes the design and construction of a solar dryer to dry mango slices [7]. The objective of this work is to develop an indirect solar dryer integrated with solar air heater for drying tomatoes and to investigate its performance under natural and forced convection modes of drying.

2. Description of Solar Dryer

The schematic diagram of the indirect solar dryer is shown in Fig.1. The experimental set-up of dryer is fabricated from wood which is easily available and consisted of the following two main components: the solar collector and the drying chamber. These main components are described below.

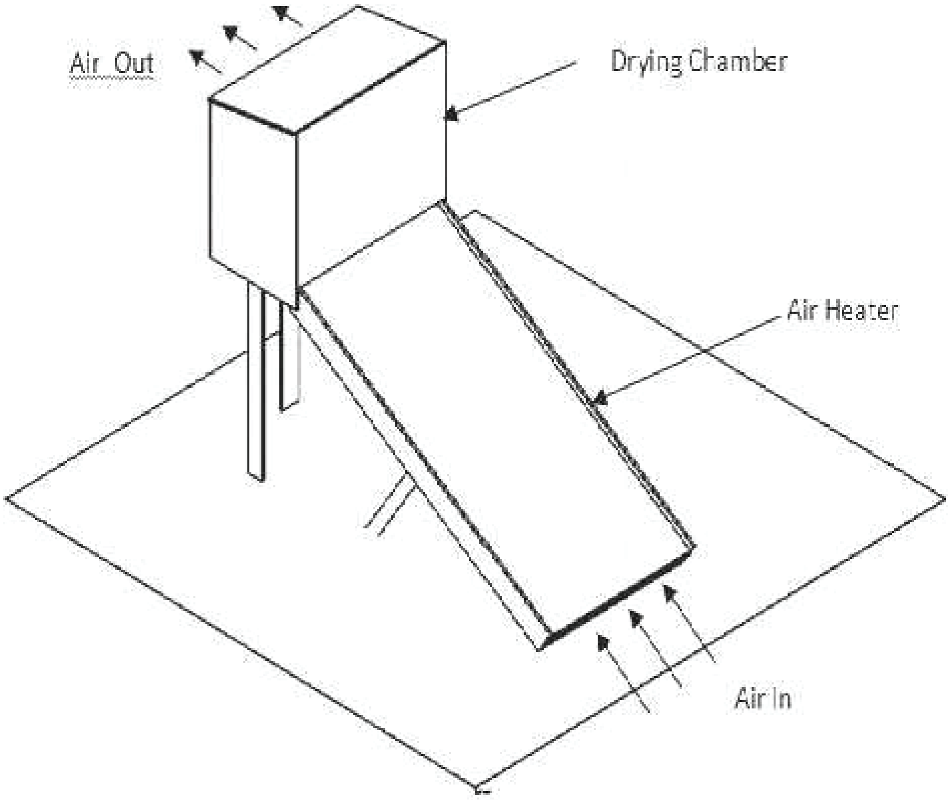

Fig. 1. Schematic diagram of experimental set up

2.1. Solar Collector

Solar collector is basically a top-open, wooden box of dimensions 1300 mm × 600 mm × 120 mm made from 12mm thick plywood. The solar collector was inclined at an angle to receive maximum solar energy. The inclination angle of the collector is given by the relation $(\phi\text{-}10^{o}) \leq \beta \leq (\phi+10)$ [8]. The design parameters of the solar collector are given in Table 1. The Solar Collector consists of absorber plate, cover plate and insulator, which are described below.

2.1.1 Absorber Plate

The absorber plate used in solar collector is a GI sheet painted with matt-black paint. The absorber plate was placed 30 mm below the cover plates to absorb incident solar radiation transmitted by the cover plates, thereby heating the air trapped between them.

2.1.2 Cover Plate

Two plates of ordinary window glass each of thickness 4 mm were used as cover plates placed over the absorber plate. A 10 mm gap was maintained between these two glass covers. These glass plates also retarded heat from escaping i.e. they form a confinement for heated air.

2.1.3 Insulator

It was placed under absorber plate. It was used to minimize heat losses from the system. Glass wool was used as an insulator in present study with thermal conductivity 0.07W/m-K. The thickness of insulation was 40 mm.

Table1. Design parameters of the solar collector

Parameters	Value
Area	0.78 m^2
Length	1.3 m
Width	0.6 m
Absorber plate	0.3 mm GI sheet
Surface treatment	Black paint coating
Glazing	Normal window glass of thickness 4 mm
No. of glazing	2
Back insulation	Glass wool of thickness 40 mm
Casing	Made of wood
Collector tilt	32 degree (latitude)
Air flow area	0.018 m^2
Distance between glazing	10 mm
Distance between cover and absorber plate	30 mm

2.2. Drying Chamber

The drying chamber is also a wooden box of dimensions 600 mm x 600 mm x 300 mm. The material, wood has been chosen since wood is poor conductor of heat and it has smooth surface finish, heat loss by radiation is minimized. Three drying trays were used in drying chamber to accommodate the material to be dried. The design parameters of drying chamber are given in Table 2.

Table2. Design parameters of the design chamber

Parameters	Value
Length	600 mm
Width	600 mm
Height	300 mm
Material	Plywood
No. of shelves	3

3. Materials and Methods

3.1. Materials

Fresh tomatoes (Lycopersicum Esculentum Mill) were purchased from local market in Hamirur, (Himachal Pradesh), India. Fresh samples were sorted visually by colours and size. Tomato is considered to be rather complex with an inner wall structure resembling a fibrous material while the pulpous area containing the seeds resemble a non-porous material; it is considered to be hygroscopic. The initial moisture content of tomato samples was determined by using oven method [9] at 105°C for 4 hr. Average moisture content was found 93% (wb). In the tropics region tomatoes are available throughout the year but in temperate region it is a seasonal crop and, hence there is surplus in one reason and shortage in another. Currently, tomatoes are preserved in the form of ketchup, paste and juice.

3.2. Experimental Procedure

Experiments were performed in an indirect solar dryer installed at the terrace of energy department of National Institute of Technology, Hamirpur (HP), India. The solar collector was inclined at angle of 32^o due south which is the angle of latitude of the experimental site. The tomatoes to be dried were washed in fresh running water and no pretreatment was given to the tomatoes. Then the slices of tomatoes of uniform thickness were placed on the trays in the drying chamber. The initial mass of tomato slices was taken 1800 g. These slices were kept on the three trays in the drying chamber with 600 g in each tray. The experiments were carried out between 9:30 am to 3:30 pm on sunny days during March-April, 2011. The drying was carried out to final moisture content of 10% from initial moisture content of 93% (wb). During the experiments, ambient data (i.e. solar irradiance, temperature and relative humidity) as well as inside temperature of the drying chamber and mass of the tomatoes were recorded. In forced convection, a solar photovoltaic module of 3 W was used to drive a fan of 12V and 0.14A rating so that air could flow at larger rate.

3.3. Instrumentation and Measurement

The temperatures were measured with the help of RTD (Resistance temperature detector). A RTD operates on principle that the electrical resistance of metal changes as its temperature changes. The Pt-100 RTD (0.01°C) sensors were fixed at various required places in the drying chamber and solar collector, for measuring temperatures of the absorber plate, hot air and drying chamber. The total incident solar radiation was measured by using a pyranometer Kipp and Zonen CM10. This apparatus consists of one thermopile and a numerical integrator allowing the reading of instantaneous fluxes by digital display. The relative error measurement is about ±2%. Air velocity was measured by using a hot wire anemometer (model KM-909). The theoretical range speed of the anemometer varies from 0.0 m/s to 30 m/s with resolution 0.01m/s. The mass losses were recorded by weightings with a type Metter PL-1200 digital display electronic balance of 0.01 g precision. The ambient air relative humidity and exit air relative humidity were measured with the help of digital hygrometer (with an accuracy of ±2.5%).

4. Efficiency Calculation

The performance of drying method is determined in terms of efficiency of the dryer which is defined as the ratio of heat utilized in evaporating the moisture from tomatoes during drying method to that of total solar insolation on the collector during drying. The thermal efficiency of the solar collector and drying efficiency of the solar dryer were calculated using following formula:

4.1. Collector Efficiency

$$\eta_c = \frac{\dot{m} C_{pa} (T_o - T_i)}{A_c I} \tag{1}$$

4.2. Drying Efficiency of the Drying Chamber

$$\eta_d = \frac{m_w h_L}{A_c I t} \tag{2}$$

Where m_w was obtained from the following relation

$$m_w = \frac{m_p (M_i - M_f)}{(100 - M_f)} \tag{3}$$

5. Result and Discussion

5.1. Performance Study at No Load

Fig2. shows the variation of the average temperature of air at outlet of solar collector, mean plate temperature and solar insolation during the day in March, 2011. The outlet temperature depended upon solar insolation and ambient temperature. It slowly increased in morning, reached to peak value in noon and started decreasing in after-noon. Similar observation was made by Rathore and Panwar [11]. The temperature at outlet of solar collector and ambient temperature ranged between 50 to 62°C and 23 to

32°C respectively. After passing through collector, air temperature was reduced to 45 to 52°C in the drying chamber. Solar insolation was in the range of 440 to 935 W/m^2.

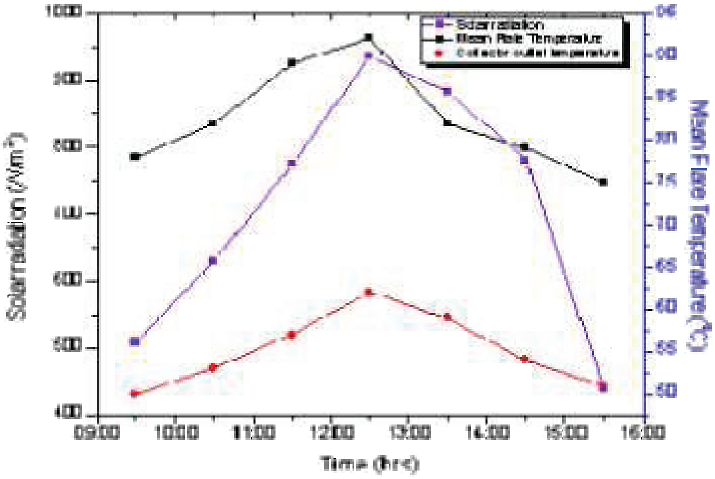

Fig. 2 Variation of collector outlet temperature, mean plate temperature and solar insolation with time during the day of experiment.

5.2. Performance Study at Load

5.2.1 Natural Convection Mode

The natural convection mode of drying is also known as passive mode because in this mode no source is used for blowing the air. The drawing air entered through tomatoes with average velocity of 0.75 m/s. The temperature drop of drying air was in the range of 4-7°C. For 1.8 kg of tomatoes the mass decreases to 998 g on the first day which was further reduced to 180 g on the second day i.e. the last day of drawing. We did not observe constant rate drying period, the tomatoes dried in the falling rate period only. During night, very negligible reduction in the mass of tomatoes was observed. The drying time was reduced by 56% for same moisture removal as compared to open sun drying.

5.2.2 Forced Convection Mode

This mode of drying is also known as active mode drying, since in this mode a fan is used for the movement of air. In forced convection mode, the drying air entered through the tomatoes with an average velocity of 2.18 m/s. The temperature drop of drying air was in the range of 3-5°C. For 1.8 kg of tomatoes, the mass decreases to 885 g on the first day which was further reduced to 140 g on the second day i.e. the last day of drying. It took 65% less time as compared to open sun drying for the same moisture removal.

5.2.3 Comparison between Natural Convection and Forced Convection Mode

The comparison between natural and forced convection is shown in Fig. 3. It is observed that forced convection removed more moisture from tomatoes as compared to natural convection in the same time. This is because the rate of heat transfer in forced convection is more than in natural convection. But in forced convection, additional power supply is required to run the fan which increases cost of solar dryer.

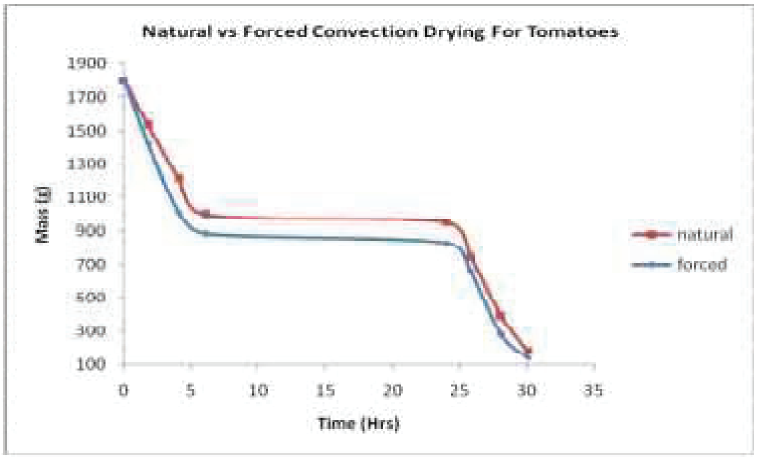

Fig. 3 Comparison between Natural Convection and Forced Convection Mode

6. Conclusion

The developed solar dryer is capable of producing an average temperature of 45°C, which is suitable for dehydrating most of the food products. The overall efficiency of the drying chamber was found to be 17% and the efficiency of the collector was 30%. In natural convection, the mass of tomatoes was reduced from 1800 g to 180 g in two days drying time and in forced convection, the mass of tomatoes was reduced from 1800 g to 140 g in same period. The mass flow rates of 0.00653 kg/s and 0.019 kg/s were found in natural and forced convection. The quality of dried tomatoes in term of colour, flavour, texture and time required for drying was favorable in natural and forced convection as compared to open sun drying.

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