DESIGN AND DEVELOPMENT OF LOW COST SOLAR DRYER

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ABSTRACT

A low cost cabinet solar dryer was developed at the College of Renewable Energy and Environmental Engineering, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat, to test its performance for tomato slice drying. The experiment was conducted during the month of October 2015. The results showed that drying of tomato slice took a full day on an average insolation rate of 1030.52 W/m². During the study, the minimum and the maximum temperature recorded was 31°C and 62°C. The minimum and the maximum relative humidity observed inside the dryer was 26 per cent and 64.02 per cent. Efficiency of Dryer calculated was 34.87 per cent. The initial and final moisture content of the product recorded were found to be 90.48 per cent and 7.73 per cent. Results revealed that low cost cabinet solar dryer is more feasible than the open sun drying method.

KEY WORDS: slice, solar dryer, tomato

INTRODUCTION

In India, agriculture is a major source of employment, income and foreign exchange. It offers great opportunities to stimulate economic growth. Capitalizing on these opportunities requires modification of agricultural processing systems and application of sustainable energy technologies. Solar drying is an excellent way to preserve food for a sustainable world. Drying is the oldest technique of preserving agricultural products. High prices and shortages of fossil fuels have increased the emphasis on using renewable energy resources. Drying of agricultural products using renewable energy such as solar energy is environmental friendly and has less environmental impact. The major advantage of drying food products is the reduction of moisture content to a safe level that allows extending the shelf life of dried products. Open sun drying is the cheapest method, but the quality of the dried products is far below standards. Improvement of product quality and reduction of losses can only be achieved by the introduction of suitable drying technologies.

Solar drying refers to methods of using the sun's energy for drying, but excludes open air sun drying. A Solar dryer is an enclosed unit, to keep the food safe from damages from, birds, insects, and unexpected rainfall. The food is dried using solar thermal energy. Drying is a complex process due to the fact that it involves simultaneous heat and mass transfer. Solar dryers are in much demand to reduce energy consumption and moreover to improve the quality of food products. Solar dryers are devices that use solar energy to dry substances, especially agricultural product. Solar dryer make use of solar radiation, ambient temperature and relative humidity. Black absorbing surface which collects the light and converts it to heat; heated air is passed naturally or mechanically circulated to remove moisture from material placed inside the enclosure.

MATERIALS AND METHODS

Fresh tomato (Variety: Himsikhar) were purchased from local market of Deesa nearby Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar. Ripen, fresh tomatoes were washed to remove dust, dirt, etc. Plate 1 and 2 shows the raw material and slices of tomatoes. The initial moisture content of tomato slice was determined.

Most of the energy we receive from the sun comes in the form of light, a short wave radiation, not all of which is visible to the human eye. When this radiation strikes a solid or liquid, it is absorbed and transformed into heat energy. The material becomes warm and stores the heat, conducts it to surrounding materials or radiates it to other material of lower temperature. Put in simple terms, if you place a container full of liquid in the garden on a sunny day, in a short time the contents of the container become warm. Solar collectors work in much the same way, but are very much efficient. Drying is basically a phenomenon of removal of liquid by evaporation from a solid. A major part of energy consumption during drying is for the evaporation of liquid water in to its vapour (2258 kJ/kg at 101.3 kPa). The water may be contained in the solid in various forms like free moisture or bound form which directly affects the drying rate. Moisture content is expressed either on dry or wet basis, e.g. moisture content in wet (Xw) basis is the weight of moisture per unit of wet material (Ekechukwu and Norton, 1999 and Hussain and Bala, 2007).

The main principle of low cost solar cabinet dryer is based on greenhouse effect where the solar heat is trapped inside the drying chamber and thus increases the temperature level. It is a direct type solar cabinet dryer, here solar collector and cabinet are same. The product is directly exposed to the sun radiations. The drying is rather less uniform, but it does not allow the dust and other contamination to enter in to chamber. Direct solar dryers expose the substance to be dehydrated to direct sunlight. They have a black absorbing surface which collects the light and converts it to heat; the substance to be dried is placed directly on this surface. This drier may have enclosures, glass covers and/or vents in order to increase efficiency. It is based on natural phenomenon. Here fresh air having atmospheric temperature enters the dryer at the bottom end of the solar collector and leaves at the upper most portion of the drying chamber through exhaust air outlet.

Performance assessment of low cost solar cabinet dryer

A solar cabinet dryer forced convection was assessed for the drying of tomato slice. Solar power meter (make: Tenmars electronics co., Ltd, Taiwan) was used to measure global solar radiation, which is available in College of Renewable Energy and Environmental Engineering (RE & EE) laboratory. The Solar power meter was put on the ground surface to measure solar radiation at the College of Renewable Energy & Environmental Engineering Dantiwada Agriculture University, sardarkrushinagar. It measures solar radiation in W/m² on instant time basis.

Relative humidity

Relative humidity is the ratio of the partial pressure of water vapor in an air-water mixture to the saturated vapor pressure of water at a prescribed temperature. The relative humidity of air depends on temperature and the pressure of the system of interest.

$$RH = \frac{P_w}{P_{ws}} \times 100$$

Pws = Saturation vapour pressure (hpa)
Pw = Vapour pressure

Wind velocity

Wind speed, or wind velocity, is a fundamental atmospheric rate. Wind speed is caused by air moving from high pressure to low pressure. Wind is the horizontal movement of air. The instrument used to measure wind speed was anemometer, which is an indicator that will spin in the wind. The anemometer rotates at the same speed as the wind. It gives a direct measure of the speed of the wind. Normally drying is faster when the wind is blowing and air is dry. If the air is dry but the wind is not blowing, then the water present in the product saturate the surrounding air, preventing additional water from evaporating. Drying is faster when the air is dry and the wind is blowing. More moisture will be carried away, bringing more dry air in contact to the product, allowing further evaporation. The process of evaporation requires a large amount of energy. This energy is needed to give individual water molecules enough energy to escape the liquid and become gaseous. If the air is wet (humid is the correct term), then the air will already have a lot of water in it. In this case, evaporation will be prevented, regardless of whether the wind is blowing or not.

Moisture content

Water content or moisture content is the quantity of water contained in a material, such as soil (called soil moisture), rock, ceramics, fruit, or wood. Moisture content inside food product promotes growth of bacteria, yeasts, and mold. The solar dryer was tested to study the behaviour in terms of moisture removal pattern from tomato slice at different temperature.

Moisture content is expressed as a percentage of moisture based on wet weight (wet basis) or dry matter (dry basis). Wet basis moisture content is generally used.

$$M_w(wetbasis) = \frac{w-d}{w} \times 100 \quad \textbf{... (1)}$$

Where,

W = Weight of sample product

d = Dry weight of sample product

M = Moisture content on a percent basis

The experiment was conducted to determine moisture content on wet basis. The dried tomato slice sample was weight after 12 hours to calculate moisture content with respect to temperature using equation 1.

Drying rate

The moisture content data in each of experiments were analyzed to determine the moisture lost by sample in a known time interval. The drying rate was expressed as g water/g dry matter- h. The drying rate can be calculated as -

$$DR = \frac{WML}{Time \quad \text{int}\,erval \times DM}$$

Where,

WML = Weight of moisture loss

DM = Drying matter

Hourly drying efficiency

The drying efficiency were calculated by the following formula

$$\eta_{di} = \frac{m_w \times \lambda}{I \times A} \times 100$$

Where,

m_w=Mass of water evaporated per hour, kg

λ = Latent heat of vaporization, kcal / kg K

I = Solar insolation, W/m^2

A = Total collector area,m^2

Experimental procedure

For achieving stable environmental condition in the drying chamber, the dryer was operated at no load condition at least one hour prior to its loading (Plate 3). The temperature of the preheated air was controlled with the help of adjustable exhaust window. Tomato slice of 600 g was loaded in each tray for the study of thin layer drying behavior to determine the moisture loss data. The moisture loss of the contents was determined by measuring weight of sample at the regular interval of 30 minutes except for first and second reading. Loading of the material was carried out at 9.00 am and stopped when the final moisture content of the tomato slice was reached about 7 to 8 per cent (w.b). The ambient temperature was measured with the help of dry bulb and wet bulb thermometer. The temperature of drying air was measured with help of data logger system. The average gap between the glass and the absorber surface was maintained at 24.13 cm for air circulation. A 5 W fan operated by solar panel was provided at the bottom of the dryer. The solar dryer was oriented facing south direction and at a tilt angle of 30° with respect to horizontal, which is near equivalent to latitude of the location (24.36175^0).

RESULTS AND DISCUSSION

Performance curves for forced convection solar cabinet dryer

No load performance

The no load test was carried out to know the trend of various operating parameters with respect to time. Temperature profile at various positions in dryer is presented in Figure 1. It was observed that the temperature increased till 13:30 hrs. then started decreasing. The temperature increasing trend was from tray 1 which was at bottom to tray 3 placed at top of the dryer. The maximum temperature attained in the dryer was 75^{o}C at 13:30 hrs.

Full load performance

Full load performance was carried out under loading rate i.e. 1800 g. per batch and dryer had three tray each tray containing 600 g. tomato slice. The temperature profile achieved inside the dryer was shown in Figure 2. The temperature inside cabinet dryer was represented with curve lines having crossed tick marks. From Figure 2, the temperature condition was showed in graph at the end of drying period of one day and at the starting time of the next day was represented by steep downward curve and the tray 1, 2 and 3 temperature was showed with steep upward curve. The maximum temperature achieved inside the dryer was 62^{o}C at 13:30 hr. The average drying temperature achieved inside the dryer was 55.81^{o}C. The results shows in case of that tray 1, drying was faster as compared to tray 2 and tray 3. Figure 2 also revealed that, as the temperature increased, the relative humidity decreased. The maximum recorded relative humidity was 64.02 per cent in solar dryer at time 9:30 and the minimum humidity was 26 per cent in solar dryer at time 13:30 hrs.

Moisture content of tomato slice during drying was represented in Figure 3. The moisture content of sample was increased during night time as shown in Figure 3. Total drying time of 08:00 hours was required to dry tomato slice in forced convective solar dryer at a loading rate of 600 g. per tray and total loading of 1800 g. per batch. The initial moisture content of the tomato slice in first tray was 93.83 per cent (w.b) decreased to bone dry condition in 8 hrs. of solar drying as shown in Figure 3. The initial moisture content of the tomato slice in second tray was recorded as 93.45 per cent (w.b) and decreased to bone dry condition in 8:30 hrs. of solar drying. The initial moisture content of the tomato slice in third tray was recorded as 93.17 per cent (w.b) and decreased to bone dry condition in 8 hrs. of solar drying.

Drying efficiency

The drying efficiency of the dryer is the important parameter for evaluation of the dryer. The variation of drying efficiency with drying time and solar insolation was graphically represented in Figure 4. The drying efficiency of tomato slice drying increased with increased the solar insolation. The drying efficiency was increased in the initial hours of drying and then falls as shown in Figure 4. The maximum drying efficiency of tomato slice drying in low cost solar cabinet dryer was recorded as 53.47 per cent. The average drying efficiency of tomato slice drying in low cost solar cabinet dryer was recorded as 34.87 per cent. The zero drying efficiency indicated that the product was dried up to its bone dry condition so further drying of the product was not possible.

- Open sun drying : Cement concrete floor having size : 4 × 5 × 0.20 m
- Convection dryer : Aperture area : 0.71 m^2 Dimension : 92.7 × 78 × 31.75 cm

The results presented in Table 2 showed that the higher net return was obtained in low cost solar drying method as compared to open sun drying method. It was found that higher Net profit (Rs./kg) of drying of 1 kg of tomato slice Rs.364.56 Rs./kg as compared to open sun dryer (341.27 Rs./kg). So the use of low cost solar showed benefit of Rs. 23.38 as compared to open sun drying for tomato slice.

Madhlopa *et al.* (2002) evaluated the performance of the dryer by drying fresh samples of mango (*Mangifera indicus*). Both fresh and dried mango samples were analysed for moisture content (MC), pH and ascorbic acid. During the dehydration period, meteorological measurements were made. The air heater converted up to 21.3% of solar radiation to thermal power, and raised the temperature of the drying air from about 31.7°C to 40.1°C around noon. The dryer reduced the MC of sliced fresh mangoes from about 85 per cent (w/w) to 13 per cent (w/w) on wet basis, and retained 74 per cent of ascorbic acid. It was found that the dryer was suitable for preservation of mangoes and other fresh foods. While performance evaluation of a solar wind-ventilated cabinet dryer, Bukola *et al.* (2011) reported that the system efficiency increased as the air velocity through the system increased. During the period of test, the average air velocity through the solar dryer was 1.62 m/s and the average daylight efficiency of the system was 46.7 per cent.

CONCLUSION

The temperature inside the dryer was increased from bottom tray to top tray. The minimum temperature in the dryer was found in bottom tray and the maximum temperature was achieved in top tray. The maximum temperature attained in the dryer was 75^{o}C at 13.30 hrs., when the insolation was high i.e. 1087 W/m^2. The average temperature inside drying chamber was 59.56^{o}C at average solar insolation of 978.12 W/m^2, ambient temperature 28.23^{o}C and relative humidity of 34.87 per cent. The maximum temperature achieved inside the dryer under full load condition was 62^{o}C at 26 per cent relative humidity and 1086 W/m^2 solar insolation. The average drying temperature achieved inside the dryer was 55.81^{o}C. The drying rate increased as the increase in solar insolation and *vice versa*. The maximum drying efficiency of tomato slice drying in low cost solar cabinet dryer was recorded as 53.47 per cent.

REFERENCES

Bukola, B. O.; Tajudeen M. A. O. and Taiwo, O. F. (2011). Performance evaluation of a solar wind-ventilated cabinet dryer. *The West Indian J. Engg*., 33(1/2): 12-18.

Hossaina, M. A. and Bala, B. K. (2007). Drying of hot chilli using solar tunnel drier. Solar Energy, **81**: 85–92.

Madhlopa, A.; Jones, S. A. and Saka, J. D. K. (2002). A solar air heater with composite-absorber systems for food dehydration. *Renewable Energy*, **27**: 27-37.

Ekechukwu, O. V. and Norton, B. (1999). Review of solar-energy drying systems II: an overview of solar drying technology. Energy Conversion Management, **40**(6): 615 – 655.

Table 1: Drying rate of different drying methods for tomato slice

Parameters	Tomato Slice	
	Open Sun Drying	**Convection Drying**
Initial moisture content, %wb	93.40	93.48
Final moisture content, %wb	7.85	7.43
Time taken to remove moisture, hr	31.50	5.50
Drying rate, moisture loss kg/hr	271.58	1564.54

Table 2: Cost economics of tomato slice drying under different structures

Sr. No.	Particulars	Cost of Drying of Tomato Slice (Rs./hr.)	
		Open Sun Drying	**Convection Drying**
1	Capital investment, Rs.	7000.00	9700.00
2	Fixed cost (Rs./hr)		
	a. Depreciation @ 10 %	0.26	0.36
	b. Interest @	0.16	0.22
	c. Repair and maintenance	0.03	0.04
	Total Fixed cost (Rs./hr)	0.45	0.63
3	Variable cost (Rs./hr)		
	a. labour charges		18.75
4	Total cost, Rs./hr	56.25	19.38
5	Total quantity dried in one batch, kg/hr	0.63	0.32
6	Cost of drying, Rs./kg	89.28	60.55
7	Cost of raw material, kg/hr	9.45	4.80
8	Total cost ,Rs/kg	98.73	65.35
9	Selling price. Rs./kg	440.00	430.00
10	Net profit, Rs./kg	341.27	364.65

Plate 1: Raw material of tomato

Plate 2: Raw material of tomato slice

Plate 3: Experimental set up

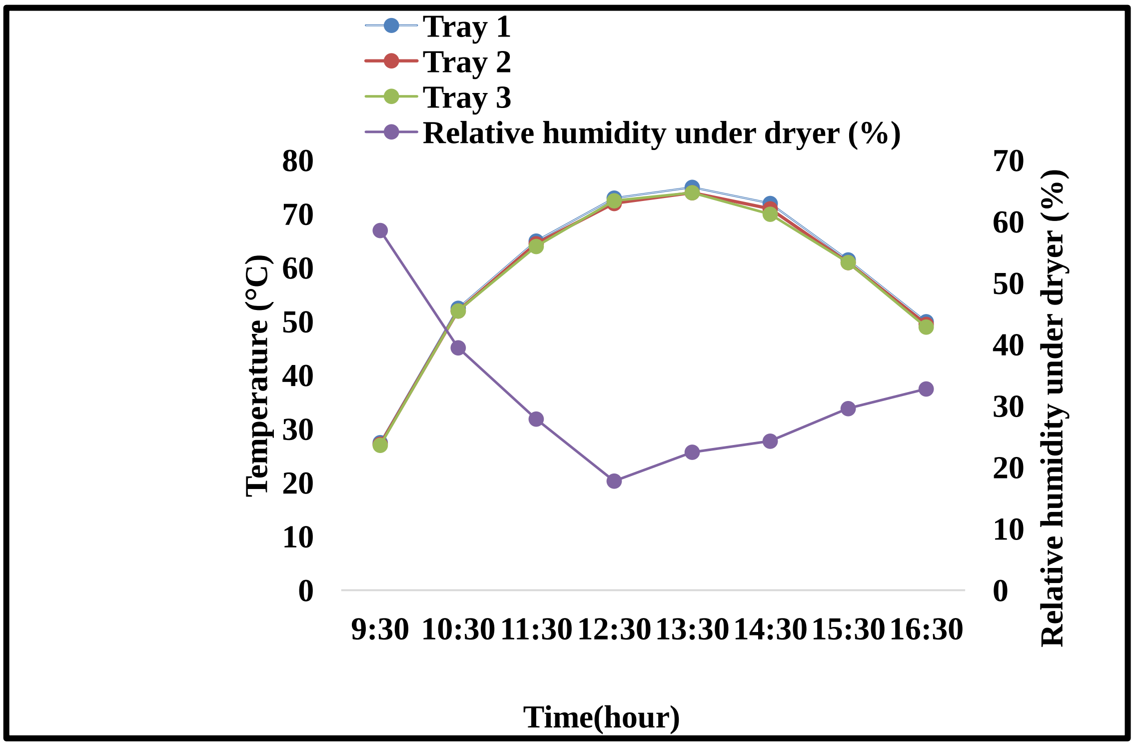

Figure 1: Temperature and relative humidity profile during no load testing of dryer

[MS received : May 29, 2017] *[MS accepted : June 19, 2017]*