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Drying of Apricots Using a Proficient Dish Type Solar Air Heater

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Abstract: The present experimental work is to study drier in the form of solar air heater that dries Apricots (Prunus armeniaca). A small dish type solar air heater, connected to a drying chamber was developed in May, 2012 to evaluate its performance for drying apricots. The efficiency of this solar air heater was evaluated in May, 2012 at three air flow rates. Results showed that flow rates significantly ($P< 0.000$) affected the efficiency of the solar air heater. Efficiency improved from 20% at the natural flow rate of 0.01kg. sec^{-1} to 42.6% at a high convective flow rate of 0.21 kg. sec^{-1}. Furthermore apricots were dehydrated at a temperature of 50 °C and less than 15% relative humidity. Apricots were dried to a moisture content of less than 8%. It was experiential that apricots took 13 hours of lost moisture from 85% to 8%. It was concluded that solar air heaters must be operated at high flow rates to get maximum efficiency to get valuable drying of apricots.

Key words: Solar Radiation · Solar energy conservation · Dish type Air Heater · Air Flow Rates · Efficiency · Apricots · Drying Rate · Moisture Lost

INTRODUCTION

Solar energy is available in great amount in all parts of Pakistan. This energy can be trapped and utilized in the form of useful heat load by an efficient solar air heater. A solar collector in the form of solar air heater with convective heat flow, having efficiency of 40% to 50% is best choice for valuable drying of apricots [1]. Apricot (Prunus armeniaca) drying by customary methods of open air sun drying is not agreeable, as the apricot becomes contaminated with bacteria and insect and spoils speedily in the unrestrained ambient temperature and high relative humidity [2]. Post harvest losses apricots due to open air drying which are 10 to 15%. These losses can be reduced by the use of solar drier in the form of solar air heaters. Solar air heaters supply constructive drying environment to the apricots to be dried out and also it can make light of pathogens like molds, bacteria and insect that may attack apricots [3]. Solar air heater with convective heat flow enhanced solar drying that could smooth the progress of early crop harvest, long term storage and quality perfection of apricots. The system of drying should be studied for superior solar drying to get precious dried apricots [4].

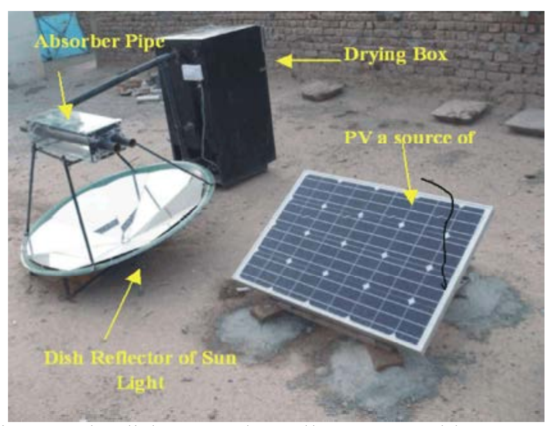

Fig. 1: The dish type solar collector assembly

The objective of the Study: overall objective of the study was to develop a proficient dish type solar air heater that provide optimum drying conditions to dry apricots (Figure. 1) . The factor which are studied are the

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daily solar intensity, efficiency of the solar air heater with different mass flow rates of air, moisture lost in each hour and drying rate in each hour of drying of apricots.

MATERIALS AND METHODS

Performance of Collector: The solar air heater efficiency is determined at three different levels of air flow rates to check the collector performance. The efficiency is determined by taking a percentage of the ratio of heat loaded by the collector and heat available to the collector in unit time.

Heat Available to the collector can be calculated by taking the apricot of absorber area and solar intensity at unit area. Where solar intensity is determined by a mechanical Pyranometer. The heat available can be calculated using the formula used by [5, 9]:

$$Q_i = A_{ab} \times I_s \tag{1}$$

Also heat loaded by the collector is determined by the product of air flow rate, specific heat value of air and change in temperature of inlet and outlet ducts. The heat outlet is calculated using the formula used by [3, 10, 13].

$$Q_o = AFR \times C_a \times \Delta T \tag{2}$$

By taking the ratio of equation 2 to 1 for calculating efficiency we have the formula used by [15, 17, 18].

$$\eta = \frac{AFR \times C_a \times \Delta T}{A_{ab} \times I_s} \tag{3}$$

Mass Flow Calculations: The air flow rate through the dish type solar air heater is determined by the apricot of air speed at outlet, density of air and outlet ducts cross sectional area. The flow rate is calculated by using the formula used by [11, 12]

$$AFR = V_o \times \rho_a \times A_o \tag{4}$$

Moisture Calculation: Moisture in the apricots is determined after each hour of drying. Apricots are dried in less then 8% moisture content to minimize mold, insects and bacterial attacks. The initial moisture content is determined by oven method while the moisture after each hour in drying is determined by taking the initial weight and weight lost after each hour with the help of an electric balance. The formula for determining the moisture loss which is given by [14 and 17]

$$M_c = \frac{w_i - w_f}{w_i} \times 100 \tag{5}$$

Drying Rate of Apricots: Drying rate is defined as the quantity of water evaporated per gram of dry matter per unit area in unit time. The drying rate of apricots is determined to study how much moisture is lost in each hour of drying from a unit mass of dry matter in the apricots. The drying rate is determined for these apricots by using the formula used by [6, 8].

$$D_r = \frac{\left(w_i - w_f\right)}{\left(D_m \times A_p \times D_t\right)} \tag{6}$$

Preparation of Samples for Drying: After blanching in hot water, the apricots were treated with 1% solution of potassium Meta-bi-sulfate. Apricots were dipped for 2 minutes. The pre treatment helps to prevent the apricots from an attack of molds and bacteria. It also helps to retain the color of the apricots as it reduces oxidation of the metals present apricots [8 and 9]. Set the flow rate to 0.21 kg.sec^{-1}. Note the dryer temperature with the help of a thermometer placed in the drying chamber. The temperature must not be less than 45°C. The temperature of the drying should be in the range of 50°C to 55°C. Also determine the humidity in the drying chamber as well as the outside environment with the help of digital hygrometer. The humidity must be less than 15% inside the drying chamber. Then apricot cross sectional area was determined by determining the radius with the help of steel tape. The apricots were then placed on the trays of the drying chamber and the trays were placed in the drying chamber. Determine moisture lost and drying rate after each hour of drying. Dry apricots until the moisture content reaches less than 10% [7, 10, 16]

RESULTS AND DISCUSSIONS

Solar Intensity: Figure. 2 show the average solar irradiance for a drying period which is recorded with the help of Mechanical Pyranometer in the days of drying of apricots. It is clear from the graph that solar intensity is high at noon. It is 1.0 calories per square centimeter per minute. The solar air heater was used for collecting solar energy in the form of heat for drying purposes from 9:00 am to 5:00 pm. It means that a total of 8 hours were available for drying period. Chi squared goodness of fit test is applied to the data using Easy Fit Professional Version 5.5 Statistical Software to find how close are the observed values to those which would be expected under the fitted normal distribution. Figure 2 shows the results of solar radiation intensity. The data are normally distributed with chi square value of 0.998 and P value = 0.982. These results of solar radiation intensity were same as recorded by Ahmad, 1989, Iftikhar *et al.* 1987, Karim *et al.* 2003 and Liaqat 2005.

Performance of the Collector: The efficiency of the solar air heater was evaluated in May, 2012 at three different air flow rates. The one 0.01 kg.sec^{-1} was the natural air flow rate while the other two were forced air flow rates 0.21 kg.sec^{-1} and 0.25 kg.sec^{-1} . The various air flow rates were changed by changing the fan speed. Increased by air flow rate significantly increased the efficiency of the solar air heater because at low flow rate of the air into the collector there was high temperature of the absorber and due to high temperature more heat was lost from the collector to the surroundings which resulted in lower efficiency of 20 % at the natural air flow rate of 0.01 kg. Sec^{-1}. Efficiency of 35% was recorded at high flow rate of 0.25 kg.sec^{-1}. Table 1 shows LSD test for efficiency with various flow rates. Efficiency increased significantly by increasing air flow rate because air moved more heat with itself to the drying chamber from the collector. As a result less heat is lost from the collector to the surroundings. The data of efficiency at different flow rates was replicated three times and analyzed by a completely randomized design using MSTATC software. The statistical analysis (Table. 1) showed that air flow rates have a significant effect on the efficiency of the dish type solar air heater. This significant increase in efficiency with the mass flow rate was also recorded by Yeh *et al.* 1995 and Gul *et al.* 2005 . These results are also in the agreement with the findings of Karim *et al.* 2004, Bolaji, 2005 and Suleyman, 2006, who recorded a significant increase in efficiency of a solar air heater with an increase in air flow rate.

Drying Environment: The temperature of the drying chamber, ambient temperature and temperature of the absorber along with the time of day was recorded with thermometer. The temperature of absorber started increasing at 7:00 am and reached to a maximum of 110°C at 12:00 noon. Due to this the heat from the absorber was transferred to the drying chamber by the air blowing inside the solar air heater and temperature of the drying chamber increased with increased in absorber's temperature. The suitable temperature range for drying

Table 1: Mean Table for Efficiency

Flow Rates (kg.sec^{-1})	Efficiency (%)			
	R1	R 2	R 3	Mean
0.01	24.1	22.8	19.0	21.9**
0.21	32	33.6	35.2	33.6**
0.25	40.3	40.3	42.6	41.7**
	32.13ns	32.23ns	32.27ns	

Mean values followed by ** are significant at 1% level and ^{ns} mean not Significant.

$LSD_{0.01}$ for Mean = 4.2, $LSD_{0.05}$ for Mean = 5.5

$LSD_{0.01}$ for Interaction= 3.7, $LSD_{0.05}$ for Interaction= 3.8

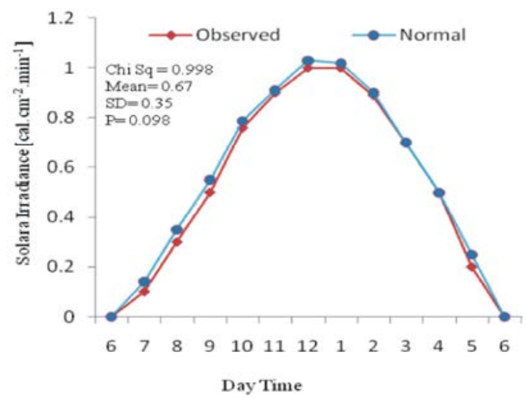

Fig. 2: Solar Irradiance Graph

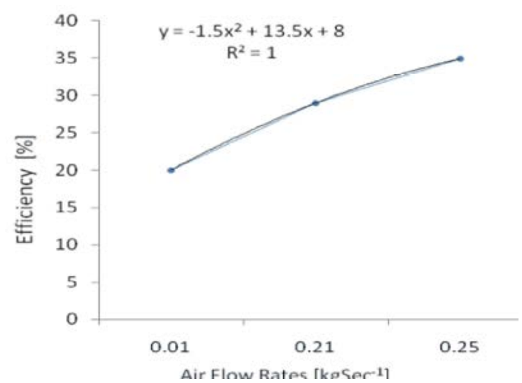

Fig. 3: Efficiency of the Dish Type Solar Collector

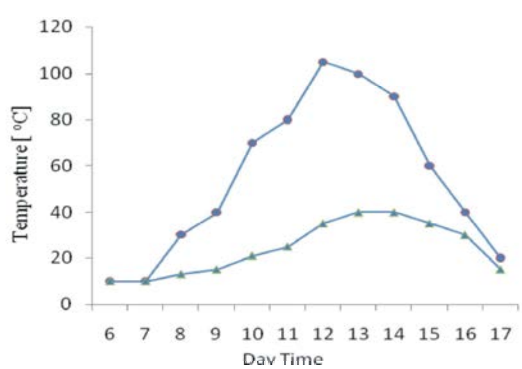

Fig. 4: Temperature Data of the Drying Chamber

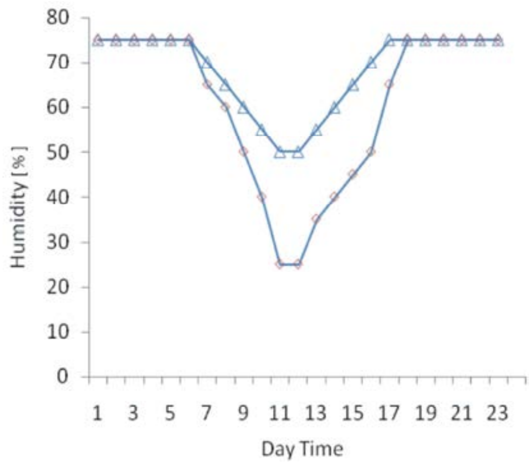

Fig. 5: Humidity Data of the Drying Chamber and outside Environment

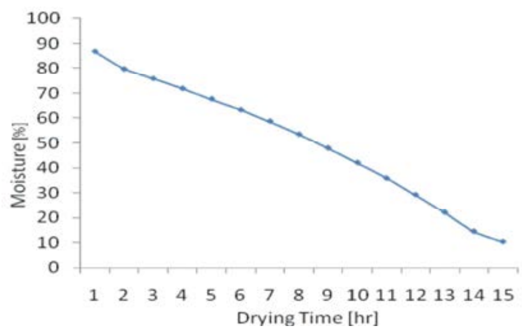

Fig. 6: Moisture Lost in each Hour of Drying from Apricots

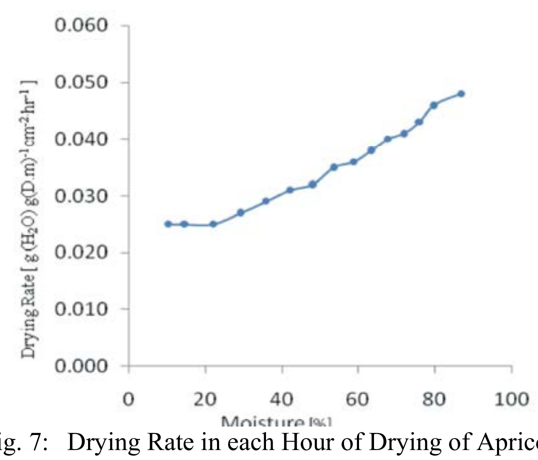

Fig. 7: Drying Rate in each Hour of Drying of Apricots

apricots is from 40 to 50°C [12, 16]. The outside temperature variations at the time of day. The temperature range in morning from 8:00 am to 10:00 was 33°C and from then tell 4:00 pm it raised to 43 °C. In the drying chamber of the collector at 9:00 am temperature of the drying chamber was 40°C and at 12:00 noon it reached to 50°C. The temperature remains in the range of 40°C to 50°C for 7 hours (7:00 am to 4:00 pm). For drying of apricots the humidity range required must be less than 30% [6, 9]. The humidity of drying chamber started decreasing from 50% at 9:00 am in the morning and decreased to 20% at 12:00 noon. The humidity remains in the range of 20% to 50% for 7 hours (9:00 am to 4:00 pm). The humidity of open air remained 63% from 8:00 to 11:00 am which decreased to 49% from 11:00am tell 4: 00 pm If we look at the humidity and temperature data in Figure. 4 and 5 so a total of 7 hours per day were available for apricots drying by the drying chamber of the dish solar air heater.

Drying of Apricots: The moisture lost in each hour for apricots is shown in Figure 6. Apricots were dried at a temperature of 45 to 50°C and humidity of 15 to 20 %. Apricot took 13 hours to reduce moisture content to less than 8%. The moisture lost rate of apricot is uniform and this type of moisture lost increased the quality of the dried apricot as it was dried at a very low temperature as well as mass flow rate. The drying rate of apricot is shown in Figure 7. Apricot showed a very consistent drying rate. This was due to low temperature and low mass flow rate. The drying rate starts from 0.45 g (H_2O) /g (d.m). cm^{2} hr and after 10 hours it reaches to 0.28 g (H_2O) /g (d.m). cm^{2} hr. The results of moisture lost and drying rate are the same as recorded by Karim *et al.* 2003and Bolaji, 2005. The results are also in accordance with the findings of Mahmood *et al.* 2005.

Conclusions and Recommendations: It was concluded that

- The efficiency of the solar air heater increased with the increased of air flow rate" so it is recommended to operate solar heaters at high flow rates.
- Also apricots dried by the use of efficient solar air heater dried quickly, safe from pest attack and are of good quality.

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List of Abbreviations:

- AbArea of the absorber (m^2)
- AoArea of outlet duct (m^2)
- Ap Cross sectional area of the apricot in (cm^2)
- Ca Specific heat capacity of air ($kJ.kg^{-1}.°C^{-1}$)
- Da Density of air ($kg.m^{-3}$)
- Dm Dry matter in the apricot (g)
- DpDiameter of the apricot (cm)
- DtDrying time (hr)
- Dr Drying rate ($g_{(H2O)}.g^{-1}_{(dm)}.cm^{-2}.hr^{-1}$)
- F.R Mass flow rate ($kg.min^{-1}$)
- HoRelative Humidity at outlet (%)
- HiRelative Humidity at inlet (%)
- Hdr Relative Humidity of the drying chamber (%)
- Is Incident radiation ($kJ.m^{-2}.min^{-1}$)
- M.c Moisture content of the apricot (%)
- T_{amb}Ambient temperature (°C)
- ΔT Difference of inlet and outlet temperatures (°C)
- Qi Heat input to the collector ($kJ.min^{-1}$)
- Qo Heat 0utput by the collector ($kJ.min^{-1}$)
- Rp Diameter of the apricot (cm)
- ViVelocity of air at inlet ($m.sec^{-1}$)
- Vo Velocity of air at outlet ($m.sec^{-1}$)
- W_f Final weight of the apricot (g)
- W_lWeight lost of the apricot (g)
- W_i Initial weight of the apricot (g)
- W_t Total weight of the apricot (g)
- η Eta , Efficiency of the solar collector (%)