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PERFORMANCE OF A FORCED CONVECTION SOLAR DRIER INTEGRATED WITH GRAVEL AS HEAT STORAGE MATERIAL

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ABSTRACT
An indirect forced convection solar drier integrated with sensible heat maternal (gravel) was developed and tested its performance for drying of pineapple slices under the metrological conditions of Pollachi (latitude of 10.39 ^{o} N, longitude of 77.03 ^{o}E), India. The results showed that the moisture content (wet basis) of pineapple was reduced from about 87.5% to 14.5% (equilibrium moisture content) in about 29 h in bottom tray and 32 h in top tray. Performance parameters such as drying characteristics, drying rate, specific moisture extraction rate and solar air heater thermal efficiency are discussed in this paper.

KEY WORDS
Solar drier, heat storage materials and drying

1. Introduction

In India, sun drying is the most common method used to dry the agricultural products like grains, fruits and vegetables. In sun drying, the crop is spread in a thin layer on the ground and exposed directly to solar radiation and other ambient conditions. The rate of drying depends on solar radiation, ambient temperature, wind velocity, relative humidity, initial moisture content, type of crops, crop absoptivity and mass of product per unit exposed area [1]. This form of drying has many disadvantages such as degradation by wind-blown debris, rain, insect infestation, human and animal interference that will result in contamination of the product. Speed of drying and quality of dried product will reduce due to over or under drying, intermittent sunshine, interruption and wetting by rain [2]. Hence, more emphasis is needed in using solar energy sources.

There are several types of driers developed to serve various purposes of drying food products as per local need and available technology. The best potential and popular type of driers are natural convection cabinet type, forced convection indirect type and green house type [3].

A solar drier is an energy efficient option in the drying processes. Several experimental studies reported the performance of various solar driers for food crop drying [4] for copra drying, [5] for onion drying, and [6] for pineapple drying. Use of forced convection solar driers seems to be an advantage compared to traditional methods and improves the quality of the product considerably [7, 8]. Common sensible heat storage materials used to store the sensible heat are water, gravel bed, sand, clay, concrete etc [9].

The objective of this research work is to develop a forced convection solar drier integrated with heat storage materials for drying various agricultural crops. Experiments were conducted for drying of pineapples at metrological conditions of Pollachi, India. The system performance and the drying characteristics are discussed in this paper.

2. Materials and Methods

2.1 Experimental set up

A schematic diagram of the forced convection solar drier is shown in Fig. 1. The solar drier consists of flat plate solar air heater of area 2 m^2 (2 m × 1 m) connected with drying chamber. The solar air heater has 2 mm thick copper absorber plate coated with black paint to absorb the incident solar radiation. The absorber plate is placed directly behind the transparent cover (glass) with a layer of air separating it from the cover. The air to be heated passes between the transparent cover (glass) and the absorber plate. To reduce the losses from topside of the absorber plate and to increase the temperature of air by green house effect, a glass cover of 5 mm thickness was placed. The gap between the glass and the absorber surface was maintained at 25 mm for air circulation. One side of the collector was connected to the blower with the help of reducer and the other side was attached with drier cabin. The 100 mm gap between the absorber and insulation was filled with gravel to store the heat during sunshine hours and to obtain hot air during off sunshine hours. The gravel selected was with average size of 10 inch in dimension which is normally used for concrete construction. This enables better heat absorption capacity during sunshine hour and the stored heat was utilized during off sunshine hour. The drying chamber is made up of GI sheet of 2 mm thickness with width, depth and height of 1 m × 1 m × 1.5 m respectively. The drying chamber was insulated with glass wool of 10 mm thickness. The solar air heater was tilted to an angle about 25^{o} with respect to horizontal. The system is oriented to face south to maximize the solar radiation incident on the solar collector.

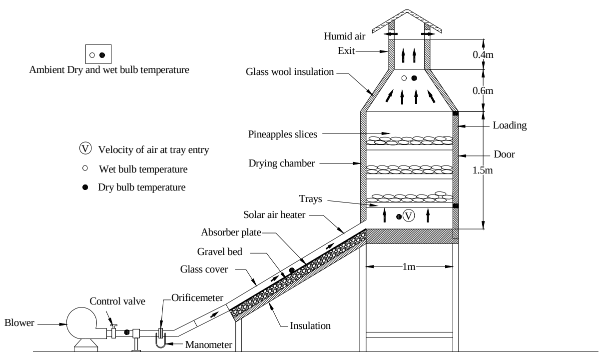

Figure 1. Schematic view of experimental setup

Six calibrated RTD (Pt 100) temperature sensors with ± 0.5 ^{o}C accuracy were fixed at different locations (as shown in Fig. 1) of the solar drier to measure the temperature of drying air through digital indicator having 0.1 ^{o}C resolution connected with rotary selector switch. Energy consumption of the blower was measured with an energy meter having ± 1% accuracy. A U tube manometer was fixed in the path of air circuit to measure the velocity of air entering the drier. The velocity of air at inlet of the tray was measured with the help of vane type anemometer having ± 0.01 m/s accuracy. A digital electronic balance of 1 kg capacity having an accuracy of ± 0.01 g was used to weigh the samples.

2.2 Experimental procedure and calculations

Drying experiments were carried out to study the dryer performance by drying pineapple slices. Pine apples were pealed and sliced to 10mm thickness. About 35 kg pineapple slices were loaded over the trays of drier chamber. Then, the air blower is switched on and the airflow rate through the solar flat plate air heater was adjusted to 0.03 kg/m^{2}s with the help of control valve. During the experimentation, drying characteristics of pineapple and temperature at various locations in solar collector and drying chamber were measured for every one-hour interval. Experiments were carried out continuously for the period of 32 h.

The quantity of moisture present in a material can be represented on wet basis and expressed as percentage. Five samples of about 10 g each were taken from different trays and kept in a convective electrical oven, which was maintained at 105 ± 1 ^{o}C until constant weight has reached. The initial *(W_t)* and final mass *(W_d)* of the samples were recorded with the help of electronic balance. The moisture content on wet basis was calculated using the Eq. (1). The procedure was repeated every one hour interval till the end of drying.

$$M_{wb} = \frac{(W_t - W_d)}{W_t} \times 100 \qquad (1)$$

The drying rate should be proportional to the difference in moisture content between material to be dried and the equilibrium moisture content. The concept of thin layer drying was assumed for the experiments as per Eq. (2). Mathematically it can be expressed as thin layer drying equation and the moisture ratio was calculated by using the Eq. (3).

$$DR = \frac{dM}{dt} = -k(M_t - M_e) \qquad (2)$$

The specific moisture extraction rate (SMER), which is the energy required for removing one kg of water. SMER is calculated by Eq. (3)

$$\mathrm{SMER} = \frac{\mathrm{m_d}}{\mathrm{P_{bl}}} \qquad (3)$$

where m_d is the amount of moisture evaporated (Kg) and P_{b1} is energy consumption by the blower in KgKWhr^{-1}.

The instantaneous thermal efficiency of the solar air heater was estimated by using Eq. (4) according to (Kadam and Samuel, 2006).

$$\eta_{th} = \frac{c_p m_a (T_o - T_a)}{A_S I} \times 100 \qquad (4)$$

where c_p is the specific heat of air in J/kg K, m_a is the mass flow rate of air in kg/sec; T_a is the ambient temperature, T_o is the outlet air temperature. A is the surface area of the solar collector in m^{2} and I is the solar intensity in W/m^{2}.

3. Results and discussion

The variation of solar intensity and ambient relative humidity are shown in Fig. 2. The average ambient humidity recorded during experimentation was about 68%. The maximum solar intensity was observed to be about 891 W/m^{2}. Fig. 3 shows the variation of ambient and drier outlet temperature. Maximum drying air temperature recorded was about 58.6 ^{o}C during peak sunshine hours and the temperature was reduced to about 33.4 ^{o}C during off sunshine hours and nights. The average temperature measured at the drier outlet was about 49 ^{o}C. The average ambient temperature recorded was 30 ^{o}C. In the drying chamber outlet, a high relative humidity of about 82% was recorded during initial stages of drying and gradually reduced to about 43% at the end of drying.

Length of sunshine at this location (meteorological conditions of Pollachi) is 11 hrs. But the potential sunshine is only 8 and half hours. During the remaining time, heat stored in the material is used for heating the air. The temperature of the air at driers outlet gets decreased during off sunshine hours. These experiments were carried out during the summer month of the year 2008. Since India is a tropical country, it receives sufficient sunshine during summer, which can be retained by low cost heat storage materials like gravel. Hence selection of gravel as heat storage medium is considered to be the best possible choice to minimize the drying time.

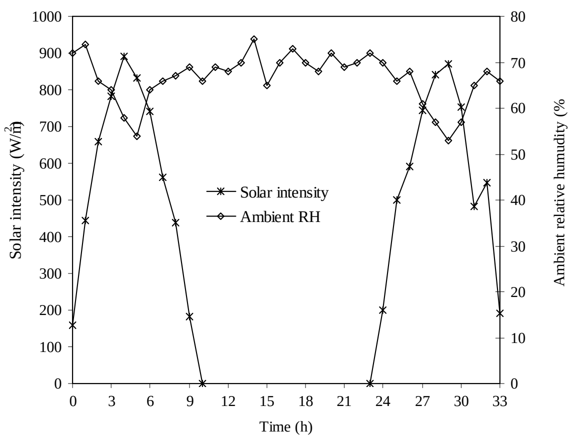

Figure 2. Variation of solar intensity and ambient relative humidity

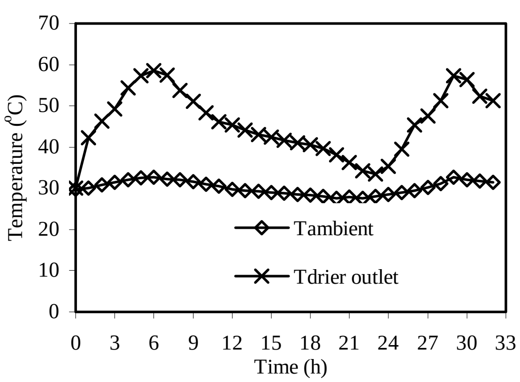

Figure 3. Variation of temperature with time

The variation of moisture content (wet basis) with drying time at top and bottom of the tray is illustrated in Fig. 4. The average moisture content of the pineapple was reduced from about 87.5% to 14.5% in 32 and 29 h for top and bottom trays respectively. The moisture reduction during initial stages of drying was found to be very high due to free moisture migration from the outer surfaces and then gets reduced due to internal migration of moisture from inner layers to the surface. The reduction in moisture content at bottom tray was about 5 to 8% higher than that of top tray.

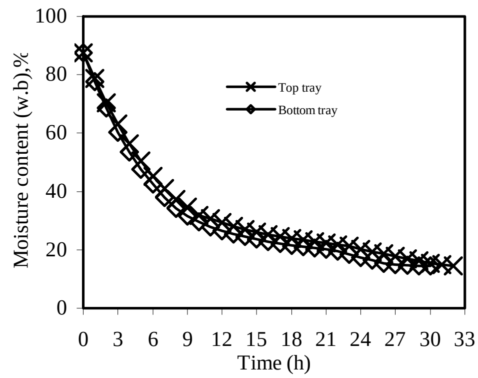

Figure 4. Variation of Moisture content with time

High drying rate of about 10 kg of water / kg of dry matter. h was observed during initial stage of drying. Drying rate gets decreased with increase in drying time. Drying occurs in the falling rate period with steep fall in moisture content in initial stages of drying and becomes very slow in the later stages. The drying rate of pine apple in present system was high compared to sun drying due to its high heat and mass transfer coefficients. Drying rate in bottom tray was found to be higher compared to top tray.

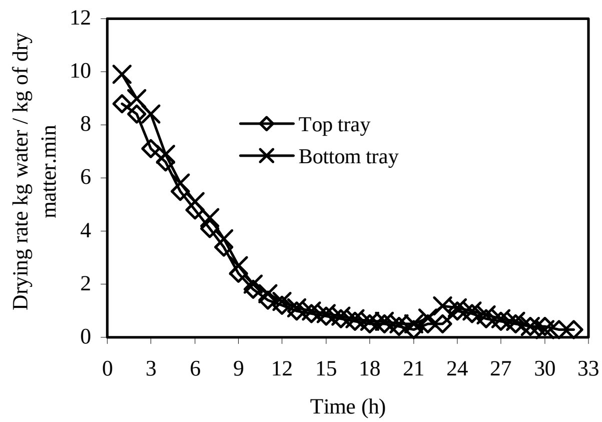

Figure 5. Variation of drying rate with time

The specific moisture extraction rate was estimated to be about 0.89 kg/kW.h. The efficiency varies between 14% and 28% during peak and off sunshine hours, respectively. The average solar air heater efficiency was about 23%. The results obtained in this study are similar to the earlier study reported by Shanmugam and Nataraj [6]. In this work gravel (low cost energy storage material) is used to store the heat during potential sunshine hours and off sunshine hours as well.

4. Conclusion

The performance of an indirect forced convection solar drier integrated with heat storage material was developed and tested its performance for pineapple drying. The product dried to the equilibrium moisture content in 29 h for top tray and 32 h for bottom tray. The specific moisture extraction was calculated as 0.89-kg/kW h. Thermal efficiency of the solar drier was estimated to be about 21%. It could be concluded that, forced convection solar drier is quite suitable to produce high quality dried products .

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