AN EXPERIMENTAL STUDY OF FORCED CONVECTION GREEN HOUSE DRYING

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ABSTRACT

In the present study a greenhouse dryer is designed, fabricated and its performance is tested in the force convection mode of heat transfer. A thermal model of the system is developed in the forced convection greenhouse dryer and in the natural convection open sun drying mode. Experiments were conducted in the premises of SHIATS-DU Allahabad at latitude of 25°N. Measurements of solar intensity, relative humidity inside and outside the greenhouse dryer, moisture removal rate, air velocity and temperatures at different points were recorded. It is find that the average convective heat transfer coefficient for the forced convection greenhouse drying mode is higher than the open sun drying.

Key words: Forced convection greenhouse dryer, convective mass transfer coefficient.

INTRODUCTION

Now a day’s solar drying is a renewable and environmentally friendly technology. Solar drying can be considered as an advancement of natural sun drying and it is a more efficient technique of utilizing solar energy. For a better performance the solar drying systems must be properly designed in order to meet particular drying requirements of specific products and to give optimal performance. Designers should investigate the basic parameters such as dimensions temperature, relative humidity, airflow rate and the characteristics of products to be dried etc.

The most common process of crop drying is known as open sun drying (OSD), during which solar radiation falls directly on the crop surface and is absorbed up to certain limit of temperature. The absorbed radiations heat up the crop and evaporate the moisture from the crop. Sodha et al. modes.[1] presented a simple analytical model based on simultaneous heat and mass transfer at the product surface and included the effect of wind speed, relative humidity, product thickness, and heat conducted to the ground for open sun drying and for a cabinet dryer.[2] Condori M, Luis S. Greenhouse driers have the regular greenhouse structure (when not in use for crop production),
where the product is placed in trays receiving solar radiation through the plastic cover, while moisture is removed by n forced air flow. Mulet et al. [3] proposed a method of standardizing open sun drying time by defining the equivalent time based on the average solar radiation input. Hossain et al.[4] redesigned, fabricated and installed a mixed mode type forced convection solar tunnel dryer at the Department of Farm Power and Machinery, Bangladesh Agricultural University, Bangladesh for drying of red and green chillies under the tropical weather condition. Shanmugam et al. [5] designed and fabricated a desiccant integrated solar dryer to investigate its performance under the hot and humid climatic conditions of Chennai, India during the month of June. Dincer and Dost [6] presented a method to determine the moisture diffusion coefficient and moisture transfer coefficient for a solid object by employing the drying coefficient and lag factor.

Ratti and Crapiste [7] evaluated the heat transfer coefficient under forced convection from the data on crop drying and heat and mass balances. The experimental heat transfer coefficients were correlated by dimensionless expressions with Nusselt and Reynolds numbers. Anwar and Tiwari [8] evaluated the convective heat transfer coefficients for some crops under a simulated condition of forced mode in indoor open and closed conditions. Manohar and Chandra [9] studied the drying process in greenhouse type solar dryer using natural as well as forced ventilation and the drying data were represented with the Page drying equation. Condon' and Saravia [10] presented an analytical study of the evaporation rate in two types of forced convection greenhouse dryers using single and double chamber systems. Kumar A and Tiwari [11] compared the convective mass transfer coefficient of open sun drying, greenhouse dryer under natural and forced convections for drying onion flakes. It was found that the rate of moisture evaporation in case of greenhouse drying is more than that in open sun drying during the off sunshine hours due to the stored energy inside the green house.

The purpose of this work was to evaluate the heat transfer coefficient. The experiments were conducted after the crop harvesting season May 2013. This study was limited to constant rate drying from 7.5 to 8 hr of the day. The half hourly data for rate of moisture removal, crop temperature, relative humidity inside and outside the greenhouse and ambient air temperature for the complete drying period have been recorded. These data were used for determination of the convective heat transfer coefficient at every half an hour of drying time for bitter melon with the following conditions: (a) Open sun drying (OSD) under natural convection. (b) Greenhouse drying (FGHD) under forced convection. A suitable empirical model is presented to regress the convective heat and mass transfer coefficients as a function of drying time.

**Materials and methods**

The Nusselt number is a function of Grash of number and Prandtlnumbers for natural convection. The Nusselt number is a function of the Reynolds and Prandtl numbers for force convection.

\[
Nu = \left[ \frac{h_{c} K}{\kappa} \right] = C(GrPr)^{n} \quad \text{(for natural convection),}
\]

\[
Nu = \left[ \frac{hc}{K} \right] = C(RePr)^{n} \quad \text{(for forced greenhouse convection)}
\]

Where C and n are the constants

Now the convective heat transfer coefficient under natural convection can be determined as -----

\[
h_{c} = \left[ \frac{K}{K} \right] C(GrPr)^{n}
\]
Moisture evaporation is given as

\[ Q_e = 0.016 h_c (P(T_p) - \gamma P(T_e)) \]

The \( h_c \) in the above expression with moisture evaporation is termed the convective mass transfer coefficient in the case of crop drying.

Substituting the value of \( h_c \) in above, \( Q_e = 0.016 \frac{Z}{A} \) C(GrPr)\(^n\) [P(Tp) - \gamma P(Te)]

The moisture evaporated found by dividing the latent heat of vaporization (k) and multiplying by the area of the tray \( (A_t) \) and time interval \( (t) \).

\[ M_{ev} = \frac{Q_e}{A} = 0.016 \frac{Z}{A} [P(T_p) - \gamma P(T_e)] t A_t \] C (Gr Pr)\(^n\)

\[ Z = 0.016 \frac{Z}{A} [P(T_p) - \gamma P(T_e)] t A_t \]

Taking the logarithm of both side, \( \ln \left[ \frac{M_{ev}}{Z} \right] = \ln C + \ln (GrPr)^n \)

This is the form of a linear equation \( Y = mX_0 + C_0 \), where

\[ Y = \ln \left[ \frac{M_{ev}}{Z} \right], \quad X_0 = \ln[Gr Pr], \quad m = n; \quad \text{and} \quad C_0 = \ln C; \quad \text{thus} \quad C = e^{C_0} \]

(for natural convection)

Similarly, for forced green house convection

\[ Y = \ln \left[ \frac{M_{ev}}{Z} \right], \quad X_0 = \ln[Re Pr], \quad m = n; \quad \text{and} \quad C_0 = \ln C; \quad \text{thus} \quad C = e^{C_0} \]

**Experimental set up**

Two stainless steel wires mesh trays of 0.50×0.50m\(^2\) were used to accommodate 0.400 kg samples of bitter melon as thin layers, respectively. A roof type even span greenhouse with an effective floor covering 1.0 × 1.0 m\(^2\) has been made of aluminum plate (of L-shape c/s) and plastic film covering of 1.5mm. thikness. The central height and height of the walls were 1.285 and 1.0 m, respectively. An air vent with legs 0.1m and an effective opening provided at the roof of 0.15×0.15 m\(^2\) and a fan of 150 mm sweep diameter with air velocity 5 m/s was provided on the sidewal of dryer for forced convection. A continuous supply of A/C current 220V was supplied. The experimental set up for open sun drying and forced convection drying mode is shown in Fig. 1 and 2. The greenhouse had an east-west orientation during the experiments.

![Fig. 1 Open sun drying (OSD)](image1)

![Fig. 2 Forced green house drying (GHD)](image2)
Fig. 3 Instruments used in the experiments

Instrumentation builds up

A digital humidity/temperature meter was used to measure the relative humidity and temperature of air in the greenhouse, of ambient and above the crop surface. It had a least count of 0.1% relative humidity with accuracy of ±3% on the full scale range of 5-99.9% of relative humidity and 1°C temperature with accuracy of ±1% on the full scale range of 10-80°C. A non-contact thermometer, having a least count of 1°C and full scale range of 18 to 260°C was used for measurement of the crop temperature. A top loading digital balance (gold line) of 500 g weighing capacity, having a least count of 0.01 gm was used to weigh the sample during drying. The difference in wave length calibrated by solarimeter (Central Electronics Ltd., India). It measures solar radiation in m W/cm², having a least count of 2 m W/cm² with ±2% accuracy of the full scale range of 0-120 mW/cm². The air velocity across the greenhouse section was measured with an electronic digital anemometer, a fan to produce forced convection of Zigma Pvt. Ltd. fitted on side wall of the greenhouse dryer.

Sample preparation

The same sizes of samples were maintained of fresh bitter melon (karalla) cut into small slices 5 mm thickness with the help of chips cutter. The slices were soaked in water for 4 h and then conditioned in a shed for 1/2 h after removing the excess water. The same sizes of samples were same for open sun drying and inside the forced convection greenhouse in all the cases.

Experimentation

The experiments on OSD were always under natural convection and forced convection under FGHD was done with the help of air vent provided at the roof and an A/C fan on the side of the greenhouse dryer. The experiments were revised type in nature. Experiments were conducted in the months of May 2013 for open and forced convection greenhouse dryer by using a fan on the side of dryer, in the Climatic conditions of SHIATS Allahabad. The 0.400 kg samples were kept in the wire mesh tray for the experiments. Observations were taken under open sun and inside the forced greenhouse simultaneously. The observations were recorded from 9 am at every 1/2 hour interval for the 17 times continuous drying. All the experiments of forced greenhouse drying (FGHD) have been conducted simultaneously with the open sun drying (OSD) for experimental study.
RESULTS AND DISCUSSION

Variation of relative humidity with respect to the time of the day is shown in fig. 4. At 1.30 ‘O’ clock relative humidity inside the greenhouse and of the environment becomes equal. Variation of solar intensity with respect to the time of the day shows in fig 5. It is highest at 1.00 ‘O’ clock. Solar intensity and falls down in the afternoon than the rate of rise in the morning. In the fig 6 the variation of air velocity is also shown which plays an important role in open sun drying. This has promoted the faster rate of moisture removal in open sun drying than in FGHD in the initial stage of drying. The values of constants ‘C’ and ‘n’ are obtained by simple linear regression analysis, and thus the values of $h_c$ were determined for both open sun drying and forced convection greenhouse drying mode. Fig. 8 shows the variation of convective heat transfer coefficients Vs time for open sun drying and FGHD drying modes. It is observed that the maximum rate of moisture removal took place in the beginning of the drying time. The mass removal rate becomes nearly constant after 240 minutes of drying time in FGHD. The convective heat transfer coefficient inside forced convection greenhouse drying mode is more than open sun drying. Similar results have been observed by D. Jain et al. [12] and S K Shukla et al [13]. Whereas Ajeet Kumar Rai et al. [14] have reported that the convective heat transfer coefficient is higher in open sun drying when it is compared with the greenhouse drying in natural convection mode.

Result Data for Open sun and forced convection Greenhouse drying modes

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>n</th>
<th>$h_c$ (W/m²°C)</th>
<th>$h_{av}$ (W/m²°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open sun drying mode</td>
<td>0.87</td>
<td>0.31</td>
<td>1.862-3.265</td>
<td>2.545</td>
</tr>
<tr>
<td>Forced convection greenhouse drying mode</td>
<td>1.46</td>
<td>0.3824</td>
<td>1.693-3.673</td>
<td>2.832</td>
</tr>
</tbody>
</table>

Fig. 4. Variation of relative humidity Vs time

Fig. 5. Variation of solar intensity Vs time

Fig. 6. Variation of air velocity Vs time

Fig. 7. Variation of Moisture removal rate Vs time
CONCLUSION

A greenhouse dryer is designed and fabricated to work in force convection mode. A thermal model of the system is developed. The convective heat transfer coefficients for bitter melon under open sun and forced convection mode were determined by using the values of the constants ‘C’ and ‘n’ in the expression of Nusselt number. C and n in the open sun drying were found to be 0.87 and 0.31, whereas for the forced convection greenhouse drying the corresponding values are found to be 1.46 and 0.3824 respectively. The maximum values of convective heat transfer coefficients under open sun drying and forced convection greenhouse drying were found to be 3.26513 W/m$^2$°C, and 3.67323 W/m$^2$°C. Where the average convective heat transfer coefficient for the forced convection greenhouse drying mode is higher than the open sun drying. It is concluded that-

![Variation of Convective heat transfer coefficient (W/m$^2$°C) Vs time](image)

1. The maximum rate of moisture evaporation took place in the beginning of the drying time (1-4 h). The mass transfer rate became approximately constant after 6 h of drying time.
2. The convective mass transfer coefficient in the beginning of drying behaves like a wetted surface and at the end of the drying like a dry surface.
3. The convective mass transfer coefficient as a function of drying time has been established with the help of a two term exponential curve model.

REFERENCES

Where, 
\[ T_i = \frac{T_p + T_e}{2} \]

\[ C_p = \frac{\frac{\Sigma X_0 Y - \Sigma X_0 \Sigma Y}{N_0 \Sigma X_0^2 - (\Sigma X_0)^2}}{\frac{\Sigma X_0^2 Y - \Sigma X_0 \Sigma XY}{N_0 \Sigma X_0^2 - (\Sigma X_0)^2}} \]

\[ \rho = \rho_v L/\mu \]

\[ \mu_v = 1.718 \times 10^{-5} + 4.620 \times 10^{-8} T_i \]

\[ \rho_v = 353.44/ (T_i + 273.15) \]

\[ K_v = 0.0244 + 0.7673 \times 10^{-4} T_i \]

\[ C_{ij} = 999.2 + 0.1434 T_i + 1.101 \times 10^{-4} T_i^2 - 6.7581 \times 10^{-8} T_i^3 \]