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INVESTIGATION ON THERMAL ANALYSIS OF SOLAR CABINET DRYER WITH HEAT STORAGE SYSTEM

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Abstract: Thermal analysis of a solar cabinet dryer with heat storage system was carried out in the Department of Unconventional Energy Sources & Electrical Engineering, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola for drying ginger slices. The loading capacity of the dryer was about 10 kg slices per batch. The drying characteristics of the dryer were studied and compared with open sun drying method. The maximum temperature attaineded in solar cabinet dryer was 53.0, 54.3, 54.8, 55.00 and 55.8 °C in T_1, T_2, T_3, T_4 and T_5 drying trays of the dryer, respectively. The average ambient temperature, solar intensity, relative humidity and wind velocity was obsereved to be 35.91°C, 472.53 W/m^2, 16.32 % and 0.76 m/s, respectively. The maximum temperature developed in heat storage system was recorded to be 67.46°C whereas, the average ambient temperature was varied from 28 to 39.9°C. Drying time for drying ginger slices for reducing its moisture content from 79.51% to 9.67% (wb) was found to be 15 h in solar cabinet dryer whereas, 17.25 h was observed in the open sun drying method. The heat storage system containing gravel with iron scrap extended the drying hours by 3 h after sunset also. The colour of solar dried ginger slices was found better as compared to open sun dried ginger slices. The powder of ginger slices dried in dryer was prepared and had good quality, colour, appearance, taste, smell and overall acceptability than open sun dried ginger powder. The fats content of 2.06% and 1.86% was observed in ginger powder prepared from the slices dried in solar cabinet dryer and in open sun drying, respectively.

Keywords: Solar system, dryer, heat storage thermal analysis and ginger slices

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INTRODUCTION

Drying of fruit and vegetables is one of the oldest methods of food preservation. In addition, drying enhances the storability, transportability, nutritional value retention, flavour and texture of food products reducing moisture content of foodstuff down to a certain level slows down the action of enzymes, bacteria, yeasts and molds. Thus food can be stored and preserved for long time without spoilage (Jithinraj and Karim, 2014). Solar energy is by far the most attractive alternative energy sources for the future. But the main problem of solar energy is its intermittent nature. However, solar drying is in practice since long time for preservation of food and agricultural crops. This was done particularly by open sun drying under the open to sky. This process has several disadvantages like spoilage of product due to adverse climatic conditions like rain, wind, moist, dust, loss of material due to birds and animals. Solar cabinet dryer with heat storage system become popular due to considerable reduction in drying time and significant improvement of product. Solar dryer for domestic as well as industrial usage could be an effective alternative of saving conventional energy. The provision of heat storage material in solar cabinet dryer such as gravels, sand, iron scraps, etc. which can store the heat energy during sunshine hours and provide the heat during off sunshine hours. By the introduction of heat storage system in solar dryer, additional drying hours could be made available (Bal *et al*., 2010; Chauhan *et al.,* 1996; Mohanraj and Chandrasekar 2009).
Thermal storage system enable drying to continue after sunset provided there is enough sunshine during the day. However, the intensity of solar radiation is sometimes so low that the temperature of the thermal mass rises by a very small or no margin above the ambient level. So, this still limits the continuity of the drying process in a solar dryer with a thermal mass (Madhlopa *et al.,* 2002; Anuradha and Oommen, 2013 and Ayyappan and Mayilsamy, 2012).

In many cases continuous drying is preferred. However, solar cabinet dryer is operated only during day time for 8 to 9 h only. The conventional source of energy is to be used to continue the drying after sun set. Thermal storage system could be coupled with the solar dryer to improve its efficiency, operating hours of solar dryers (Kamble *et al*., 2013). This could also save conventional source of energy. In view of the above, there was need to study solar dryer with heat storage system for drying vegetable. Therefore the study was undertaken on solar cabinet dryer with heat storage system for drying ginger slices. Ginger is an important spice cash crop of the world. It is one of the earliest known oriental spices and is being cultivated in India for both as fresh vegetable and as a dried spice. Ginger and its products have varied applications in culinary preparation, bakery products, toiletry products, perfume industries, meat products, wine, and soft drinks making. Dried ginger is used both as a spice and medicine (Deshmukh *et al*., 2014). Dry ginger contains essential oil 1-3%, oleoresin 5-10%, starch 50-55%, moisture 7-12% with small quantities of protein, fiber, fats and ash (Eze and Agbo, 2011 and Jayashree *et al.,* 2012).

MATERIAL AND METHODS

The solar cabinet dryer integrated with heat storage system was developed in the Department of Unconventional Energy Sources & Electrical Engineering, Dr Panjabrao Deshmukh Krishi Vidyapeeth, Akola (Dr. PDKV). The thermal analysis of solar cabinet dryer with heat storage system was evaluated at full load condition. Under the full load condition (10 kg per batch) the ginger slices were spread over the stainless steel wire mesh drying trays. The experiment was conducted in the month of April 2015. The initial weight of the samples was recorded. The sample of 100 gm of fresh ginger slices were placed in all five trays of the dryer. The weight loss was recorded at an interval of one hour and simultaneously the temperature, relative humidity, solar radiation and air velocity inside the solar cabinet dryer. Drying was carried out between 8:30 to 20:30 h with heat storage system.
The freshly harvested gingers were properly washed in fresh running water and then they were cut into slices of 4-6 mm thickness. The initial moisture content of the sliced ginger was determined by hot air oven. The ginger slices of were spread uniformly in a thin layer on the five trays of the solar cabinet dryer containing 2000 g each (Fig. 1 and 2). The temperature attended in the drying chamber, weight loss of ginger slices, Rh, air velocity and ambient

condition and temperature developed in the heat storage system were observed. The sample of ginger slices were also kept for open sun drying for comparing with the data obtained from the solar cabinet dryer.

Fig.1 Ginger slices drying in day time

Fig.2 Ginger slices drying continued after sunset

RESULTS AND DISCUSSION

Drying kinetics of ginger (*Zingiber officinale*) slices

The solar cabinet dryer with heat storage system was evaluated for drying of ginger slices. The maximum temperature attaineded in solar cabinet dryer was 53.0, 54.3, 54.8, 55.0 and 55.8 °C in T_1, T_2, T_3, T_4 and T_5 drying trays, respectively (Fig 3). The average ambient temperature, solar intensity, relative humidity and wind velocity was obsereved to be 35.91°C, 472.53 W/m^2, 16.32 % and 0.76 m/s, respectively.

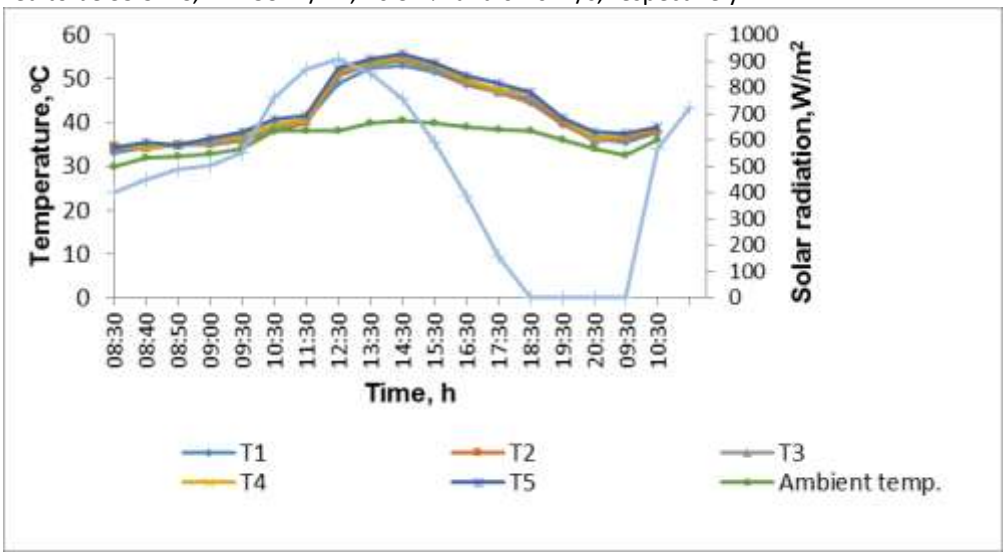

Fig. 3 Temperature variation in solar cabinet dryer

From Fig. 4 it is seen that the heat storage system supplied the heat to the drying chamber during off sunshine hour and remarkable difference in temperature of drying chamber and ambient was obsereved upto 20:30 h .

The temperature developed in the heat storage system of solar cabinet dryer during day time and after sunset was measured at upper and lower layer of heat storage bed viz., bottom, middle and top positions. From Fig. 5 it is seen that the temperature developed in the heat storage system at its upper layer was observed to be 36.81 to 55, 38.94 to 68.23, 38.80 to 67.46°C at bottom, middle and top position, respectively (Fig. 4). The ambient temperature was varied from 28 to 39.9°C and solar intensity was varied from 98.90 to 933.80 W/m^2.

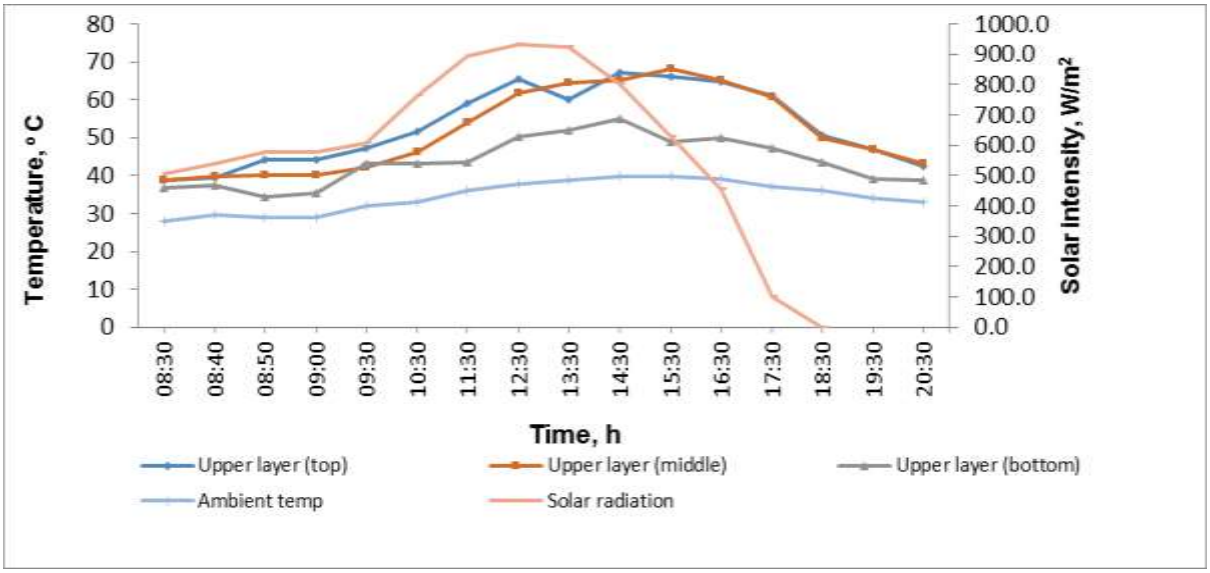

Fig. 4 Temperature developed in the heat storage system at full load condition

The variation in moisture content of ginger slices dried in solar cabinet dryer and open sun drying (OSD) are given in Fig 5. The moisture content of ginger slices samples dried in soplar cabinet dryer reduced from 79.51 to 9.67% (wb) in 15 h, in solar cabinet dyer whereas, it was found to be 17.25 h in open sun drying in the month of April 2015.

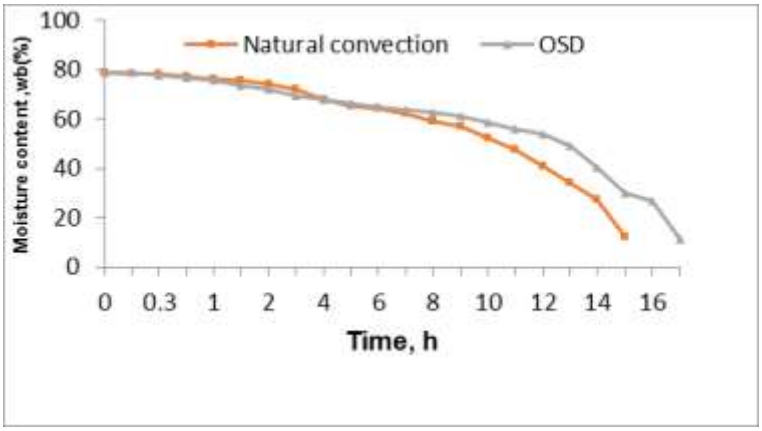

Fig. 5 Variation in moisture content of ginger slices in solar cabinet dryer and open sun drying

The ginger powder was prepared form the ginger slices dried in solar cabinet dryer and in open sun drying method and its composition is given in Table 2. The composition of market ginger powder was also found out for the comparison point of view. It is seen from Table 1 that higher percentage of fat was retained in the ginger slices dried in solar cabinet than that of the open sun dried and market ginger powder.

Table 1. Composition of ginger powder

Composition	*Ginger powder samples*		
	S_1	*S_2*	*S_3*
Moisture content (%)	*11.43*	*8.91*	*7.72*
Ash content, %	*4.27*	*4.08*	*4.03*
Fat, %	*1.863*	*2.060*	*1.137*

S_1 - Powder prepared from sun dried ginger slices
S_2 - Powder prepared from solar cabinet dryer
S_3 - Market ginger powder

Sensory evaluation of ginger powder

The samples of ginger powder were subjected to sensory evaluation testing using 1-9 Hedonic scale (Rahman, 2013). The samples of ginger powder viz., sun dried ginger powder (S_1), cabinet dryer dried ginger powder (S_2) and market ginger powder (S_3) was given to the ten panelists for sensory analysis. The mean scores of color, pungency, smell and overall acceptability of different samples are presented in Table 2. The mean values of sun dried ginger powder (S_1) and market ginger powder (S_3) was found at par with each other whereas, the mean value of the sample of cabinet dryer dried ginger powder was significant difference. The quality attributes i.e. colour has a significant difference whereas, other three attributes viz., pungency, smell and overall acceptability are at par with each other.

Table 2. Sensory evaluation of ginger powder samples

Factor	*Means*				*CD (5%)*	*CV, %*
Samples	*6.450^a (S_1)*	*7.325^b (S_2)*	*6.500^a (S_3)*		*0.359*	*11.97*
Quality Attributes	*7.367^a (Color and appearance)*	*6.67^b (Taste/ pungency)*	*6.567^b (Smell)*	*6.433^b (Overall acceptability)*	*0.415*	

**The row-wise values superscripted by similar letter are at par with each other*
S_1 - Powder prepared from sun dried ginger slices
S_2 - Powder prepared from solar cabinet dryer
S_3 - Market ginger powder

CONCLUSIONS

The drying time required for drying 10 kg of ginger slices from 79.51 to 9.67% (wb) was found to be 15 h in solar cabinet dryer whereas, 17.25 h was found in open sun drying method. It was observed that the heat storage system supplied heat for about 3 h after sunset also. The ginger powder obtained from solar cabinet dryer was found to be in dark green colour, better in smell and taste as compared to open sun dried ginger powder sample.

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