ANALYSIS OF THERMAL PERFORMANCE OF SOLAR AIR DRYER FOR THREE DIFFERENT ABSORBER PLATES

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ABSTRACT

Prime focus of this paper is to perform analysis of solar air heater cum dryer system. The categorical objectives of this paper are to compare the thermal performance of three different solar air heaters (Type I, Type II, and Type III) and also to study analytical and experimental performance of this fabricated solar drying system. This system can be used for drying various agricultural products like fruit and vegetables. During the course of study, red chilies, mint and grapes were successfully dried in the solar dryer. In this experiment, various parameters were used in absorber plate such as solar air heater with absorber plate (Type I), solar air heater having wire mesh (Type II), and Solar air heater having aluminum fins (Type III). The maximum thermal efficiency was achieved in this experiment in Type III, at air flow rate 4.20 m/s.

Keywords: Solar air heater, solar air dryer, Thermal efficiency, Solar flux W/m², Mass flow rate and Absorber plate.

1. INTRODUCTION

Solar air heater (SAHs) are cheaper and widely used as solar energy collection devices employed to deliver heated air at low moderated temperature for space heating, drying agricultural product like Fruit, seeds and vegetables and which is some industrial application. Traditional solar air heaters mainly consist of panels, insulated hot air ducts and air blowers in active system. The panel consists of an absorber plates and a transparent cover. There are many parameters affecting on the solar air heater efficiency e.g. collector length, collector depth, type of absorber plate, glass cover plate, wind speed etc. The absorber plate area and heat transfer coefficient between the air and the absorber plate are two important parameters affecting the efficiency of the collector. Increase in these parameters will increase the collector efficiency.

Fig1: Schematic diagram of solar air heater

Nomenclature

- dx₁: Thickness of thermocole
- dx₂: Thickness of plywood
- hₐ: Convective heat transfer coefficient from glass cover to air
- I: Solar radiation (W/m²)
- k₁: Thermal conductivity of thermocole
- k₂: Thermal conductivity of Plywood
- m: Mass flow rate (kg/s)
- P: The pressure (N/m²)
- Qₒ: Collector gain useful energy(W)
- R: Specific gas constant (287/J/kgk)
- T: Temperature
- Tₐ, in: Inlet air temperature
- Tₐ, out: Outlet air temperature
- U: Overall heat transfer coefficient
- V: Air- velocity at outlet (m/s)
- η: Thermal efficiency
- ν: Specific volume (m³/kg)

2. DRYER DETAILS

The solar dryer is a device that uses solar energy to dry foods, vegetables etc. Solar drying is the most common form of food preservation and extends the food shelf life. The dehydration of foods aim at reducing a high density product, which when adequately packed has a long shelf life, after which the food can be rapidly and simply reconstituted without substantial loss of flavor, taste, color etc. In this experiment, the red chilli, mint and grapes are generally dried from an initial moisture content of about 89% (wet bases). The solar drying system is classified primarily according to their heating modes and...
the manner in which the solar heat is utilized. In broad terms, they can be classified into two major groups, namely active solar energy drying system and passive solar energy drying systems. This paper describes the thermal performance of three different solar air heater (i) solar air heater with absorber plate (Type I), (ii) solar air heater having wire mesh (Type II) and (iii) solar air heating having aluminum fins (Type III) and also describes the performance of solar drying. It has been found that the maximum thermal performance achieved in Type III at air flow rate 4.20 m/s.

3. THERMAL PERFORMANCE EQUATIONS

3.1 THERMAL EFFICIENCY

It is the ratio between the gain useful energy and the solar radiation incoming to the solar heater, which is called thermal efficiency. The thermal efficiency is denoted by \( \eta \). We have

\[ \eta = \frac{Q_u}{I A_c} \]  

(1)

Where \( Q_u \) is the collector gain useful energy (W), \( I \) is the solar radiation (W/m\(^2\)) of the heater surface, \( A_c \) is the absorber surface area of the collector (m\(^2\)). The useful energy gain (\( Q_u \)) can be calculated by following equation:

\[ Q_u = \dot{m} C_p (T_{a,out} - T_{a,in}) \]  

(II)

Where \( \dot{m} \) is the mass flow rate (kg/s), \( C_p \) is the specific heat of air at constant pressure (kJ/kg.K), \( T_{a,out} \) is the temperature of air at outlet, \( T_{a,in} \) is the temperature of air at inlet. Putting the value of \( Q_u \) from equation (II) in equation (I), we get

\[ \eta = \frac{\dot{m} C_p (T_{a,out} - T_{a,in})}{I A_c} \]  

(III)

Equation for Mass flow rate (\( \dot{m} \)) is:

\[ \dot{m} = \rho A V \]  

(IV)

Where \( \rho \) is the density of air (kg/m\(^3\)), \( A \) is the cross section area of pipe at exit (m\(^2\)) and \( V \) is the velocity of air at exit (m/s).

Density of air (\( \rho \)) can be calculated by following equation:

\[ P \nu = RT \]  

(V)

Where \( P \) is the pressure (N/m\(^2\)), \( \nu \) is the specific volume (m\(^3\)/kg), \( R \) is the specific gas constant (287 J/kg.K) and \( T \) is the temperature.

\( \nu \) can be written as:

\[ \nu = \frac{1}{\rho} \]  

(VI)

So, equation for \( \rho \) is:

\[ \rho = \frac{P}{RT} \]  

(VII)

3.2. OVERALL HEAT COEFFICIENT (U)

\[ \frac{1}{U} = \frac{1}{h_a} + \frac{dx_1}{K_1} + \frac{dx_2}{K_2} \]  

(VIII)

Where \( U \) is the Overall heat coefficient of the collector, \( h_a \) is the convective heat transfer coefficient, \( dx_1 \) is the thickness of thermocole, \( dx_2 \) is the thickness of plywood, \( K_1 \) is the thermal conductivity of thermocole, \( K_2 \) is the thermal conductivity of plywood.

3.3. CONVECTIVE HEAT TRANSFER COEFFICIENT (H\(_a\))

\[ h_a = 2.5(\Delta T)^{0.25} \]  

w/m\(^2\). (Standard value for \( h_a \))

(IX)

Heat losses

\[ Q_{side} = U A_c (T_{a,out} - T_{a,in}) \]

\[ Q_{top} = U A_k (T_{a,out} - T_{a,in}) \]

\[ Q_{bottom} = U A_c (T_{a,out} - T_{a,in}) \]

\[ Q_{total} = Q_{side} + Q_{bottom} + Q_{top} \]

Fig 2: Mint before and after dry

Fig 3: Red chili before and after dry
Where $Q_{top}$ is the heat loss on the top of the collector, $Q_{side}$ is the bottom heat loss of the collector, $Q_{side}$ is the side loss of the collector and $Q_{total}$ is the total loss of the collector.

3.4 MOISTURE CONTENT (%)-

Moisture content is the percentage of moisture present in the product. That reduces during drying period, the moisture removed from the drying product at the level till the equilibrium condition between the humidity of air or the moisture content in air and the moisture in the product.

Moisture content (%) - initial weight – final weight *100 / initial weight.

4. EXPERIMENTAL SET-UP

The design and fabricated of an experimental set-up is shown in fig 4. This Experiment was designed and fabricated in order to given data for the testing. The experimental set-up mainly consists of wooden plywood box. The thickness of plywood box was 12 mm. We have tested the solar air heater at three different phases viz. Type I, Type II and Type III. The internal dimension of plywood box was 1476 × 726 × 174 mm. The plywood box was painted dark rubber black paint and the external side of plywood box was insulated with 25.4 mm thickness compact thermocol. It was also insulated 27 gauge aluminum sheet after the insulating thermocol. Two normal window glass was used to placed above solar chamber. The thickness of glass was 5 mm. The window glass was fitted with supported on bits. The distance between the first glass and bottom of the plywood box was 114 mm and the distance between first glass and second glass was 60 mm. In this experiment the absorber plate was made from aluminum sheet. The thickness of this aluminum sheet was 22 gauges. The aluminum sheet was painted in rubber black paint to the purpose of more heat. The computer fan was used to force the air through solar chamber. There were two computer fans are used in the solar collector. The diameter of fan was 80 mm. And also design and fabricated solar dryer chamber which chamber was attached the solar air heater with the help of pipe. The dryer chamber is made from plywood box. The internal dimension of dryer chamber was 311 × 311 × 484 mm, which chamber was also insulated the compact thermocol and aluminum sheet. The diameter of outlet hole of dryer chamber was 60 mm. Which was used to LM-35 sensor which measures the temperature at different point, such as glass surface, absorber plate, drying chamber temperature, We have also used the alcohol thermometer to measure ambient temperature. The solar radiation was measure to the help of digital solar power meter and air-velocity measure from digital anemometer. Which experiment was conducted in the day of May-June 2015 in Rajasthan. The testing of this experiment was performed between 10 AM to 4 PM. The interval of reading was 30 minutes. The solar radiation was measure horizontal as well as inclined at 26 degree.

Table 1: Design details of solar drying system

Fig4: Experimental set-up on SAHs
5. RESULTS AND DISCUSSION

Collector performance tests were conducted on days with clear sky condition. The collector slope was adjusted to 26 degree which is considered suitable for the geographical location of Jaipur Rajasthan (latitude 26.92° N longitude 75.82° E altitude & 431m above sea level). The collector was provided with LM-35 temperature sensor for measuring temperature of absorber plate, drying chamber temperature, glass temperature, inlet temperature and alcohol thermometer to measure the ambient temperature. Experimental studies had been performed during the 22 days (30.05.2015-22.06.2015) period. The test was conducted between 10:00 AM and 4:00 PM solar time. The moisture removed (%) and thermal performance of all three types, type I, type II and type III solar air heaters were calculated using above equation at velocity of air 4.20m/s. Fig.5 shows the hourly temperature variations of Type I collector and exit air velocity is 4.20 m/s, during the experiments. The solar flux (W/m²) is also shown in the secondary axis. Daily average temperature on the Absorber plate, drying chamber temperature, Global radiation, ambient temperature are measure as 90.76°C, 75.46°C, 800.75 W/m² and 42.46 respectively. The average thermal efficiency is calculated as 42%. On this day 100gm red chili we put it in drying chamber and after drying 80% moisture removed.

![Fig 5: Temperature variation with time with air flow rate 4.20 m/s of Type II on May 30, 2015](image1)

The hourly temperature variations of Type II at mass flow rate 0.012kg/s and exit air velocity is 4.20 m/s as shown in fig 6. Daily average temperature on the Absorber plate, drying chamber temperature, Global radiation, ambient temperature are measure as 80°C, 66.6°C, 805 W/m² and 35.5°C respectively. The average thermal efficiency is calculated as 43.9%. On this day 500gm grapes we put it in drying chamber and after drying 20% moisture removed.

![Fig 6: Temperature variation with time with air flow rate 4.20 m/s of Type II on June 5, 2015](image2)

The hourly temperature variations of Type III at mass flow rate 0.011kg/s and exit air velocity is 4.20 m/s as shown in fig 7. Daily average temperature on the Absorber plate, drying chamber temperature, Global radiation, ambient temperature are measure as 77.7°C, 73.2°C, 871.15 W/m² and 39.5°C respectively. The average thermal efficiency is calculated as 45.9%. On this day 500gm grapes we put it in drying chamber and after drying 20% moisture removed.

![Fig 7: Temperature variation with time with air flow rate 4.20 m/s of Type I on June 15, 2015](image3)
Table 2: Moisture removed for red chili, mint and grapes

<table>
<thead>
<tr>
<th>Material Used In Dry Chamber</th>
<th>Before Drying (gm)</th>
<th>After Drying (gm)</th>
<th>Moisture Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red chili</td>
<td>100</td>
<td>20</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>20</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>300</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>100</td>
<td>66.67</td>
</tr>
<tr>
<td>Mint</td>
<td>250</td>
<td>20</td>
<td>92</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>200</td>
<td>60</td>
</tr>
<tr>
<td>Grapes</td>
<td>500</td>
<td>400</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>240</td>
<td>40</td>
</tr>
<tr>
<td>Corianders</td>
<td>300</td>
<td>120</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>140</td>
<td>52</td>
</tr>
</tbody>
</table>

The capacity of drying chamber is 100gm per day so overall moisture removed 89 % weight basis.

Table 3: Overall thermal efficiency of Type I , Type II and Type III

<table>
<thead>
<tr>
<th>Name of Parameters</th>
<th>Absorber surface Area(m²)</th>
<th>Overall Thermal Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar air heater with absorber plate (Type I)</td>
<td>1.125</td>
<td>42.0</td>
</tr>
<tr>
<td>Solar air heater having wire mesh (Type II)</td>
<td>1.495</td>
<td>43.0</td>
</tr>
<tr>
<td>Solar air heater having aluminium fins (II)</td>
<td>1.275</td>
<td>45.9</td>
</tr>
</tbody>
</table>

To check the quantity of moisture present in the red chilies used in the solar dryer, an electric oven drying experiment was conducted. 220gm red chilies were kept at 120ºC for shows and the loss of weight and percentage of moisture removed at the basis of weight was calculated and found that the moisture content was 86%. The same tabulated in table 4

Table 4: Moisture removed in red chili before and after drying at temp 120ºC in an Electric oven

<table>
<thead>
<tr>
<th>Material used in oven</th>
<th>Before drying (gm)</th>
<th>After drying (gm)</th>
<th>Moisture Removed (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red chili</td>
<td>220</td>
<td>30</td>
<td>86</td>
</tr>
</tbody>
</table>

6. COST ESTIMATION

The overall cost of the experiment was Rs 17970. The description of the product is stated below:

Table 5: Cost Estimation of Project

<table>
<thead>
<tr>
<th>S NO.</th>
<th>DESCRIPTION</th>
<th>AMOUNT (Rs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Plywood</td>
<td>4200</td>
</tr>
<tr>
<td>2</td>
<td>Glass</td>
<td>2600</td>
</tr>
<tr>
<td>3</td>
<td>Aluminum</td>
<td>2800</td>
</tr>
<tr>
<td>4</td>
<td>Stand</td>
<td>3100</td>
</tr>
<tr>
<td>5</td>
<td>Computer fan</td>
<td>240</td>
</tr>
<tr>
<td>6</td>
<td>Thermocolle</td>
<td>1100</td>
</tr>
<tr>
<td>7</td>
<td>M.S tray</td>
<td>380</td>
</tr>
<tr>
<td>8</td>
<td>Fevicol</td>
<td>110</td>
</tr>
<tr>
<td>9</td>
<td>Voltage divider</td>
<td>240</td>
</tr>
<tr>
<td>10</td>
<td>Making Charge(labor)</td>
<td>3200</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>17970</td>
</tr>
</tbody>
</table>

7. TECHNO ECONOMICS

The payback period of the solar air dryer setup depends on overall cost of fabrication, maintenance cost and operating cost. The overall fabrication cost is Rs. 17970

Table 6: 220gm red chili to be dried by electricity in an oven

<table>
<thead>
<tr>
<th>1. Oven cost</th>
<th>Rs. 8900</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. One year electricity cost</td>
<td>Rs. 6480</td>
</tr>
<tr>
<td>Total cost</td>
<td>Rs. 15380</td>
</tr>
</tbody>
</table>

8. CONCLUSIONS

1. Fruits and vegetables can be use in off season without change quality by making use of a solar air dryer
2. The system can be constructed with the material which is locally available and cheap.
3. Solar air heater with aluminum fins contains higher thermal efficiency compare to solar air heater having absorber plate.
4. Solar air heater with aluminum fins has improved thermal efficiency as aluminum fins increase the heat transfer area.
5. The maximum average thermal efficiency acquire as 45.9 % in solar air heater with aluminum fins at exit air velocity 4.20 m/s.

REFERENCES


[10]. Ho-Ming Yeh, Chii-Dong Ho. Effect of external recycle on the performances of flat-plate solar air heaters with internal fins attached. Renewable Energy 34 (2009) 1340-1347

