Dehydration of Persimmon by Concentrating Parabolic Trough Solar Air Heater

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***Abstract*-Parabolic Trough Solar (PTS) air heater was developed locally to solve the drying of persimmon with a parabolic trough and a drying box which contains a reflected steel sheet, an absorber tube, an angle iron and a fully insulated home script refrigerator. Solar irradiance results were noted for the months of Oct- Dec, 2012. Four air mass flow rates were conducted with one natural flow rate of 0.53 kg minute-1 (M-1) and three convective air mass flow rates of 1.35 kg M-1, 1.87 kg M-1 and 1.97 kg M-1 respectively. The range of temperature for the drying of persimmon was 40-60oC and less than 15% humidity was accomplished through dehydrating time. It was found that air mass flow rates and months of the year would both significantly affect the efficiency of parabolic trough solar air heater for the drying of persimmon. Persimmon slices were dried with a high temperature 55oC and high air flow rate (1.97 kg M-1). It was also noted that during the month of November, the PTS air heater efficiency reached the maximum for the drying of persimmon due to the high air mass flow rate. The study as a whole concludes that PTS plays an important role in the drying of different agricultural products including persimmon in this energy crisis world. The study recommends more researches on the design and efficiency of the PTS air heater, which will help the farmers from losses at the field level and also will utilize the perishable commodity of agriculture during the peak season of the crop matures, and thus the farmers' overall well-being will be increased.**

Keywords*- *Solar Air Heater; Collector Efficiency; Drying Persimmon

I. INTRODUCTION

Parabolic Trough Solar (PTS) air heater is a low-cost implement and can concentrate a solar intensity into the absorber tube filled with a heat transfer fluid [1]. The performances of a dish type concentrated solar air heater at three different flow rates were 0.0401, 0.0675, and 0.0405 kg/s for drying of different agricultural products, and the maximum efficiency was recorded at 11 to 12 pm during the last three months of the year [2]. The performance and testing of the PTS air heater used two different models, including the glass shielded and unshielded elements. Shielded and unshielded receivers obtained the peak thermal efficiency of 53.8% and 55.2% respectively [3]. A solar air heater is a simple device to heat the air by a solar energy system and to utilize solar energy with different solar collectors for the drying of the agricultural products; it is widely used in this energy crisis world [4]. Passive solar energy related to the design of buildings collecting and transforming solar energy is used for passive heating, day lighting, space heating, active solar cooling, heat pumps, desalinization and industrial high temperature heat [5]. Drying is one of the oldest methods for the preservation of agricultural products such as fruits and vegetables. During drying process, temperature, velocity and relative humidity of drying air are important parameters for hot air drying process [6]. The drying times in conventional ovens could be twice as long as in PTS air heater; during sun drying, it could range from 2 to 6 days, while during solar collector drying, it could range up to 8-15 hours, depending on temperature and humidity. Drying time is shorter for slices and other cuts of fruits and vegetables [7]. Drying system efficiency for the forced convection was higher for the first day comparing with the following days due to the fast drying in the moisture falling stage [8]. The water content in vegetables and fruit is the most important parameter that may adversely affect its quality when it is not dried by a solar collector [9]. Drying rate usually has two different phases, the initial constant rate period during which the material's surface is saturated with vapor and evaporation continuously if the material's surface has enough water to evaporate, and the falling rate period, when the surface is not vapor saturated, i.e., at the critical point. Moisture diffusion is controlled by internal liquid movement: when water is continuously depleted on the surface in the falling rate period, the moisture content continues to decrease until the equilibrium is achieved and drying stops [10]. Pakistan receives solar radiation with great intensity about 20MJ. m-2d-1 of solar isolation with an annual total of 7000 MJ. m-2 throughout the year [11]. Keeping in view, the importance of drying persimmon present study was conducted on a PTS air heater connected to a drying box (Locally developed) at the Department of Agricultural Mechanization, The University of Agriculture, Peshawar-Pakistan.

II. OBJECTIVES OF THE STUDY

The broad objective of this research is to study the utilization of PTS air heater for the drying of different agricultural products to reduce the farmer cast in the field level also with the following specific objectives.

1. To design and construct the PTS air heater by the use of local technology.

2. To utilize PTS air heater for dehydration of agriculture products, e.g. persimmon.

A. Design and Construction of PTS Air Heater

The following procedure is adopted for the designing of PTS locally, which includes:

1) Parabolic Trough Solar Air Heater

Concentrator reflector is a steel sheet that focuses the solar radiation on a single point with a diameter of black painted steel absorber tube being 0.05m. Absorber tube receives air from the environment which is heated in the absorber tube by solar radiation. This hot air is abstracted to the drying box for further process.

The focal length is taken into consideration and constructed (Fig. 1). Parabola accords with Eq. (1) [12].

$$Fp = D/16d \tag{1}$$

Fp = Focal point, D = Diameter of the trough (m), d = depth of the trough (m).

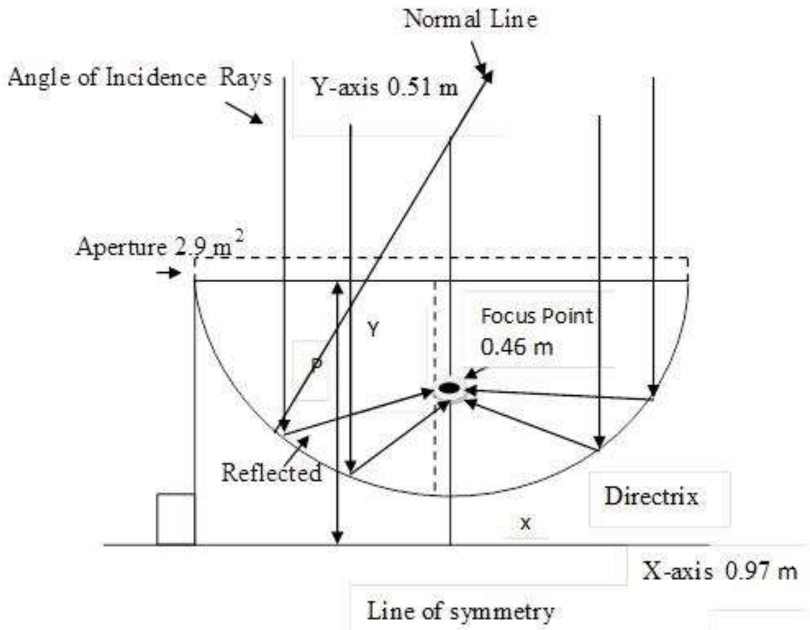

Fig. 1 Dimension of Parabola

2) Drying Chamber

Drying chamber is a fully insulated box inside with polystyrene foam. A small DC fan, having a diameter of 0.05 meters, is fixed to an outlet which sucks hot air from the absorber tube (Fig. 2).

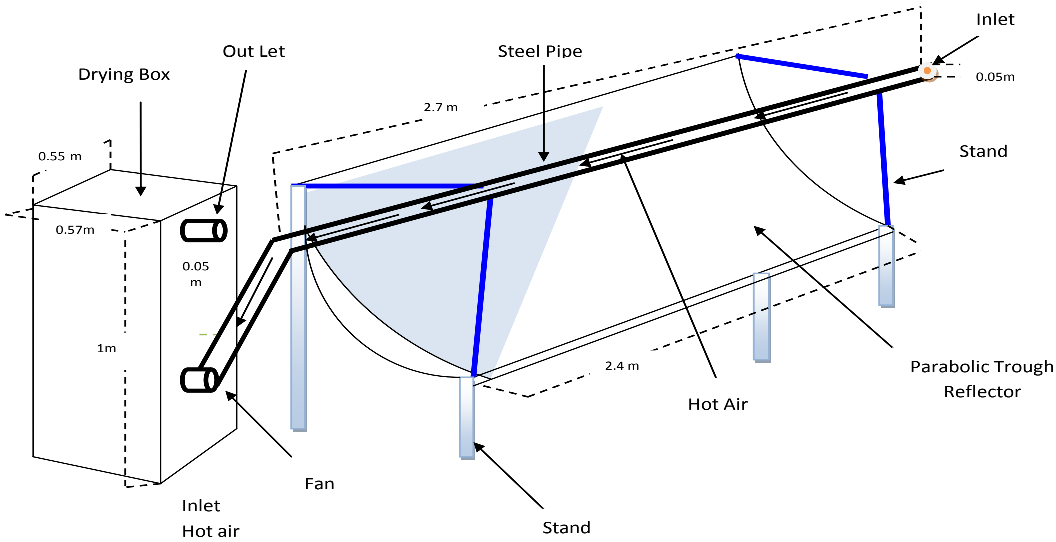

Fig. 2 The PTS air heater assembly

3) Calculating Solar Intensity Data

The solar intensity data are calculated with Eq. (2) [13].

$$Si = 0.88 \times Cv \quad (2)$$

Si = solar intensity (kJ.m-2 M-1), 0.88 constant values of solar intensity, Cv = Chart value.

4) Calculating Absorber Area

As the absorber tube is composed of a steel pipe, the area is calculated from Eq. (3) [14].

$$Aabt = \pi\ rabt\ Labt \quad (3)$$

Aabt = area of absorber tube (m2), π = constant, rabt = radius of absorber tube (m), Labt = length of absorber tube (m).

5) Calculating the Aperture Area of the Solar Air Heater

Aperture area of the curve surface is applied by Simpson's rules shown in Eq. (4).

$$Aa = h/3[y1 + yn + 1) + 4(y2 + y4 + \ldots\ldots\ldots\ldots + yn) + 2(y3 + y5 + \ldots\ldots\ldots + Yn+1)] \quad (4)$$

Aa = aperture area (m2), h = equal offset (m2), y1 + yn +1 = sum of first and last ordinates. y2 + y4 +… +yn = sum of even ordinates, y3 +y5 +.... + Yn+1 = sum of remaining odd ordinates.

6) Efficiency of a Parabolic Trough Solar Air Heater

Efficiency is calculated using Eq. (5) [15].

$$\acute{\eta} = Ho / Hi \times 100 \quad (5)$$

ή = Percent efficiency, Ho = heat output of the collector (KJ M-1), Hi = heat input of the collector (kJ M-1).

The heat output of the collector is calculated with Eq. (6) [16].

$$Ho = F.R\ air \times Cair\ X\ \Delta T \quad (6)$$

Ho = Heat output of the collector (kJ M-1), F.R air = The air mass flow rate at outlet (kg M-1), Cair = Specific heat of air ($kJ.kg^{-1}.^{o}C^{-1}$), ΔT = Difference in inlet and outlet temperature (^{o}C).

Heat input of the collector is calculated with Eq. (7) [16].

$$Hi = (½\ Aabt\ Si) + (½\ Aabt\ Art\ Irt) \quad (7)$$

A_{abt} = absorber area tube (m), S_i = solar intensity ($KJ.\ m^{-2}\ M^{-1}$), A_{rt} = area of reflecting trough (m), I_{rt} = reflected radiation coming from the trough ($kJ.m^{-2}\ M^{-1}$).

The mass air flow rate is calculated with Eq. (8) [17].

$$F.R\ air = Vo \times Dair \times Ao \quad (8)$$

F.R $_{air}$ = The air mass flow rate at the outlet (kg M^{-1}), V_o = velocity at the outlet (m.sec^{-1})

D_{air} = density of air at outlet (kg. cm^{-3}), A_o = outlet ducts of the cross sectional area (m^2)

7) Determination of Persimmon Moisture

Moisture content of persimmon is determined after each hour of drying in the PTS air heater drying box and is calculated with Eq. (9) [18].

$$Mc = Mi\text{-}Mf/Mi \times 100 \tag{9}$$

Mv = percent moisture vapor of the product, Mi = initial mass (g) of the product, Mf = final mass (g) of the product.

8) Determining the Drying Rate of the Drying Matter

The drying rate for persimmon slices is determined by using Eq. (10) [19].

$$Rd = Dp(Mi – Mf) / Sa \times t \tag{10}$$

Rd = drying rate of the persimmon (g H2o.hr-1), Dp = drying product, Mi = initial moisture content (g), Mf = final moisture content (g), t = time (hr), Sa= surface area (cm2) of persimmon slices.

9) Persimmon Preparation for Drying

Before drying, the persimmon were washing and peeled to remove the tough outer skin, and stainless steel knives were used for cutting the slices. Sparing treatment was done to maintain an attractive color and prevent fungal and bacterial growth by using sodium metabisulphite at the rate of 0.3 % for 1 kg persimmons to dip in for 2 minutes.

III. CALCULATING PERCENT RELATIVE HUMIDITY AND TEMPERATURE

Relative humidity and temperature were recorded by digital hygrometer.

A. Experimental Layout

This study used two-factorial Complete Randomized Design (CRD) for determining the effect of different air mass flow rates (0.53, 1.35, 1.87 and 1. 97 kg M-1) from October –December, 2012, on the performance in terms of efficiency of a PTS air heater. The dried persimmon slices were analyzed to show the effect of different air mass flow rates (0.53, 1.35, 1.87 and 1.97 kg M-1) on the drying rate of persimmon.

B. Results and Discussion

The PTS air heater was developed from the locally script material and was used for the drying of persimmon slices. The PTS includes temperature and humidity of the collector and drying box, the efficiency of the parabolic trough solar air heater.

C. Temperature and Humidity of the Collector and DryingBox

The relation between the temperature and humidity of the collector and drying box is shown in Fig. 3. The temperature of the absorber sloped positively from 9:00am reaching maximum of 140^{o}C at 12pm, affecting the increase of temperature in the drying box with a range of 40^{o}C - 60^{o}C. The temperature in the drying box exceeded 58^{o}C at 10:00 am and reached maximum 60^{o}C at 12:00 pm. The efficient drying time was from 9:00am - 4:00pm i.e. a total of 7 hrs. Per day was provided by the PTS air heater to dry fruits and vegetables. Digital thermo-hygrometer was used for recording the water contents of the ambient air and drying chamber, and the range was found to be less than 20%.

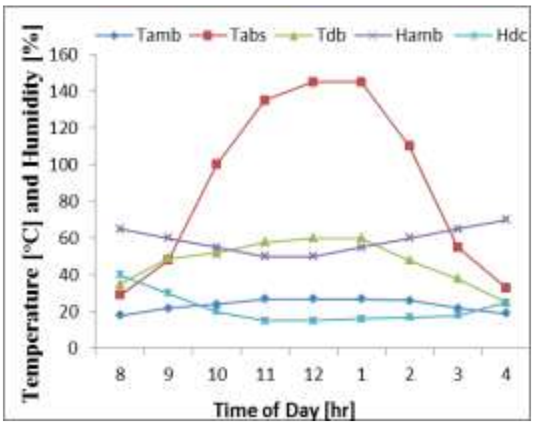

Fig. 3 Temperature and humidity of the collector and drying box

D. Efficiency of the Parabolic Trough Solar Air Heater

Parabolic trough solar collector's efficiency was analyzed at four different mass air flow rates. 0.53 kg M-1 was the natural one while 1.35 Kg M-1, 1.87 kg M-1 and 1.97 kg M-1 were convective air flows. Fig. 4 explains the relation of the air mass flow rate and efficiency, which is found highly significant in terms of effect on the efficiency of the PTS air heater. The efficiency of the PTS air heater increases significantly with the increase of air flow rates. An increase of the mass air flow rate from 0.53 Kg M-1 - 1.35 Kg M-1 increases the efficiency by 10 - 15%; while an increase of mass air flow rate from 1.35 Kg M-1 - 1.87 Kg M-1 increases the efficiency by 15 - 20%. The figure also explains that when the mass air flow rate increases 1.87 Kg M-1 - 1.97 Kg M-1 the efficiency range goes to 20 - 25%. This shows that there is a positive relation between the mass air flow.

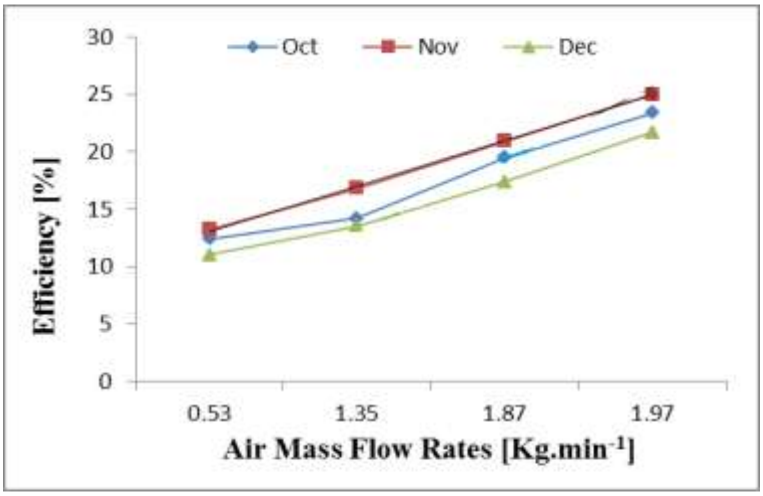

Fig. 4 Efficiency VS mass flow rate

The PTS air heater efficiency is affected by various mass air flow rates and different months of the year. Mean values of data indicate that maximum efficiency (25.0 %) was recorded with an air flow rate of 1.97 kg M-1 during November, while the minimum (12.4 %) was obtained with a flow rate of 0.53 kg M-1 during October. The interaction between mass air flow rates and months are also significant, i.e. efficiency increases with high flow rates in the months of October and November. However, highest efficiency (25 %) was recorded in the month of November at higher air flow rates (1.97 kg M-1), due to the moderate weather conditions in the valley where the experiment was conducted.

E. The Drying of Persimmon in PTS Air Heater

Persimmons being perishable require suitable method of preservation and majority of the farmers are not aware of the drying of persimmons produced in the field.

The relation between drying of persimmon and the months are presented in Fig. 5. Moisture loss by Persimmon is high with high temperature and low humidity in the drying box of the PTS air heater.

In PTS air heater, it takes drying box 16 hrs to dry the persimmon in October. After drying in the PTS air heater drying box, the moisture content was reduced from 89.7% to 13%. This is attributed by the fact that during the month of October, there is a moderate hot weather with low humidity.

In November, the experiment of the persimmon took 13hr for drying, and the moisture content reduced from 79.8% to 13%. The reason is a moderate weather in the valley. In December, the persimmon was dried for 18 hours. And the moisture content was reduced from 87.3% to 8% after drying. This is due to the fact that the drying time in the box is increased due to the start of severe cold weather in the valley.

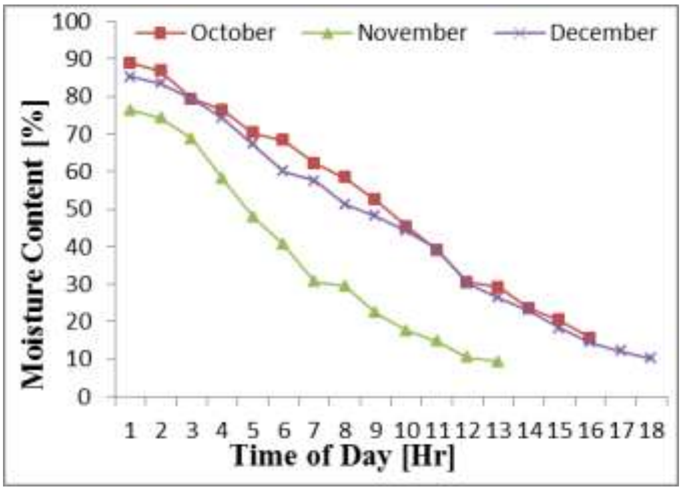

Fig. 5 Moisture content of persimmon Oct-Dec, 2012

The drying rate of persimmon in October was 0.033 gH2O. d.m. cm-2. hr-1 and the moisture content was reduced from 86.5% to 21 % because the PTS air heater efficiency was 23 % given in Fig. 6.

Persimmon showed a fast drying rate in November 0.035 gH2O. d.m. cm-2. hr-1. This is because the collector had an efficiency of 23 to 25 % The drying rate in the month of December, 2012 was (0.029 gH2O. d.m. cm-2. hr-1) as recorded because of a low efficiency of the PTS air heater.

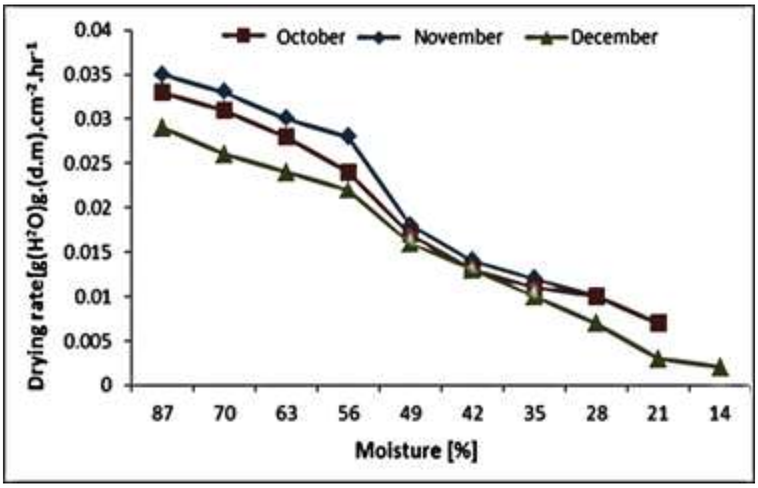

Fig. 6 Drying rate of persimmon Oct-Dec, 2012

IV. CONCLUSIONS AND RECOMMENDATIONS

The findings of the study conclude that the efficiency of the PTS air heater increases with an increase of the air mass flow rates. The study also reflects the interrelationship between the efficiency of the collector with the different season of the year. The increase in the air mass flow rate increases the efficiency of the drying box. The drying rate of persimmon was high during the month of October and low in the month of December. The study recommends more empirical researches on the topic to encourage the use of the collector for the drying of other perishable products and byproducts in the agriculture to meet the food security threat.

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