Application of ANN and prediction of drying behavior of mushroom drying in side hybrid greenhouse solar dryer: an experimental validation

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ABSTRACT

The newly developed Heat Exchanger Evacuated Tube Assisted Drying System (HE-ETADS) is fabricated in roof of campus of MITS, Gwalior, India. Heat transfer analysis of developed drying system is carried out by drying mushroom inside it. The heat transfer coefficient plays a significant role in drying method. The study emphasizes on determining the convective as well as evaporative heat transfer coefficients (CHTC & EHTC) and the determination of best drying rate model fit for mushroom drying inside novel drying system. The artificial neural network is developed for predicting the CHTC & EHTC. Value of CHTC & EHTC varies from 2.10 to 3.43 and 25.68 to 49.85 W/m\(^2\)°C respectively. The developed ANN model helps in predicting the heat transfer coefficient once trained using input factors like solar radiation, relative humidity, environmental temperature and time. The value of R\(^2\) for the developed ANN model is 0.99, which shows that model predicts the value very close to the calculated value of heat transfer coefficients. Drying kinetics of mushroom is tried to fit in nine drying rate models. The Midilli-Kucuk model shows the better fit among the other models.

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agriculture products are exposed to direct contact of dust, dirt, insect, animals as well as open environmental influences and necessity of protection during the adversative climatic conditions such as in rainy season. Apart from these limitations, drying results are dependent on good weather conditions. The recent drying method and system has more efficiency, provides hygiene, and is capable of keeping the crops innocuous from loss. Dehydration of food products conducted inside the drying system using thermal energy. These drying system control and manage the drying cabin temperature, as well as other affecting parameters (room temperature, relative humidity, air speed). Adequate dehydration helps in preserving flavor, texture as well as quality assessment in term of color index of dried product [1], [2], [3].

To lead an energetic as well as hearty life, human beings want adequate food and a balanced nutritious diet. Vegetables and fruits contain various types of vitamins, minerals, and fiber. Vegetables and fruits also provide antioxidants that safeguard us from many chronic diseases. But the maximum of the vegetables and fruits are seasonal. Seasonal excess and small shelf-life makes this crop decrease [4]. Around 30% of overall production gets spoiled at different post-harvest phases. Mostly the product gets spoiled caused by microbial action by bacteria, enzymes, yeast, and molds [5]. Food product preservation can decrease decomposition of seasonal excess, and can return high market value in term of profit through requirement [6].

Drying is one of methods for preserving the crop for a long time and makes it available throughout the year [7]. OSD is the old-style method that is mostly adopted in various tropical as well as subtropical regions of the country [8]. Therefore, the quality assessment of dehydrated products play a significant role in human beings life, and it is affected caused by environmental influences [9],[10]. Abandoned drying rate, fluctuations in climate conditions i.e. rain and dew, necessity of large floor area, more drying period, maximum labour cost are also some of limitations of OSD [11]. Various efforts have been made in developing mechanical to overcome the driers in recent year’s disadvantages of natural or open sun drying. Most of this mechanical drying system needs conventional sources for their operation. As energy assets of fossil fuel are reducing at a fast rate and also these system causes pollution. Mechanical driers or drying system using the power of sun as a source of energy, and can overcome these problems [12]. Solar energy is richly available and is pollution-free. Hence solar driers are nearly attractive and sustainable. Different kinds of drying system are present for the dehydration of foodstuffs. [13], [14], [15].

After gone the literature survey, it is found that a large number of researches are done on solar dryer under free and forced mode and very few researches assisted with FPC. Also no one has reported the performance of solar dryer assisted with ETSC. The paper presents an experimental validation of drying kinetics. The ANN model is also trained and evaluated to predict the CHTC and EHTC for OSD and HGSD respectively. The error analysis shows the deviation between the experimental, calculated and ANN predicted values.

**PREVIOUS STUDIES ON SOLAR DRYER**

Previous study indicates that a large number of solar drying systems coupled with Flat plate collector (FPC) [16], [17], and [18]. ETSC can be the right choice for FPC solar isolation trap; ETSC is consisting of two same type glass tubes – inside as well as outside. Inside tube is glazed through selective glaze and room b/w these both tubes is evacuated. Due to the room b/w both tubes, no heat loss occur by convection as well as conduction. This phenomenon increase the efficiency of this types of collectors [19], [20], [21], and therefore performance of drying system would be higher assisted with ETSC as compared to FPC in term of efficiency. A few numbers of researchers conducted investigation on drying system assisted with ETSC [22], [23]. A number of experiment have been carried out on drying behavior of different foodstuff product for example rice [1], cassava [2] ginger [24],[25] pork strips [26], prickly pear cladode [27], tomato [28], onion [29], and grapes [30], [31],[32],[33].Further, literature has also stated that no study has been conducted on the drying of mushroom in solar drying with ETC. Table1 shows the outcomes of previous research.

**EXPERIMENTATION**

**Experimental Setup**

Important component of newly developed drying system are the ETSC, greenhouse drying chamber, pump, and heat exchanger. The line diagram and pictorial view of novel dryer are shown in Figure 1, Figure 2 correspondingly. The drying system was fabricated for metrological conditions of Gwalior region Madhya Pradesh, India (26°.2183N and 78°.1828E). Dimension of the drying cabin is selected in such a manner that design aspect ratio is 3 in term of floor area to volume. Greenhouse (hut type) is higher than the drying chamber which is made up of 2.51 m 2.61 m, 1.81 m central height & elevation of sidewalls towards 1.05 m from the ground and 30-degree roof is covered by canopy cover. The new thing is in this drying system that, it is coupled with 02 ETSC in series. Ten numbers of tubes are connected in one solar collector. The space b/w inside and outside tubes to create the vacuum, and to reduce the conduction and convection heat loss The entire drying setup is installed in solar energy lab of MITS Gwalior. Facing of system in south direction to get maximum solar radiation during the whole day of experimentation. To connect the outlet of ETSC to the drying cabin, a rubber hose is used. That is made of Ethylene Propylene Diene Monomer (EPDM).
Table 1. Summary of previous studies

| Sr.no. | Authors                  | Year | Product          | Findings of Investigation                                                                 |
|--------|--------------------------|------|------------------|------------------------------------------------------------------------------------------|
| 1.     | Etim, Ben Eke, and       | 2020 | Banana           | Examined influence of air inlet shape as well as size on drying kinetics.                 |
|        | Simonyan [34].           |      |                  |                                                                                           |
| 2.     | Bhardwaj, Kumar, and     | 2019 | Valerina Jatamansi | The energy efficiency of the collector increases by 16.12% after using sensible heat    |
|        | Chauhan [35].            |      |                  | storage material with a solar collector attached to the dryer.                            |
| 3.     | Sansaniwal, Kumar, and   | 2017 | Ginger rhizomes  | Find out the drying performance of solar dryer in the terms of CHTC and Efficiency of     |
|        | Rajneesh [36].           |      |                  | collector under active and passive mode.                                                 |
| 4.     | Kumar et al. [37].       | 2016 | Ginger           | Computed \( h_i \) and \( h_e \) for indirect dryer in active mode. \( h_i \) and \( h_e \) |
|        |                          |      |                  | was calculated 3.95 and 160.97 W/m²°C respectively.                                     |
| 5.     | Sundari et al. [38].     | 2014 | Grapes           | Experimental studies on Muscat grape kinetic drying in a solar drying with ETC.         |
| 6.     | N Rajeshwari et al. [33].| 2012 | Grapes           | Find out the low-cost material effective box-type used for the manufacture of the dryer    |
| 7.     | Wiriyaumapaiwong et al.  | 2012 | Pork strips      | The experiment conducted on mathematical modeling of pork strips                          |
| 8.     | Zomorodian et al. [30]   | 2009 | Grapes           | Experimental study done on different drying kinetics models.                             |
| 9.     | Ezekoye et al. [11]      | 2006 | Rice             | Improvement as well as execution the assessment of changed incorporated passive solar   |
|        |                          |      |                  | grain dryer.                                                                             |
| 10.    | Alakali et al. [25]      | 2005 | Cassava          | Evaluated the drying kinetics and heat transfer coefficient.                             |

A wire and tube types of heat exchanger (2m × 0.66m) is placed inside drying cabin, and hot water is circulated in this tubes comes from the ETSC. This concept is taken in consideration to enhance the drying cabin temperature. A 12volt DC pump also used to circulate hot water from ETSC to heat exchanger in a closed loop [39].

Mass flow rate of water can be varying by using regulator valve. Two air vents also provide on the top of drying system to remove or escape the moisture from inside the drying cabin.

Measuring Instruments and Devices
A fully automatic data logger is used for measuring the data such relative humidity (RH), ambient temperature, drying cabin temperature, solar isolation. A number of equipment (Listed in Table 2) is connected to the data logger to record the above environmental parameters. Instead of these instrument other portable measuring instrument such as weighing m/c, anemometer, and IR temperature gun also used.

Sample Preparation
Mushrooms bought from the nearby market of Morar Gwalior. These were cleaned carefully to remove floor dirt.

Experimental Method
Experimentation was conducted in month of March 2018 from 11:00 am -04:00 Pm. Data was recorded at every 1 hour interval. Mushroom samples were kept on a set of rectangular sized wire mesh tray inside the drying cabin. These trays were stored at electronic balance gadget to decide moisture content (MC) cloth elimination for each drying length. A numbers of thermocouples were placed at different locations to observe the data i.e. drying cabin temperature, crop surface temperature, floor temperature, and inlet and outlet temperature of hot water in side heat exchanger. A anemometer (least count 0.1 m/s) is used to degree air goes along with the waft simply above the product floor. Sun isolation statistics of drying days are recorded with the aid of the use of a virtual solar electricity meter. Before and after drying mushroom samples are shown in Figure 3.

Convective Heat Transfer Coefficient (CHTC)
Nusselt Number \( (N_u) \) play a vital role in the calculation of CHTC \( (h_t) \) as,

\[
h_t = \left( \frac{K}{L_c} \right) \times N_u
\]

Where,

\[
L_c = \frac{l \times b}{2}
\]

Rate of heat-absorbing,

\[
q_e = 0.016 \times h_i [P(T_p) - \gamma_e P(T)] \quad (2)
\]
Figure 1. Schematic of HGSD systems with ETSC (Patent Application No:201921001878) [40].

Figure 2. Actual picture of novel drying system.
Table 2. Uncertainty and accuracy of different instruments

| Instruments                                      | Accuracy | Range            | Uncertainty |
|-------------------------------------------------|----------|------------------|-------------|
| Thermocouple                                    | ±0.1°C   | –10 to 95 °C     | ±0.22 °C    |
| Hygrometer (model HT-315)                       | 0.1 %    | 10 % to 95 % R.H.| 0.058       |
| Weight machine                                  |          | 0.0001 to 20Kg   | 0.00055     |
| Pyranometer (version WACO-206, least clarity ±10 W/m²) | ±10 W/m² | 0–24 hours       | 1.41        |
| Data logger (Make:-DataTaker; dEx Software interface) |         |                  |             |

Figure 3. (a) Fresh Mushroom (b) Dried Mushroom.

Using Eq. 1 and Eq. 2,

\[ q_e = 0.016 \left( \frac{K}{L_c} \right) \left[ P(T_p) - \gamma \gamma P(T_e) \right] \times N_u \]  \hspace{1cm} (3)

\[ m_{\text{ev}} \text{ can be determined by } m_{\text{ev}} = \frac{q_e}{\lambda} \times A_t \times t \]

\[ m_{\text{ev}} = \left[ \frac{0.016 \left[ P(T_p) - \gamma \gamma P(T_e) \right]}{L_c \times \lambda} \right] \times N_u \]

Now, in active mode Nusselt Number can be computed as:

\[ \text{Nu} = \frac{m_{\text{ev}}}{R} = C' (\text{Re} \times \text{Pr}) \]

Hence, constant can be computed using following relations.

\[ n = \frac{N_0 \sum XY - \sum Y \sum X}{\sum \left( \sum X \right)^2} \]

\[ C = \frac{\sum X^2 \sum Y - \sum X \sum XY}{N_0 \sum \left( \sum X \right)^2} \]  \hspace{1cm} (5)

Characteristic of Air

Thermal characteristic of air could be estimated following Jain and Tiwari Model [41].

\[ C_v = 999.2 + 0.143T_i + 1.101 \times 10^{-4}T_i^2 - 6.7581 \times 10^{-8}T_i^3 \]  \hspace{1cm} (7)

\[ K_v = 0.0244 + 0.7673 \times 10^{-4}T_i \]  \hspace{1cm} (8)

\[ \beta_v = \frac{353.44}{T_i + 273.15} \]

\[ \mu_v = 1.718 \times 10^{-5} + 4.620 \times 10^{-8}T_i \]  \hspace{1cm} (9)
Experimental Uncertainty Analysis

The experimental observation of open sun drying and hybrid greenhouse solar drying were measured using different equipment’s. Uncertainty of relative humidity (Rh), solar radiation, air flow rate, ambient temperature, and MC has been taken in consideration during the designing of drying system.

Let various independent parameters \(x_1, x_2, x_3 \ldots \ldots \ldots \ldots x_n\) influences some output \(R\), & \(w_R\) is elaborate uncertainty, hence \(w_1, w_2, w_3 \ldots \ldots \ldots \ldots w_n\) be uncertainty in independent variables \[44\].

Where,

\[
U(Y) = \left[ \left( \frac{\partial Y}{\partial x_1} \right)^2 u^2(x_1) + \left( \frac{\partial Y}{\partial x_2} \right)^2 u^2(x_2) + \ldots \ldots \right]^{1/2} + \left( \frac{\partial Y}{\partial x_n} \right)^2 u^2(x_n) \right]^{1/2} \tag{17}
\]

The resultant uncertainty in the calculation of drying temperature can be evaluated as,

\[
U_T = [(U_{thermocouple})^2 + (U_{connection\ point})^2 + (U_{reading})^2]^{1/2} \\
U_T = [(0.25)^2 + (0.1)^2 + (0.1)^2]^{1/2} = 0.287
\]
Total uncertainty in experimentation is calculated as:

\[ U_{\text{Exp}} = \left( (0.287)^2 + (0.223)^2 + (0.14)^2 + (0.100)^2 + (1.41)^2 \right)^{0.5} = \pm 1.46 \]

RESULTS AND DISCUSSION

Throughout experimentation process, solar intensity varied from 100–800 W/m². A little variation is occurred in solar radiation intensity due to sudden cloud cover. Inside greenhouse air temperature does not vary due to the use of ETSC. The atmospheric temperature fluctuated between 20.0 and 36.0°C and inside greenhouse air temperature maintained between 29 to 69.2°C. The relative humidity varied in the atmospheric condition ranged between 32% and 42.5% and in the drying chamber maintained between 30% and 42.2%. The mushrooms dried at the temperature of 15–25°C more than the air temperature. The preliminary moisture content in mushroom was 80.6% on wb and dry up to it got absolute moisture content 2.9% on wb. The variation in Rh and solar intensity in open sun drying (OSD) and hybrid greenhouse solar dryer (HGSD) are shown in Figure 4. The mushroom mean surface temperature \( T_m \) and temperature above the mushroom \( T_c \) variation during drying is given in Figure 5.

![Figure 4.](image-url)

(a)

![Figure 4.](image-url)

(b)

Figure 4. Experimental data of solar radiation intensity (I) and Relative humidity (Rh) in (a) OSD and (b) HGSD.
Figure 5. Variation of mean surface temperature $T_m$ and temperature above the mushroom $T_c$ during drying in (a) OSD and (b) HGSD.

Figure 6. Variations of CHTC ($h_c$) in open sun drying (OSD) and HGSD.

The experimental observed value of mean surface temperature ($T_m$) of mushroom and air temperature ($T_c$) above the mushroom in the drying chamber of HGSD, and inside air relative humidity of dryer were used to find out thermal physical property of humid air inside HGSD by following Eq. (discussed in Table 2). These were data used to evaluate Reynolds number and Prandtl number (Pr). Then Prandtl number was calculated 0.696 within the limit of ambient temperature. By following the Nusselt No.-($Nu$) Correlations (Eq no.) value of CHTC ($h_c$) was calculated at
Table 4. Summaries of \( h_c \) and \( h_e \) estimated from the experimental drying value of mushroom in HGSD

| Product | \( C \)  | \( n \) | CHTC \( (h_c) \) \( \text{W/m}^2\text{°C} \) | EHTC \( (h_e) \) \( \text{W/m}^2\text{°C} \) |
|---------|--------|--------|----------------|----------------|
| Mushroom | 0.21   | 0.32   | 3.43           | 49.85          |

half hours intervals. The constant \( c \) and \( n \) depend upon the thermal and geometry parameters of HGSD, and also vary with the orientation of HGSD. It may be evaluated from regression analysis. Variations of \( h_e \) in open sun drying (OSD) and HGSD is shown in Figure 6.

The value of CHTC \( (h_c) \) for mushroom fluctuate between 1.2 – 0.64 \( \text{W/m}^2\text{°C} \) for OSD and 3.43 – 2.34 \( \text{W/m}^2\text{°C} \) for HGSD. The quantity of H.E is necessary for moisture evaporation \( (Q_e) \) can be determined by Eq.3. The quantity of moisture evaporated plays a role in finding out the EHTC \( (h_e) \) from the surface of the mushroom. EHTC \( (h_e) \) lies between 8.16 – 22.54 \( \text{W/m}^2\text{°C} \) and 49.85 – 16.32 \( \text{W/m}^2\text{°C} \). The variation in EHTC with respect to drying period was detected to be greater than CHTC as demonstrate in Figure 7. The maximum EHTC was achieve b/w 12:00 to 02:00 PM due to increasing in solar intensity during experimentation. Summary of \( h_c \) & \( h_e \), estimated from the investigational drying value of mushroom in HGSD is discussed in Table 4.

Drying Performance

The drying performance of the HGSD in terms of mass reduction in comparison with OSD is shown in Figure 8.

The curve was plotted M.R vs. drying period is displayed in Figure 9 in which amount of M.R is removed from the mushroom dried. M.R is directly related to drying air temperature, that is also depend on the solar radiation as well as dimension (characteristic length) of dried product. Likewise, EHTC also related to the air flow rate

Figure 7. Variations of EHTC \( (h_e) \) in open sun drying (OSD) and HGSD.

Figure 8. Drying performance of the HGSD in terms of mass reduction in comparison with OSD.
Figure 9. \( M.R_{\text{exp}} \) equated with Midili-Kucuk model (MKM).

Table 5. Model Used to experimentally drying graph

| Model Name                      | Equation                        | \( a \) | \( b \) | \( K \) | \( n \)  |
|---------------------------------|---------------------------------|---------|--------|--------|--------|
| Midili-Kucuk Model (MKM)        | \( M.R = a \exp(-kt^n) + bt \) | 1.004   | -.014  | .84    | .75    |

Figure 9. Configuration of ANN for predicts HTC.

and partial pressure of water vapor. Drying air temperature, air velocity, and characteristic length of mushroom play a significant role in deciding value of drying rate as well as EHTC. The internal uncertainty has been calculated for experimental measurement throughout drying of mushroom. External uncertainty has been carried out for error throughout observation of temperature, \( R_h \), \( m_{\text{exp}} \). The overall percentage of uncertainty was evaluated as \( \pm 1.46\% \). The experimentally observes that \( M.R_{\text{exp}} \) decrease slowly with rise in time. Higher value of \( R^2 \), and lower value of \( \chi^2 \) and RMSE b/w observed value of mushroom vs. drying period and those models that provide the optimum \( M.R_{\text{pre}} \).
The most suitable model of dried mushroom was found to be Midili-Kucuk model (MKM) with $R^2 = 0.99847$, $\chi^2 = 0.00043$, and RMSE = 0.0304. Therefore drying kinetics performance of mushroom in HGSD is defined by the MKM (Discussed in Table 5).

Artificial Neural Network Model (ANN)

In the present study to predict the CHTC and EHTC for the case of OSD and HGSD, the neural network is trained and evaluated using the neural network toll in MATLAB R2014a. To train the network, drying period, atmospheric air temperature, Rh, and solar intensity are provided as the input value, and experimentally observed CHTC and EHTC are taken as the target value. By the hit and trial method, it was observed that the model performed better in two hidden layers with six neurons in each layer. Also, the Log function is found suitable for the first layer while the Tan function for the second hidden layer. The multi-layer feed-forward back-propagation method and Levenberg-Marquardt Learning algorithm are used in the trained network [45], [46]. The Epoch has been kept to 10,000 and 300 validation check has been done to train the network so

![Graphs showing training, validation, test, and all validation R values](image-url)

Figure 10. Validation of CHTC and EHTC for optimal topologies (a) for OSD (b) For HGSD.
it can predict the close result [47]. The configurations of the artificial neural network to validate heat transfer coefficient is shown in Figure 9. Relationships b/w experimental as well as predicted values of CHTC and EHTC for optimum topologies (a) For OSD (b) For HGSD is shown in Figure 10.

The coefficient of correlation for training, validation and testing of data are 0.97206, 0.9999, and 0.9947 correspondingly for OSD. Coefficient of correlation for the overall data set is 0.97946. As the coefficient of correlation is very close to 1, this indicates that ANN shows good relation with the experimental value and predicting the very close to results. Similarly the coefficient of correlation for training, validation and testing of data are 0.99266, 0.99996, and 0.99989 correspondingly for HGSD. Coefficient of correlation for the overall data set is 0.99353. As the coefficient of correlation is very close to 1, this indicates that ANN shows good relation with the experimental value and predicting the very close to results.

CONCLUSION

CHTC and EHTC play a vital role in moisture removal rate (MRR) from the dried product. It is found that EHTC is directly proportional to solar radiation. As the solar
intensity increased ambient air temperature also increased. During experimentation, the maximum values of $h_t$ and $h_r$ is 3.43 and 49.85 W/m²°C. In novel drying system, inside room temperature is higher than the atmospheric air temperature by 12–25°C. High room temperature inside the HGSD assisted with ETSC decreases the drying period by 60% in comparison to OSD. MKM gives the good fit for the thin layer drying kinetics of mushroom dried in HGSD. The ANN model predicts the CHTC and EHTC very close to calculated value as value of $R^2$ is 0.99. The ANN reduces the effort required in doing the mathematical calculations and the make the determination of heat transfer coefficient easier. Although the ANN model can be made more accurate by using the large input data set for training the model.

ABBREVIATION

| Symbol | Description |
|--------|-------------|
| $A_t$ | Area of tray (m²) |
| $c$ | Constant |
| $C_s$ | Specific heat of humid air (J/kg°C) |
| $G_r$ | Grashof number $= \frac{g \beta L^2 \rho_v \Delta T}{\mu_r^2}$ |
| $K_r$ | Thermal conductivity of humid air (W/m°C) |
| $L_c$ | Characteristic length (m) |
| $T_c$ | Above mushroom surface temperature (°C) |
| $T_m$ | The temperature of mushroom (°C) |
| $\text{Re}$ | Reynolds number $= \frac{\rho_v \mu}{\mu_r}$ |
| $t$ | Time (sec) |
| HTC | Heat Transfer Coefficient |
| H.E | Heat Energy |
| $\beta$ | Coefficient of volumetric |
| $\gamma$ | Relative humidity (%) |
| $\sigma$ | Surface tension of liquid vapor |
| $\lambda$ | Latent of Heat of Vaporization |
| $U_r$ | Dynamic viscosity (kg/m sec) |
| $\rho_r$ | Density (kg/m³) |
| RMSE | Root mean square error |
| $R^2$ | Coefficient of determination |
| $\chi^2$ | Chi-square |
| M.R | Moisture Ratio |
| M.R_{exp} | Moisture Ratio experimental value |
| M.R_{pre} | Moisture Ration predict the value |
| OSD | Open sun drying |
| HGSD | Hybrid Green House Dryer |

REFERENCES

[1] Chandra S, Agrawal S, Chauhan DS. Soft computing based approach to evaluate the performance of solar PV module considering wind effect in laboratory condition Energy Reports 2018;4:252–259. [CrossRef]

[2] Singh S, Agrawal S. Efficiency maximization and performance evaluation of hybrid dual channel photovoltaic thermal module using fuzzyfied genetic algorithmi. Energy Convers Manag 2016;122:449–461. [CrossRef]

[3] Gupta A, Agrawal S, Pal Y. Performance evaluation of hybrid photovoltaic thermal thermoelectric collector using grasshopper optimization algorithm with simulated annealing. J Sol Energy Eng 2020:142:061004. [CrossRef]

[4] Bala B, Morshed M, Rahman M. Solar drying of mushroom using solar tunnel dryer, Proceedings of the International Solar Food Processing Conference.2009:1–11.

[5] Medugu DW. Performance study of two designs of solar dryers. Arch Appl Sci Res 2010;2:136–148.

[6] Nahar N. Processing of vegetables in a solar dryer in arid areas. The International Solar Food Processing Conference 2009.

[7] Gatea A. Performance evaluation of mixed-mode solar dryer evaporating moisture in beans. J Agric Biotechnol Sustain Dev 2011; 3(4):65-71.

[8] Hossain M, Bala B. Drying of hot chili using solar tunnel dryer. Sol Energy 2010;81:85−92. [CrossRef]

[9] Akpinar E. Kavak. Drying of mint leaves in a solar dryer and under the open sun: Modelling, performance analyses. Energy Convers Manag 2010:51:2407−2418. [CrossRef]

[10] Wakjira M. Solar drying of fruits and windows of opportunities in Ethiopia. Afr J Food Sci 2010;4:790−802.

[11] Ezekoye B, Enebe O. Development and performance evaluation of modified integrated passive solar grain dryer. Pacific J Sci Technol 2006;7:2185−2190.

[12] Mohanraj M, Chandrasekar P. Performance of a forced convection solar drier integrated with gravel as a heat storage material for chili drying. J Eng Sci Technol 2009;4:305−314.

[13] Ayyappan S, Mayilsamy K. Experimental investigation on a solar tunnel drier for copra drying, J Sci Ind Res 2010:69:635−638.

[14] Fudholi A, Sopian K, Ruslan M, Alghoul M, Suleiman M. Review of solar dryers for agricultural and marine products. Renew Sustain Energy Rev 2010;14:1−30. [CrossRef]

[15] Diwania S, Siddiqui AS, Agrawal S, Kumar R. Performance assessment of PVT-air collector with V-groove absorber: A theoretical and experimental analysis. Heat Mass Transfer 2020;57:665–679. [CrossRef]

[16] Parikh D, Agrawal GD. Solar drying in the hot and dry climate of Jaipur. Int J Renew Energy Res 2012;1:224−231.

[17] Saravanakumarand P, Mayilsamy K. Forced convection flat plate solar air heaters with and without thermal storage. J Sci Ind Res 2010;69:966−968.

[18] Yadav A, Bajpai VK. An experimental study on evacuated tube solar collector for heating of air in India. World Acad Sci Eng Technol 2012;79:81−86.
