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DESIGN, FABRICATION AND HEAT TRANSFER STUDY OF GREEN HOUSE DRYER

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ABSTRACT

The objective of the present study was to design to fabricate and to test the green house dryer in natural mode. The system is capable of generating a continuous flow of hot air temperature up to 60°C. Experiments were conducted in the premises of SHIATS in Allahabad at latitude of 25°N. Measurement of solar intensity, relative humidity inside and outside the green house dryer, moisture removal rate, air velocity, temperature at different point were recorded. These data were used for determination of the coefficient of convective mass transfer and then for development of the empirical relation of convective mass transfer coefficient with drying time under the open sun and natural mode. It is observed that the convective mass transfer coefficient is lower for drying inside the green house than the open sun drying.

Key words: Green house dryer, convective mass transfer coefficient.

1. INTRODUCTION

Vegetables are highly seasonal and are plentifully available only at particular times of the year. In the peak season, the selling price decreases, and this can lead to heavy losses by the producers. Also, due to the abundant supply during the season, a glut in the market may result in wastage of product. Preservation of these vegetables by drying can prevent the huge wastage and make them available in the off-season at remunerative price. The main objective of drying is removal of free water (lowering the water activity below 7%) from fruits, vegetables and grains. So the extent where microorganism do not survive and reproduce simultaneously the total solid viz, sugar, organic acid etc are concentrated. For a farmer who needs to dry large quantity of crop every year, should have equipment and operating cost required for drying should be economically and justified.

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 radiation heat up the crop and evaporates the moisture from the crop [1]. During this process, the amount of solar energy received at the crop surface is lost at various stages through reflection, radiation, convection and conduction. For preventing these, placing a plastic covering over the crop produces a greenhouse effect to trap the solar energy in the form of thermal heat radiation and prevents conduction heat loss up to certain limit. Modeling drying of crops under solar energy is a complex problem involving simultaneous heat and mass transfer in a hygroscopic nature of crop. Convective heat transfer coefficients are one of the most critical parameters required for analysis and simulation of the process. Several researchers have presented various numerical models for moisture migration, considering diffusion as the primary transport mechanism [2-4]. Dincer and Dost [4] 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. Sokhansanj [5] have developed a natural convection heat transfer model in which the density of air was assumed to be a function of temperature and absolute humidity. Anawar and Tiwari[6] determined the convective heat transfer coefficient under open sun drying by using the linear regression technique.

The purpose of this work was to evaluate the heat transfer coefficient 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. The experiments were conducted after the crop harvesting season from April - May 2013. This study was limited to constant rate drying from 7.5 to 8 hr of the day. 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 (GHD) under natural convection. A suitable empirical model is presented to regress the convective heat and mass transfer coefficients as a function of drying time.

2. THEORY

Determination of convective heat transfer coefficient, $h_c = [\frac{K_v}{X}]\ C\ (GrPr)^n$

The Nusselt number is a function of the Grashof number and Prandtl numbers for natural convection.

$$Nu = [\frac{hcX}{K}] = C\ (GrPr)^n \qquad \text{(for natural convection)},$$

Where C and n are the constants

Thus, the convective heat transfer coefficient under natural convection can be determined as

The rate of heat on account of mass transfer (evaporate moisture) is given as

$$Qe = 0.0l6\ hc\ [P\ (Tp) - \gamma\ P\ (Te)]$$

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

Thus, the convective heat transfer coefficient under natural convection after putting the value of hc, $Q_v = 0.016[\frac{K_v}{X}]\ C\ (GrPr)^n\ \ [P(Tp)-\gamma P(Te)]$

The moisture evaporated is determined by dividing by the latent heat of vaporization (k) and multiplying by the area of the tray (At) and time interval (t).

$$M_{ev} = \frac{Qv}{\lambda} tAt = 0.016\frac{K_v}{X\lambda}[P(T_p) - \gamma P(T_e)]\ tA_t\ C\ (Gr\ Pr)^n ,$$

$$Z = 0.016\frac{K_v}{X\lambda}[P(T_p) - \gamma P(T_e)]\ tA^t ,\ M_{ev} = ZC(Gr\ Pr)^n$$

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

$Y = \ln\left[\frac{M_{ev}}{z}\right]$, $X_0 = \ln[Gr\ Pr]$, $m = n$; and $C_0 = \ln C$; thus $C = eC°$

$T_P(T) = \exp[25.317 - \{353.44/(T_i+273.15)\}]$

$Gr = gL3\beta\rho 2\Delta T/\mu 2$ $\mu v = 1.718\times 10\text{-}5 + 4.620\times 10\text{-}8Ti$

$Re = \rho\ v\ L/\mu$ $\rho v = 353.44/(Ti+273.15)$

$Pr = \mu\ Cp\ K$ $Cv = 999.2+0.1434\ Ti+1.101\times 10\text{-}4Ti^2 - 6.7581\times 10\text{-}8Ti^3$

Where, $Ti = (Tp+Te)/2$ $Kv = 0.0244+0.7673\times 10\text{-}4Ti$

$$n = \frac{No.\sum X_0 Y - \sum X_0 \sum Y}{No.\sum X_0^2 - (\sum X_0)^2} ,\quad C_0 = \frac{\sum X_0^2 \sum Y - \sum X_0 \sum X_0 Y}{No.\sum X_0^2 - (\sum X_0)^2}$$

3. MATERIALS AND METHODS

3.1. Experimental set up

Wires mesh trays of 0.50 × 0.50m2 and 0.50 × 0.50 m2 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 m2 has been made of aluminum plate (of L-shape c/s) and UV film covering. The central height and height of the walls were 1.285 m and 1.0 m, respectively. An air vent was provided at the roof with an effective opening of 0.15×0.15 m2 for natural convection. The experimental set up for open sun drying and greenhouse drying in the natural mode is shown in Fig.1 and Fig.2. The greenhouse had an east-west orientation during the experiments.

Fig. 1 open sun drying (OSD)

Fig.2 green house drying (GHD)

Fig.3 Instruments used in the experiments

3.2. Instrumentation

A non-contact thermometer (Raytek-MT4), having a least count of 1 °C and accuracy of ±2% on a full scale range of) 18 to 260 °C was used for measurement of the crop temperature. A digital humidity/temperature meter (model Lutron HT-3003) 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 top loading digital balance (gold line) of 500 g weighing capacity, having a least count of 0.01 g with ±2% on the full scale was used to weigh the sample during drying. The difference in weight calibrated solarimeter, locally named Suryamapi (Central Electronics Ltd., India). It measures solar radiation in m W/cm^2, having a least count of 2 m W/cm^2 with ±2% accuracy of the full scale range of 0-120 m W/cm^2. The air velocity across the greenhouse section was measured with an electronic digital anemometer model of Lutron AM-4201. It had a least count of 0.1 m/s with ±2% on the full scale range of 0.2^-0.0 m/s.

3.3. Sample preparation

The fresh bitter melon (karalla) was cut into small slices. The slices were soaked in water for 9 h and than conditioned in a shed for 1/2 h after removing the excess water. The same sizes of samples were maintained same for open sun drying and inside the greenhouse in all the cases.

3.4 Experimentation

Experiments were conducted in the months of May 2013 for open & natural convection 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 greenhouse simultaneously. The observations were recorded from 9 am at every ½ hour interval for the 17 times continuous drying. All the experiments of greenhouse drying (GHD) have been conducted simultaneously with the open sun drying (OSD) for comparative study. The experiments on OSD were always under natural convection. Natural convection under GHD was done with the air vent provided at the roof of the greenhouse.

RESULTS AND DISCUSSION

Fig 4 shows the variation of relative humidity with respect to the time of the day. At 1.00 'O'clock relative humidity inside the green house and of the environment becomes equal. Fig 5 shows the variation of solar intensity with respect to the time of the day. It is highest at 12.00 'O' clock. Solar intensity falls down rapidly in the afternoon time 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 the green house drying 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 hc were determined for both open sun drying and green house drying under natural convection mode. The variation of convective heat transfer coefficients with respect to time for open sun drying and Green house drying modes are shown in fig 8. It is observed that the maximum rate of moisture removal took place in the beginning of the drying time. The mass transfer rate becomes essentially constant after 300 minutes of drying time. The convective heat transfer coefficient inside green house drying under natural mode at initial stage of drying is lower than for open sun drying. Similar results have been observed by Shukla et al (2007) [7].

Table 1 Open sun drying and Green house drying modes

	C	n	h_c (W/m^2 °C)	$h_c$av (W/m^2 °C)
Open sun drying mode	0.91	0.2955	1.795-3.085	2.4258
Green house drying mode	0.8279	0.3091	1.37-3.276	2.3086

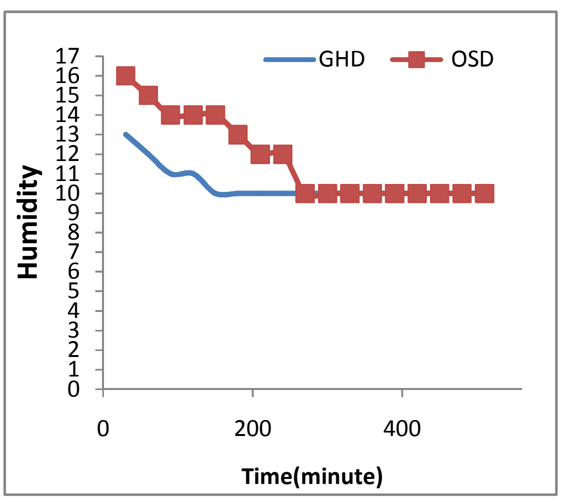

Fig.4. Variation of relative humidity Vs time

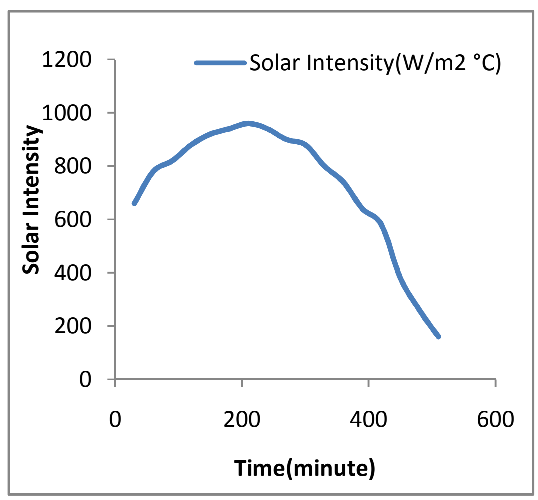

Fig.5. Variation of solar intensity Vs time

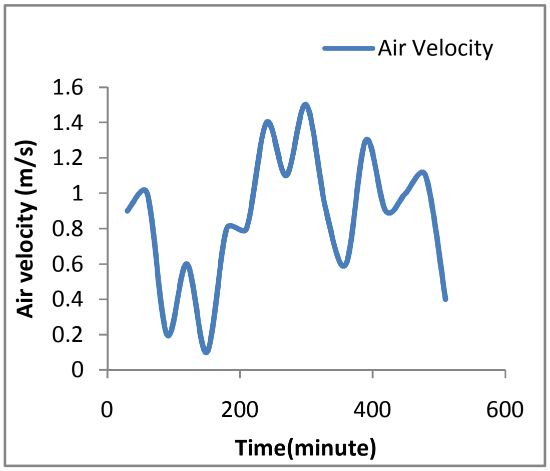

Fig. 6-variation of air velocity Vs time

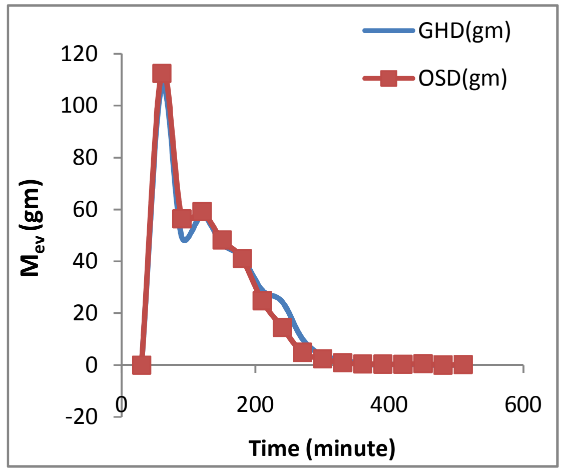

Fig. 7-variation of Moisture removal rate Vs time

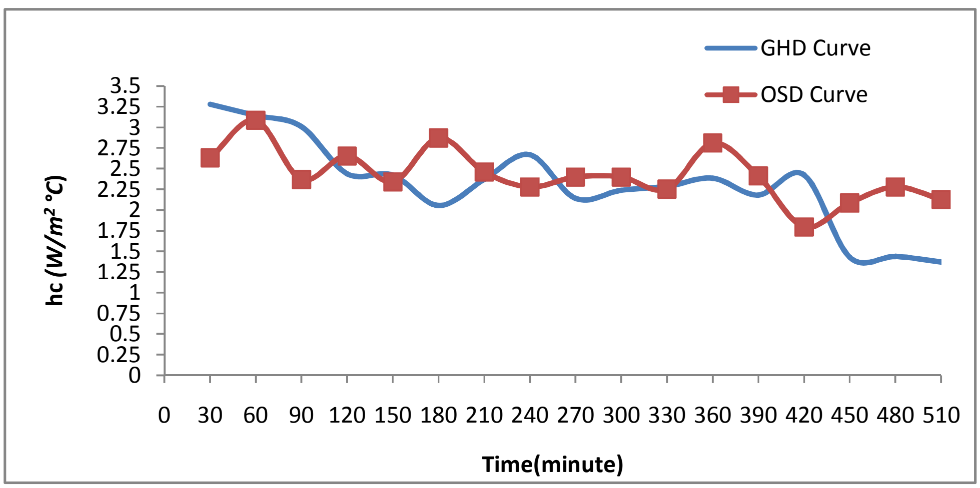

Fig. 8 Variation of Convective heat transfer coefficient (W/m^2 °C) Vs time

CONCLUSION

The convective heat transfer coefficients for bitter melon under open sun and green house drying in natural convection mode were determined using the values of the constants ‘C’ and ‘n’ in the Nusselt number expression. The values of constants C and n in the open sun drying were found to be 0.91 and 0.29556, whereas for the green house drying the corresponding values are found to be 0.82787 and 0.30907 respectively. The maximum values of convective heat transfer coefficients under open sun drying and green house drying were found to be 3.085 W/m2°C, and 3.276 W/m2°C. Whereas the average convective heat transfer coefficient for the open sun drying is higher than the green house drying in natural mode.

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