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Convective Heat Transfer Coefficient of Some Fruits Under Open Sun Drying Conditions

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Abstract: In this work, an attempt has been made to evaluate the convective heat transfer coefficient operating in fruits drying in open sun drying conditions (natural convection). Convective heat transfer coefficients have been found at different initial moisture contents and at ambient temperature by determining the values of C and n for four fruits, namely plum, grape, peach and fig. Convective heat transfer coefficient for all crops is found to be exponentially increasing with moisture content. The coefficients of the exponential model have been determined by using Statistica Routine. In studying the consistency of the models developed for all fruits, some statistical tests, such as reduced χ^2, MBE and RMSE were also used as well as correlation coefficients. The experimental error in terms of percent uncertainty was also calculated.

Key words: Convective, coefficient, frutis, drying conditions

Introduction

Sun drying is not new to the area. Traditionally, farmers and housewives dry figs, grapes, apricots, okra and various other types of products by spreading them in thin layers on mats or on paved ground, in the fields or in courtyards, thus exposing them to the sun and wind. Despite many disadvantages associated with this system, it is still practiced in many places throughout the world where plenty of solar radiation is available. Drying is a continuous process with changes in moisture content, air and crop drying and the humidity of air all occurring simultaneously. Heat is transferred from the surrounding air the from the sun to the surface of the crop in different models of heat transfer. It is utilized in two ways; i.e. to increase the crop temperature in the from of sensible heat and in removal of moisture or, in other terms, mass transfer utilizing the latent heat vapourization. The convective heat transfer coefficient is an important parameter in drying rate simulation, since the temperature difference between the air and crop varies with this coefficient [1]. Usually, two methods are available to determine the convective heat transfer coefficient of grains like barley, malt, etc. These are dimensional analysis and direct measurement of heat transfer on a grain bed by comparing the temperature curves with Shumann's exact solution. The dimensional analysis is mathematically simple and has a wide range of applications. This method is incomplete without sufficient experimental data, although it facilitates the interpretation and extends the range of application of experimental data by correlation them in terms of dimensional groups.

Smith and Sokhansanj 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 [2]. Miketinac, Sokhansanj and Tutec used five models simulating the process of simultaneous heat and mass transfer in drying a layer of barley . The heat transfer coefficient was found to vary between 43-59 W/m^{2}K depending upon the form of drying model [3].

Sanjay and Tiwari and Tiwari et.al. have developed models for the process of convective mass transfer in solar distillation units [4-5]. Goyal and Tiwari have studied heat and mass transfer in crop drying systems and have reported the values of convective heat transfer for wheat and gram as 12.68 and 9.62 W/m^{2o}C [6]. Anwar and Tiwari have determined the convective heat transfer coefficients of six crops (green chillies, green peas, white gram, onion, potato and cauliflower) dried of convective heat transfer coefficient varied from crop to crop with a range of 3.5-26 W/m^{2o}C for the crops studied. [7]. Togrul have determined the convective heat transfer coefficients of nine crops (marrow, aubergine, carrot, green bean, Albanian pepper, green pepper, potato, onion and pear) dried of convective heat transfer coefficient varied from crop to crop with a range of 0.25-3.3 W/m^{2o}C for the crops studied [8].

In this study, convective heat transfer coefficients have been found at different initial moisture contents for four fruits, namely plum, grape, peach and fig. The variations of convective heat transfer coefficient with moisture content for all fruits were investigated.

Experimental Set-up and Procedure: Sun drying experiments were performed in the months of July and August (2001) in Elazýð (locate latitude 38.4^{o}). The schematic diagram of the experimental unit is shown in Figure 1. Experimental unit assembly was located on the open top floor of a three-floor building to have a good view of the sky' s radiation. Before the experiment, the samples were thoroughly washed initially, and then pre-treated with several of chemicals. Table 1 lists the pre-treatment solutions and methods as applied to each sample.

A wire mesh tray of 0.184 x 0.273 m^2 size was used for drying the crop. The crop temperatures and air temperatures at different locations were measured at 15 minutes intervals by Fe-constantan thermocouples connected to a sixteen channel-temperature measurement unit (least count 0.1 °C). KM 8004 model, Kane May humidity measuring instrument with a least count of %1 was used for relative humidity measurement just above the crop surface. For gravimetric analysis, an electronic balance of 1.5 kg capacity and ±0.01 g sensitivity was used. The initial moisture content of all the crops was determined by a Mettler infrared moisture analyser at 80 °C. The crop was kept on the electronic balance using the tray. The crops were placed on the trays in one layer. Thermocouples were placed for measuring crop temperature and temperature of air just above the crop surface. Precautions were taken so that placement of the thermocouple does not affect the reading being shown by the balance. The humidity-measuring instrument was kept on the crop surface with its sensing ports facing downwards towards the crop surface. Every time, it was kept 2 min before recording observations. The weight of the humidity-measuring instrument was finally deducted from the electronic balance reading.

Average values of crop temperature ($\bar{T}_c$), just above the crop temperature ($\bar{T}_e$) and relative humidity ($\bar{\gamma}$) were calculated from two consecutive values for that time interval and have been used in the calculations. The difference in two consec. reading of crop weight directly gave the moisture evaporated during the 15 minute time period [6]. The whole unit was kept in open sun at a place with negligible wind velocity. The difference in weight directly gave the quantity of water evaporated during that time interval. The experimental was repeated three times for all initial moisture content for obtaining more accurate results. Experimental error in the form of per cent uncertainty was also determined for open sun drying. [9]

Observations and Computation Procedure: The convective heat transfer coefficient in open sun drying can be determined using the expression for Nusselt number as [10]

$$Nu=\frac{h_cX}{K_v}=C(Gr.Pr)^n \qquad \text{or} \qquad h_c=\frac{K_v}{X}C(Gr.Pr)^n \tag{1.}$$

The rate of heat utilized to evaporate moisture is given as [11]

$$\dot{Q}_e=0.016h_c[P(T_c)-\gamma P(T_e)] \tag{2.}$$

On substituting hc from Eq.(1), Eq(2) becomes

$$\dot{Q}_e=0.016\frac{K_v}{X}C(Gr.Pr)^n[P(T_c)-\gamma P(T_e)] \tag{3.}$$

The moisture evaporated is determined by dividing Eq. (3) by the latent heat of vaporization (λ) and multiplying by the area of the tray (A_t) and time interval (t).

$$m_{ev}=\frac{\dot{Q}_e}{\lambda}A_t.t=0.016\frac{K_v}{X\lambda}C(Gr.Pr)^n[P(T_c)-\gamma P(T_e)]tA_t \tag{4.}$$

Letting $0.016K_v/X\lambda[P(T_c)-\gamma P(T_e)]tA_t=Z$

$$\frac{m_{ev}}{Z}=C(Gr.Pr)^n \tag{5.}$$

Taking logarithm of both sides of Eq.(5),

$$\ln\left[\frac{m_{ev}}{Z}\right]=\ln C+n\ln(Gr.Pr) \tag{6.}$$

This is in the form of a linear equation,

$$Y=mX_0+C_0$$

where

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

Therefore, the values of C and n can be determined by linear regression analysis. The physical properties of humid air, i.e. specific heat (C_v), thermal conductivity (K_v), density (ρ_v), and the partial vapour pressure have been determined using the following polynomial expressions [10]. For obtaining the physical properties of humid air, T_i is taken as the average of crop temperature (T_c) and the temperature just above the crop surface (T_e):

7.
$$C_V = 999.2 + 0.1434T_i + 1.101x10^{-4}T_i^2 - 6.7581x10^{-8}T_i^3$$

8.
$$K_V = 0.0244 + 0.6773x10^{-4}T_i$$

9.
$$\rho_V = \frac{353.44}{T_i + 273.15}$$

10.
$$\mu_V = 1.718x10^{-5} + 4620x10^{-8}T_i$$

11.
$$P(T) = \exp\left[25.317 - \frac{5144}{(T_i + 273.15)}\right]$$

The experimental error has been evaluated in terms pf per cent uncertainty (internal + external). The following two equations have been used for internal uncertainty

12.
$$U_1 = \frac{\sqrt{\sigma_1^2 + \sigma_2^2 + \ldots + \sigma_N^2}}{N}$$

where σ is the standard deviation and is given as

13.
$$\sigma = \sqrt{\frac{\sum (X - \overline{X})^2}{N_0}}$$

and $X-\overline{X}$ is the deviation of observation from the mean and N and N_0 are the number of sets and number of observations in each set, respectively.

The per cent internal uncertainty, therefore, has been determined using the following expressions.

14.
$$\% \text{ internal uncertainty} = \frac{U_1}{\text{Average of total number of observations}} \, 100x$$

For external uncertainty, the least counts of all the instruments used in measuring the observation data have been considered.

Results and Discussion

The average crop temperature ($\overline{T_c}$), just above the crop temperature ($\overline{T_e}$) and relative humidity ($\overline{\gamma}$) have been used determining the physical properties of humid air which, in turn, where used for calculating the values of Grashof Number (Gr) and Prandatl Number (Pr). The constant C and n were determined by linear regression analysis and have been considered further for obtaining the values of the convective heat transfer coefficients by Eq. (1). The values of h_c and initial moisture content of plums, grapes, peaches and figs are shown in Table 2.

It can be observed from Table 2 that the values of convective heat transfer coefficient (h_c) for all fruits have been increasing with moisture content. From Table 2, it may be also concluded that the values of convective heat transfer coefficient (h_c) range between 0.155 and 1.1625 W/m^{2}°C for various fruits.

The large variation in convective heat transfer coefficient is due to (i) porosity, (ii) moisture content and (iii) shape and size of the crop. The value is highest in the case of peach as the fruits were turned at regular intervals, exposing more area. The next highest is fig. The value was found to be the lowest in the case of plum. The per cent uncertainty (internal + external) was found to be in the range 7.054-9.008 and the different values of C, n and h_c were found to be within the range of the per cent experimental error.

The changes of convective heat transfer coefficient with moisture content for the studied fruits are shown in Fig. 2. It can be seen that convective heat transfer coefficient are increasing with increased moisture content. When the data on the convective heat transfer coefficient are considered as a whole for a fruits, it is seen that the changes in the convective heat transfer coefficient may be expressed best by an exponential equation of the moisture content in the following equation.

15.
$$h_c = a.\exp(b.W)$$

Regression was done by using the Statistica routine. The correlation coefficient (r) was one of the primary criterions to decide the appropriateness of model. In addition to r, the various statistical parameters such as reduced chi-square (χ^2), mean bias error (MBE) and root mean square error (RMSE) were used to determine the quality of the

Table 1:Pre-Treatment Chemicals and Procedures Applied to Selected Fruits.

Sample	Chemicals	Procedure	Average diameter
Plum	NaOH, 10 g per litre of water	Immersed for 10-15 s	20 mm
Grape	An emulsion of 5 % K_2CO_3 and 0.5 % olive oil	Immersed for 2 min.	24 mm
Peach	No chemical pre-treatment left from pips	Peeled, divided two pieces,	55 mm
Fig	No chemical pre-treatment	No treatment	50 mm

Table 2:Initial Moisture Content (W,% wet basis) and Heat Transfer Coefficient (h_c, W/m^{2}°C) under Open Sun Drying for Plums, Grapes, Peachs and Figs.

Plum		Grape		Peach		Fig	
W	h_c	W	h_c	W	h_c	W	h_c
78.02	0.1550	80.21	0.2864	86.28	1.1625	69.59	0.4456
76.01	0.1250	78.37	0.2800	78.01	1.1260	64.28	0.3188
73.70	0.1180	75.57	0.1680	73.95	0.4760	62.08	0.3130
71.92	0.0989	73.70	0.1641	63.65	0.2935	57.96	0.3064
67.62	0.0969	70.56	0.1588	59.90	0.1877	56.59	0.2827
63.09	0.0819	68.07	0.1556	47.84	0.1590	52.36	0.2296
57.47	0.0603	63.21	0.1527	40.34	0.1490	49.34	0.2057
54.04	0.0587	59.51	0.1519			42.81	0.1989
50.82	0.0496	54.13	0.1492			39.80	0.1736
47.22	0.0485	50.97	0.1486				

Table 3:The Coefficients of Exponential Model and The Results of Statistical Analyses under Open Sun Drying for Selected Fruits

Fruits	a	b	r	MBE	RMSE	χ^2
Plum	6.918×10^{-3}	0.0387	0.9806	-0.000189	0.006689	5.594×10^{-5}
Grape	0.03292	0.02486	0.7488	-0.000630	0.03394	0.00144
Peach	0.01022	0.0558	0.9309	0.002415	0.151862	0.0323
Fig	0.04578	0.0317	0.9692	-0.001630	0.01957	0.0005

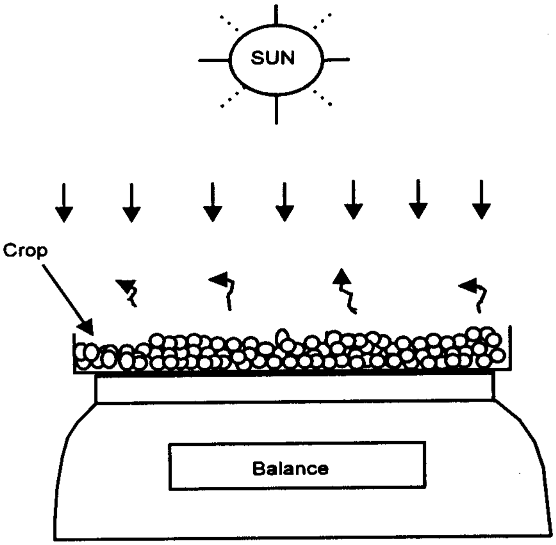

Fig. 1: Experimental set-up for open sun drying

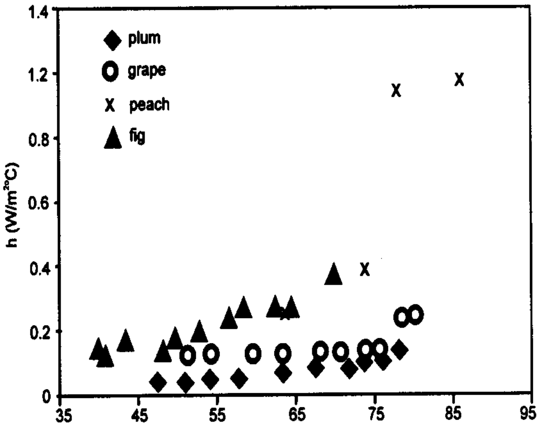

Fig. 2: The variation of convective heat transfer coefficient with moisture content for selected fruits.

fit. These parameters can be calculated as following:

$$\chi^2 = \frac{\sum_{i=1}^{N} \left(h_{c\,\exp,i} - h_{c\,pre,i} \right)}{N - n} \tag{16.}$$

$$\mathrm{MBE} = \frac{1}{N} \sum_{i=1}^{N} (h_{c\,pre,i} - h_{c\,\exp,i}) \tag{17.}$$

$$\mathrm{RMSE} = \left[\frac{1}{N} \sum_{i=1}^{N} \left(h_{c\,pre,i} - h_{c\,\exp,i} \right) \right]^{1/2} \tag{18.}$$

where $h_{c\ \exp,i}$ stands for the experimental convective heat transfer coefficient in any measurement and $h_{c\ pre,i}$ is predicted convective heat transfer coefficient for the model. N and n are the number of observations and constants respectively.

The results of the statistical computations undertaken to assess the consistency of the exponential equations are presented in Table 3. The low values of χ^2, MBE and RMSE are shown that developed equations are statistically convenient. As a result, these expressions can be used to estimate the convective heat transfer coefficient for four fruits (namely plum, grape, peach and fig) at any moisture content during the drying process with an acceptable accuracy.

Conclusions

Under open sun drying conditions, the convective heat transfer coefficient (h_c) for some fruits (plum, grape, peach and fig) were determined using the values of the constants, C and n, obtained for these fruits based on experimental data and the linear regression technique. The value of h_c was found to vary from fruit to fruit, which is due to differences in porosity, moisture content, shape and size of the fruit. Experimental errors in terms of per cent uncertainty were found to be in the range 7.054-9.008 %. The higher values in the case of the latter are due to the removal of small quantity of moisture. Furthermore, it was found that the convective heat transfer coefficient can be exponentially explained as a function the moisture content and the developed equations are statistically convenient.

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