Experimental study on triple pass solar air heater with thermal energy storage for drying mint leaves

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Abstract: Solar dryer is used to preserve agricultural products, save energy consumption and reducing environmental impact. A new type of solar collector has been designed and tested. This study deals with the design of a modular drying system consisting of two functional units, namely a triple pass flat plate air collector with thermal storage and a drying chamber. The flat plate collector is 2 m long, 1 m wide and 0.1 m deep, and incorporates absorber and thermal energy storage unit. Air flows between two glazing during first pass then in the opposite direction through the absorber during second pass and finally through the spaces between units of thermal energy storage and bottom plate into drying chamber. The experiments are conducted for drying mint leaves and the results show that considerable improvement in drying time and moisture removal. It is concluded that the design is compact, sufficiently simple and gives a high thermal performance.

Keywords: solar dryer; triple pass; absorber; thermal energy storage; mint leaves; useful collector gain; thermal efficiency.


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1 Introduction

Food is important one because, it contains essential nutrients and to gives nutritional supports for the body. All the fruits and vegetables are not available throughout a year and are seasonally available. Generally, the quantity of the food products is not up to the expected levels. It may short fall, abundantly or surplus available and also depends on season of the year. Food production and supply does not always balance with the demand of the people (Murthy, 2009). In developing countries (Esper and Muhibeuer, 1998), the food losses occurs due to lack of suitable technology, improper cultivation, fertilisation, post harvest losses, marketing and transportation problems, etc. The world’s food problem shall be solved only by reducing the food losses and that is achieved by the method of food preservation. It is therefore very essential to update existing facilities or make a new one for storing and preserving of food. Food preservation is a process to prevention of decay or spoilage and used to keep food edible for future purpose. There are many methods available for food preservation. Among the food preservation process drying is one of the best methods. Since many countries have adopted drying is the method of food preservation (Murthy, 2009). Drying is used to remove water from agricultural products to prevent growth of bacteria, microorganisms and hence preserve the product. Drying is a process to save the loss of nutritional qualities and spoilage. Solar drying technology is used to dry agriculture products and saves fuel cost. The advantages for using solar drying are process the vegetables and fruits in clean, hygienic condition; save energy; zero energy cost; protects the environment; using renewable energy (Sharma et al., 2009). Drying is processed by using hot air. The effective drying (Patel, 1999) is achieved by three factors: air should be warm (Hot); dry and moving (velocity). These three factors play an important role in the drying process (Patel, 1999).

Over the world mint is primarily used as a flavouring agent (Arslan et al., 2010). Mint is a genus of the Labiatae family, which comprises many species, varieties and hybrids. It is generally used in some situation of colds, flu, fever, poor digestion, motion sickness, food poisoning and for throat and sinus ailments (Sallam et al., 2015). Mint leaves are often put into teas and other beverages and used to make mint jelly (especially good with lamb). It is perennial with purple flowers, refreshing odour and flavour and often used as garnish.
Various researches have investigated the performance of solar dryer. Muller et al. (1989) determined that, the drying of whole mint in greenhouse solar dryer for three days to final moisture content of 10% (w.b.) from initial moisture content of 80% (w.b.). Lebert et al. (1992) studied that the effect of drying on drying kinetics of mint in three factors: air temperature, humidity and air velocity. They concluded that, the drying air temperature was the primary and important factor in the rate of drying. Kouhila et al. (2001) determined the sorption isotherms of mint (Mentha viridis), verbena (Lippia citriodora) and sage (Salvia officinalis) experimentally. The sorption isotherms of mint, verbena and sage were determined within the range of 10%–90% relative air humidity at three different temperatures (25°C, 40°C and 50°C), using saturated salt solutions method. Henderson’s equation was fitted satisfactory. The comparison between the sorption isotherms of mint, verbena and sage was studied. Jain and Jain (2004) studied the performance evaluation of an inclined multi pass solar air heater with in-built thermal storage on deep-bed for drying application and reported that the bed moisture content and drying rate depends on the time of the day and the depth of drying bed respectively. Doymaz (2006) studied a thin-layer drying behaviour of mint leaves. The results showed that the effective diffusivity for drying at 35–60°C of air temperature and 4.1 m/s of air velocity was determined in the range from $3.067 \times 10^{-9}$ to $1.941 \times 10^{-8}$ m²/s. The activation energy for moisture diffusion was found as 62.96 kJ/mol. The logarithmic empirical model was a good fit curves and satisfactorily described the kinetics of air-drying of mint leaves. Ozbek and Dadali (2007) investigated that the effect of microwave drying technique on moisture content, moisture ratio (MR), drying rate, drying time and effective moisture diffusivity of mint leaves. They reported that the by increasing the microwave output powers and decreasing the sample amounts, the effective moisture diffusivity values decreased. Akpinar (2010) carried out the performance analyses and modelling of drying mint leaves in a solar dryer and under open sun. He found that the Wang and Singh model was most suitable model. The results showed that energy utilisation ratio of the solar drying cabinet were varied between 7.826% and 46.285%. And exergy efficiency was varied between 34.760% and 87.717% for the cabinet. Tarhan et al. (2010) investigated on the effect of the drying temperature schemes on the drying kinetics of chopped mint in a rotary dryer. They reported that, the drying durations were decreased from 15 to 18 hours for constant temperature profile to 12–15 hours when rectangular wave-shaped temperature profiles were used.

Energy and exergy analysis of solar drying process of mint was done by Boulemtafes-Boukadoum and Benzaoui (2011). They obtained the results of the mint drying process in an indirect solar drier operating in natural convection and in a discontinuous way (only the day). They determined the efficiency of the solar air heater as well as the energy needed for the drying of mint. Energy analysis was done to quantify the solar energy received by solar heater and available for drying. Exergy analysis also had done to estimate the energy losses during the drying process. An indirect-mode forced convection solar dryer for drying thyme and mint was investigated experimentally by El-Sebaii and Shalaby (2013) in Tanta. The experimental setup consists of a double pass v-corrugated plate solar air heater, drying chamber and a blower. Drying experiments were performed for thyme from initial moisture content 95% and mint from initial moisture content 85% on wet basis at an initial temperature of 29°C. The final moisture contents for thymus and mint were arrived after 34 and 5 hours respectively. Midilli and Kucuk model was found convenient to describe the thin layer solar drying of mint. Page and modified Page models were found to be the best among
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The drying of mint was investigated under solar drying conditions with natural and forced convection modes by Sallam et al. (2015). They reported that the drying rate of mint under forced convection was higher than that under natural convection, especially during first hours of drying (first day). For forced convection, the rate of drying was the same in both direct and indirect drying, since the temperatures and air velocity above the trays were almost the same. Diffusion approach and Verma et al.'s models were the best models able to describe thin layer solar drying of mint for both direct and indirect drying, respectively. The main objectives of this study are,

1. to improve the performance of solar dryer by triple pass, an absorber and thermal energy storage
2. to study the effects of absorber and thermal energy storage.

2 Experimental setup

The experimental setup consists of blower, flat plate air heating chamber and drying chamber. The schematic of triple pass solar air heater is shown in Figure 1(a). The schematic of heat transfer in triple pass solar air heater is shown in Figure 1(b). The schematic of the experimental set up is shown in Figure 2. The air heating chamber was made up of 1.5 mm thick galvanized iron (GI) sheet with dimensions of 2 m × 1 m and 0.1 m deep externally and incorporates double glass, aluminium wire mesh (black painted) as an absorber and thermal energy (sensible heat) storage box filled with sand for improving the system performance. The black painted aluminium mesh (1.95 m × 0.95 m × 25 mm) was placed between second glass and box of thermal energy storage. The box of thermal energy storage was located 20 mm gap above the bottom plate and all sides were insulated by glass wool to prevent the heat loss. The air heater chamber was located at tilting angle of 11° (local latitude angle) with respect to the horizontal position facing south direction to receive the maximum solar radiation. The drying chamber was constructed by 1.5 mm thick GI sheet of dimensions 0.75 m × 0.75 m × 1.5 m and insulated all sides with glass wool. Four perforated aluminium tray with dimensions of 0.75 m × 0.75 m were placed in the drying chamber for drying agricultural product. Air flows between two glazing during first pass then in the opposite direction through absorber during second pass and finally through the spaces between unit of thermal energy storage and bottom plate into drying chamber.

During the first pass the air gains the thermal energy due to the convective and radiative heat transfer from the cover of two glasses. During the second pass the air is further heated due to the temperature of the absorber and convective and radiative heat transfer from the absorber and top surface of thermal energy storage unit. During the third pass the air is further heated due to the convective heat transfer from the bottom surface of thermal energy storage unit. The thermal energy storage box is constructed of GI sheet and filled with sand. Sand can be considered as thermal energy storage materials because; it is cheap and store thermal energy at a higher temperature. As it has lower specific heat, faster absorbing heat energy. The temperature of the storage material (sand) is increased due to conductive and convective heat transfer from the absorber and top surface of the unit. The stored heat in the sand filled in the thermal energy storage unit is released by convective heat transfer to moving air. Then the moving air being heated due
to the convective heat transfer from the thermal energy storage unit. During the sunshine hours the thermal energy is stored in the thermal energy storage unit and releases it during off sunshine hours. Due to the fast absorbing heat energy by sand, the thermal storage unit remains hot even during off sunshine hours. Hence, successive heat supply from thermal energy storage unit (sand) is occurred by convection with moving air.

**Figure 1** (a) Schematic of triple pass solar air heater (b) Schematic of heat transfer in triple pass solar air heater (see online version for colours)

**Notes:** $T_{\text{abs top}}$ – temperature of absorber box at top; $T_{\text{abs bott}}$ – temperature of absorber box at bottom; $T_{\text{in-coll}}$ – temperature of air at collector inlet; $T_{\text{out-coll}}$ – temperature of air at collector outlet; $V_{\text{air-in}}$ – velocity of air in. $h_{\text{cg1}}$ – convective heat transfer glass1 to ambient air; $h_{\text{rg1}}$ – radiative heat transfer glass1 to atmosphere; $h_{\text{rg2}}$ – radiative heat transfer glass2 to glass1; $h_{\text{cg1a}}$ – convective heat transfer glass1 to air in first pass; $h_{\text{ca1g2}}$ – convective heat transfer air in first pass to glass2; $h_{\text{rg2}}$ – radiative heat transfer thermal heat storage to glass2; $h_{\text{rg1a}}$ – radiative heat transfer absorber to glass2; $h_{\text{ga1}}$ – convective heat transfer absorber to glass2; $h_{\text{cg2}}$ – convective heat transfer glass2 to air in second pass; $h_{\text{ga2}}$ – convective heat transfer glass2 to air in second pass; $h_{\text{absa2}}$ – convective heat transfer absorber to air in second pass; $h_{\text{absS}}$ – convective heat transfer absorber to thermal heat storage; $h_{\text{Sa3}}$ – convective heat transfer thermal heat storage to air in third pass; $I$ – solar radiation intensity on the collector surface.
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Figure 2  Schematic of experimental set up (see online version for colours)

Notes: $T_{\text{amb}}$ – ambient temperature; $T_{\text{in-chamb}}$ – temperature of air at chamber in; $T_{\text{out-chamb}}$ – temperature of air at chamber out; $T_1$, $T_2$, $T_3$, $T_4$ – temperature of air at tray-1, 2, 3, 4; $R_{\text{amb}}$ – relative humidity of ambient air; $R_{\text{air-in}}$ – relative humidity of hot air at drying chamber inlet; $R_{\text{air-out}}$ – relative humidity of hot air at drying chamber outlet.

The pictorial view of the experimental setup is shown in Figure 3. The solar radiation was measured by solar power meter in W/m$^2$, air velocity was measured by digital anemometer and temperatures of different elements of the system was measured by K type thermocouples (accuracy of ±0.5°C) with digital indicator and were placed at different locations of the system. The relative humidity of the air is measured using a thermo-hygrometer using a probe with digital display having an accuracy of ±5%. The weight of the product was measured by electronic weighing machine with accuracy of 0.001 gram.

Figure 3  Pictorial view of the experimental setup (see online version for colours)
3 Experiments and calculation

Fresh mint was purchased at local market in Ukkadam, Coimbatore, Tamil Nadu, India. Before drying, the foreign materials, spoiled and discoloured were removed and only good condition mint were taken for conducting experiments. The experiments were conducted on 22nd August 2014 at Coimbatore Institute of Engineering and Technology, Coimbatore, Tamil Nadu, India. The good condition of 500 gram mint leaves were separated from 10 kg of fresh mint, cleaned with ground water and the water on leafs were removed by cotton cloth then loaded equally (125 gram) into four tray. The initial and final moisture contents of the samples were determined by the drying oven method whose temperature is fixed at 105°C. The experiments were conducted between 9.00 am to 3.00 pm and air mass flow rate was fixed as 0.06 kgs \(^{-1}\) under with thermal and without thermal storage. The system was operated under no load condition for two hours. The moisture content (weight loss) of the drying product was measured at an interval of one hour. The photo image of fresh mint before drying and drying mint in the tray is shown in Figure 4 and Figure 5, respectively. The system performance and the drying characteristics were calculated as following equations.

**Figure 4** Photo image of fresh mint (see online version for colours)

**Figure 5** Photo image of drying mint in the tray (see online version for colours)

The moisture content (Mwb) on a wet basis was calculated by (Mohanraj and Chandrasekar, 2008)

\[
M_{wb} = \left[ \frac{W_i - W_f}{W_i} \right] \times 100
\]  

(1)
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Useful collector gain ($Q_u$), collector efficiency ($\eta$) and air mass flow in the collector (Montero et al., 2010) can be expressed as equation (2), equation (3) and equation (4) respectively.

$$Q_u = m_a C_p \left[ T_{\text{out-coll}} - T_{\text{in-coll}} \right] \tag{2}$$

$$\eta = \frac{Q_u}{A_I I} \tag{3}$$

$$m_a = A_f \rho_a V_a \tag{4}$$

The MR is the ratio of the moisture content at any given time to the initial moisture content. The MR was calculated by (Sallam et al., 2015) the following equation (5).

$$\text{Moisture ratio } MR = \left[ \frac{M - M_i}{M_0 - M_i} \right] = \left[ \frac{M}{M_0} \right] \tag{5}$$

where $M$, $M_0$, and $M_i$ are the moisture content at any time, initial moisture content and equilibrium moisture content respectively.

The drying rate (kg/hour) was calculated by (Sallam et al., 2015) the following equation (6).

$$\text{Drying rate} = \left[ \frac{M_{t+\Delta t} - M_t}{dt} \right] \tag{6}$$

where $M_t$ and $M_{t+\Delta t}$ (kg water/kg dry matter) are the moisture content at time $t$ in hours and moisture content at time $t + \Delta t$ respectively.

4 Results and discussion

The uncertainty analysis was carried out as follows:

- uncertainty in temperature measurement, $w_T = \pm 0.1 ^\circ \text{C}$
- uncertainty in relative humidity measurement, $w_{RH} = \pm 3$
- uncertainty in air velocity measurement, $w_v = \pm 0.1 \text{ m/s}$
- uncertainty in solar radiation measurement, $w_I = \pm 10 \text{ W/m}^2$
- uncertainty in weight measurement, $w_m = \pm 0.001 \text{ kg}$

The result $R$ is a given function in terms of the independent variables. Let $w_R$ be the uncertainty in the result and $w_1$, $w_2$, ..., $w_n$ be the uncertainties in the independent variables. The result $R$ is a given function of the independent variables $x_1$, $x_2$, $x_3$, ..., $x_n$. The uncertainty in the result can be calculated (Akpinar et al., 2010) as mentioned by the equation (7).

$$w_R = \sqrt{\left( \frac{\partial R}{\partial x_1} w_1 \right)^2 + \left( \frac{\partial R}{\partial x_2} w_2 \right)^2 + \cdots + \left( \frac{\partial R}{\partial x_n} w_n \right)^2} \tag{7}$$

The uncertainty in calculation of mass flow rate
Uncertainty in calculation of useful collector gain

\[ Q = \frac{1}{2} \left( (0.1)^2 + (0.1)^2 \right) \frac{1}{100} = 0.2 \text{ W} \]

Uncertainty in calculation of collector efficiency

\[ \eta = \frac{1}{2} \left( (0.2)^2 + (0.1)^2 + (0.1)^2 \right) \frac{1}{100} = 0.2\% \]

where \( w_1, w_2, w_3 \) – the uncertainties in the independent variables; \( W_g \) – total uncertainty in the measurement of the result; \( w_m \) – the uncertainty in the calculation of mass flow rate (kg/s); \( w_q \) – the uncertainty in the calculation of useful heat gain (W); \( W_\eta \) – the uncertainty in the calculation of collector efficiency (%); \( P \) – pressure (bar); \( T \) – temperature (°C); \( V \) – velocity of the air (m/s).

The specific moisture extraction rate (SMER), is the amount of water removed per unit energy consumption. The same can be found using equation (8) as reported by Mohanraj and Chandrasekar (2008)

\[
\text{SMER} = \frac{\text{Total mass of water removed in kg}}{\text{Blower power}} 
\]

The SMER for mint is 0.383 kg of water/kWh and respective specific energy consumption (SEC) is 2.61 kWh/kg of water.

The variation of solar intensity on hours of the day (22-8-2014) is shown in Figure 6. The maximum solar intensity 1,276 W/m² and 1,305 W/m² was obtained at 12 and 13 hours of the day respectively. The magnitude of solar intensity varies on hours of the day.

**Figure 6** Variation of solar intensity on hours of the day (see online version for colours)
Figure 7 shows the temperature of air at different location of the solar drying system. The temperature collector inlet air was observed between 29°C–33°C and it depends on the relative humidity of the atmospheric air. It is seen that, the maximum collector outlet temperature of 54°C was observed during 12 and 13-hour. It is also observed that the collector outlet temperatures of 54°C and 48°C remains constant during 12 to 13 hours and 14 to 15 hours respectively. This is due to combined energy transfer from the system to air by means of black painted aluminium wire mesh, sensible heat storage and effect of triple pass during this period. The temperature of air at drying chamber inlet and outlet was obtained between 42°C–52°C and 30°C–46°C, respectively. This can be due to the moisture removal from mint leaves in the trays by the hot air. The range of air moisture content of the inlet and exit of the drying chamber is 26%–42% and 28%–48% relative humidity respectively.

Figure 7  Temperature variation of air at different elements of the system (see online version for colours)

Figure 8 shows that useful collector gain of the system. It is seen that the maximum useful collector gain 1,047.77 kW was obtained at 12-hour of the day, this is due to the air temperature rise is maximum during this period. The useful collector gain is calculated from equation (2) and Figure 8 shows that useful collector gain of the system. It is seen that the maximum useful collector gain 1,047.77 kW was obtained at 12 hours of the day, this is due to the air temperature rise is maximum during this period. The useful collector gain of the system depends on the rising temperature of air. The rising temperature of air is 24°C and 21°C for 12 and 13 hours, respectively. It is cleared in Table 1. The rising temperature of air is the maximum (24°C) at 12 hours, even solar intensity is a maximum of 13 hours, so maximum useful collector gain (1,047.77 kW) is obtained at 12 hours. It is seen that from Figure 6 and Figure 7, even though the lower solar intensity at 15 hour the useful collector gain of 829.29 kW was obtained, this is due to the thermal energy storage unit releases the stored heat energy during this time period. Table 1 show that temperature changes of air at collector inlet and exit with and without thermal storage. The rising temperature of air plays an important role in the useful collector gain and thermal efficiency of solar dryer. From Table 1, the constant temperature 54°C and 48°C is maintained at 12 to 13 hours and 14 to 15 hours respectively. This is due to the thermal energy storage unit. It is seen that from Figure 6 and Figure 7, even though the lower solar intensity at 15-hour the useful collector gain of 829.29 kW was obtained, this is due to the thermal energy storage unit releases the stored heat energy during this time period. It is cleared in Table 1. This may also be the reason for higher thermal efficiency of solar dryer that is shown in Figure 9.
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**Figure 8**  Useful collector gain vs. time of the day (see online version for colours)

![Useful collector gain vs. time of the day](image)

**Table 1**  Temperature changes of air at collector inlet and exit with and without thermal storage system

<table>
<thead>
<tr>
<th>Time hours</th>
<th>Temperature of air at collector inlet</th>
<th>Temperature of air at collector exit</th>
<th>Rise in temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>With thermal storage</td>
<td>Without thermal storage</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>31</td>
<td>45</td>
<td>33</td>
</tr>
<tr>
<td>11</td>
<td>31</td>
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</tr>
<tr>
<td>15</td>
<td>29</td>
<td>48</td>
<td>31</td>
</tr>
</tbody>
</table>

**Figure 9**  Thermal efficiency of collector vs. time of the day

![Thermal efficiency of collector vs. time of the day](image)

The relative humidity of atmospheric air is shown in Figure 10. It is observed that the relative humidity of atmospheric air varies between 26%–47%. The relative humidity of the dry air and humid air is shown in Figure 11. It is seen that the lower relative humidity 27%, 28% was obtained at 10-hour of the day in drying air and humid air respectively. It is observed that higher relative humidity 46%, 47% was obtained at 12-hour of the day in drying air and humid air respectively.
The moisture content of the mint is expressed from equation (1). The moisture content of the mint in four trays is shown in Figure 12. It is seen that the moisture removal rate from mint is faster in the trays 1 and 2 than 3 and 4. The temperature of hot air is decreased when it passes through mint in the trays 1 and 2 and further decreased when it passes through the trays 3 and 4 because, moisture absorption from the mint leaves.

Figure 12 shows that the time taken to reach the mint from initial moisture content to final moisture content in the four trays. The mint leaves in tray 1, tray 2 and tray 3, 4 takes 3 hours and 5 hours to reach final moisture content respectively. The average time taken to reach final moisture content 7.69% to 10% was obtained in 4 hours from initial
moisture content 82.00%. During the experimentation the mint placed in the each tray is weighed every one hour and calculated moisture content from equation (1). The mint leaves in the trays 1 and 2 are removed from the tray when it reached a final moisture content for avoiding overheating. Then the mint leaves in the trays 3 and 4 are dried continuously until it reaches final moisture content.

The initial moisture content of the mint was 82% on a wet basis. Figure 13 shows that the variation of MR in the mint versus drying time. It is clear that the MR decreased continuously with drying time. Figure 14 shows the variation in drying rate with hours of the day (hours). It is clear that the no constant rate and occurs falling rate period for the mint in all four trays. The same result was observed by Sallam et al. (2015). The drying rate is highest in the starting staring drying hours due to gas-phase controlled and depends on drying air temperature. The mint in the trays 1 and 2 was removed after reaching the required final moisture content (7.69% to 10%). Due to thus the drying rate for the mint in the trays 3 and 4 was increased after 13 hours because, air temperature directly enters into trays 3 and 4. Drying parameter study is shown in Table 2.

Figure 13  Variation of moisture ratio in the mint vs. drying time

Figure 14  Variation in drying rate with hours of the day

Table 2  Drying parameters

<table>
<thead>
<tr>
<th>Tray no.</th>
<th>Weight of mint in each tray</th>
<th>Initial moisture content</th>
<th>Final moisture content</th>
<th>Drying duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>125 gram</td>
<td>82%</td>
<td>7.69%</td>
<td>3 hours</td>
</tr>
<tr>
<td>2</td>
<td>125 gram</td>
<td>82%</td>
<td>7.69%</td>
<td>3 hours</td>
</tr>
<tr>
<td>3</td>
<td>125 gram</td>
<td>82%</td>
<td>10%</td>
<td>5 hours</td>
</tr>
<tr>
<td>4</td>
<td>125 gram</td>
<td>82%</td>
<td>10%</td>
<td>5 hours</td>
</tr>
<tr>
<td>Total weight</td>
<td>500 gram</td>
<td></td>
<td>Average drying hours</td>
<td>4 hours</td>
</tr>
</tbody>
</table>
5 Conclusions

The performance of triple pass solar air heater with thermal energy storage for drying mint leaves has been investigated experimentally. The maximum temperatures of air at collector outlet, drying chamber inlet were 54°C, and 52°C obtained at 13-hour of the day respectively. The maximum useful collector gain 1,047.77 kW was obtained at 12 hours due to the rising temperature of air is the maximum (24°) at 12 hours than other hours. The maximum thermal efficiency of collector 58.48% was obtained at 15 hours of the day for 720 W/m² (low solar intensity). The moisture removal rate is higher in trays 1 and 2 than trays 3 and 4. The average time taken to reach final moisture content 7.69% to 10% was obtained in 4 hours from initial moisture content 82.00%.

References


**Nomenclature**

\(A_c\) Collector area (m\(^2\)).

\(A_f\) Collector transversal area (m\(^2\)).

\(C_{pa}\) Constant pressure specific heat (J kg\(^{-1}\) K\(^{-1}\)).

\(I\) Solar radiation intensity on the collector surface (W/m\(^2\)).

\(m_a\) Air mass flow rate (kgs\(^{-1}\)).

\(M_{wb}\) Moisture content on a wet basis (%).

\(V_a\) Air speed at the centre of flat plate collector (ms\(^{-1}\)).

\(W_i\) Initial mass of sample (kg).

\(W_f\) Final mass of sample (kg).

\(\rho_a\) Air density (kg m\(^{-3}\)).

SMER Specific moisture extraction rate (kg of water/kWh).

SEC Specific energy consumption (kWh/kg of water).