ISSN: 0975-833X

Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 3, Issue, 8, pp.088-093, August, 2011

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

RESEARCH ARTICLE

EXPERIMENTAL INVESTIGATION ON CONVECTIVE HEAT TRANSFER COEFFICIENT FOR KHOA DRYING

*Mahesh Kumar[1], K.S. Kasana[2], Sudhir Kumar[3] and Om Prakash[4]

[1]Assistant Professor, Mechanical Engineering Department, Guru Jambheshwar University of Science & Technology, Hisar (India)-125001
[2]Ex-Professor, Mechanical Engineering Department, National Institute of Technology, Kurukshetra, India
[3]Professor, Mechanical Engineering Department, National Institute of Technology, Kurukshetra, India
[4]Associate Professor, Mechanical Engineering Department, National Institute of Technology, Patna, India

ARTICLE INFO

Article History:
Received18th May, 2011
Received in revised form
6th June, 2011
Accepted 8th July, 2011
Published online 5th August, 2011

Key words:
Khoa; Khoa drying;
Convective heat transfer coefficient;
Open Sun drying;
Greenhouse drying.

ABSTRACT

In this research paper, the convective heat transfer coefficients of khoa were investigated in an open sun and greenhouse drying for natural as well as forced convection modes. The khoa was dried in open sun conditions and in the roof type even span greenhouse with a floor area of 1.2×0.8 m^2 in natural and forced convection mode at atmospheric pressure till there is almost no variation in its mass. The experimental data were used to determine the values of the constants in the well known Nusselt expression by simple linear regression analysis and, consequently the convective heat transfer coefficients were evaluated. The convective heat transfer coefficient under forced convection greenhouse drying was found to be higher than the other modes. The convective heat transfer coefficient could be expressed exponentially as a function of the drying time interval. To test the consistency of the models developed for khoa drying, correlation coefficient, and various statistical parameters were also determined. The experimental error in terms of percent uncertainty was also evaluated.

INTRODUCTION

Khoa is a traditional concentrated milk product which is a rich source of energy containing proteins, fat, lactose and minerals. It forms an important base for preparation of various types of milk sweets. The total Indian sweet market is around ₹ 520 billion in terms of annual sales [1]. In many places khoa manufactured in January–February is stored for use in summer season. The shelf life of khoa is chiefly influenced by the moisture contents among other factors like storage temperature, raw material quality, sanitation conditions and packaging [2]. Khoa is a partially dehydrated milk product which contains sufficient moisture to permit the growth of microorganisms of which the moulds give visible growth on its surface within a few days of storage at room temperature [3]. The presence of moulds in khoa causes its fast deterioration by producing discoloration defects as well as disagreeable flavors [4, 5]. Solar radiation has a definite role in significant reduction of yeast and mould counts [6]. The most widely used and the simplest method for product dehydration is the open sun drying method in which the product is spread in a thin layer under direct sunlight. In spite of many disadvantages like product pollution and contamination, sun drying is still practiced in many places throughout the world where plenty of solar radiation is available. An advanced and alternative method to the traditional techniques is greenhouse drying, in which the product is placed in trays and receives solar radiation through the plastic cover, while moisture is removed by natural convection or forced air flow [7]. The convective heat transfer coefficient is an important parameter in drying rate simulation, since the temperature difference between the air and the product varies with this coefficient [8]. The convective heat transfer coefficient depends on the thermal physical properties of the humid air surrounding the khoa and the temperature difference between the khoa surface and the air. The convective mass transfer coefficients for various shapes and sizes of jaggery pieces in a controlled environment were evaluated [9, 10]. The usage of solar energy is a new approach in the khoa preservation which may pave a new path in the field of dairy industry. Therefore, the present studies were undertaken to evaluate the convective heat transfer coefficient for khoa with the following conditions:

(a) open sun drying under natural convection;

***Corresponding author:** mkshandilya1@gmail.com*

(b) greenhouse drying under natural convection;
(c) greenhouse drying under forced convection.

A suitable empirical model is also developed to predict the convective heat transfer coefficient for khoa as a function of drying time.

MATERIALS AND METHODS

Experimental set-up and instrumentation

A roof type even span greenhouse of 1.2×0.8 m^2 effective floor area was fabricated of PVC pipe and a UV film covering of 200 microns. The central height and the walls were maintained as 0.6m and 0.4m respectively. An air vent with an effective opening of 0.043 m^2 was provided at the roof for natural convection. A photograph of the experimental setup for greenhouse drying in the natural mode is shown in Fig.1 (a). A fan of 225mm sweep diameter and 1340 rpm with a rated air velocity of 5m/s was provided on the sidewall of the greenhouse for the forced convection experiments. A photograph of the experimental setup for greenhouse drying in the forced mode is shown in Fig.1 (b).

(a) (b)

Fig. 1: Experimental set up of greenhouse drying under (a) natural convection (b) forced convection

The orientation of the greenhouse was east-west during the experimentation. Experimental setup for open sun and greenhouse under natural and forced convection drying modes were located on the open floor of a three-floor building to have a good exposure to the solar radiation. A schematic view of the experimental setup under the open sun drying mode is shown in Fig. 3.

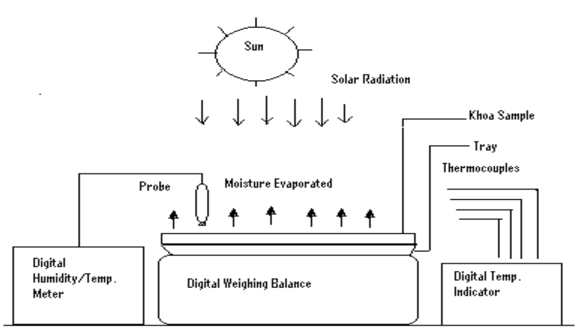

Fig. 3: Schematic view of experimental set up for open sun drying

For each mode of drying, a khoa sample of 1.5 cm thickness for single layer drying was kept in a wire mesh tray of 0.09m×0.06m size directly over the digital weighing balance of 6 kg capacity (model TJ-6000, Scaletech, made in India) having a least count of 0.1g. The khoa and air temperatures at different locations were measured by calibrated copper-constantan thermocouples connected to a ten channel digital temperature indicator with a least count of 0.1 ^{o}C (accuracy ±0.1%). The relative humidity (γ) and the temperature just above the khoa surface was measured by a digital humidity/temperature meter (model Lutron-HT 3006, made in Taiwan). It had a least count of 0.1% relative humidity (an accuracy of ±3% on the full scale range of 10 to 95% of RH) and 0.1 ^{o}C temperature (an accuracy of ± 0.8 ^{o}C on the full scale range of 50 ^{o}C). The air velocity across the greenhouse section during the forced convection drying mode was measured with an electronic digital anemometer (model AM-4201, made in Taiwan). It had a least count of 0.1m/s with an accuracy of ±2% on the full scale range of 0.2 to 30.0 m/s.

2.2 Sample preparation and experimental observations

The khoa sample was prepared by following the traditional khoa making process. The fresh milk (obtained from a herd of 15 cows) was heated over a hot plate at 150 watts in an aluminum open pan and simultaneously it was stirred and scraped with a Teflon scraper to avoid its burning. When the desired consistency was achieved, the heating was stopped and the product was allowed to cool to room temperature. Then a 100g cuboids shaped khoa sample of size $0.09\times0.06\times0.015$m^3 was prepared with the help of a wooden mold. The preparation of the wooden mold involved different processes like cutting of the wood with hand saw, fitting and finishing of the frames. Fresh samples of khoa of the same shape, size and mass were prepared by following the above procedure for open sun and greenhouse drying under natural and forced convection mode. Experiments were performed during the month of November 2010 at Guru Jambheshwar University of Science and Technology Hisar (29^{o}5'5" N 75^{o}45'55" E). Observations were taken for open sun and inside the greenhouse under natural as well as forced convection mode. The observation time interval for open sun drying was taken as half an hour whereas for greenhouse drying it was an hour. The air velocity across the greenhouse during forced convection mode was measured to be 0.55 m/s with the help of the digital anemometer. The initial mass of khoa sample for every mode of drying was 100g. The khoa sample of size $0.09\times0.06\times0.015$m^3 was kept in the wire mesh tray over the digital weighing balance. The moisture evaporated has been calculated by taking the difference of mass of khoa between two consecutive readings. The khoa sample was dried till no variation in its mass is recorded.

2.3 Thermal modeling

The convective heat transfer coefficient for evaporation under natural convection can be determined by using the following relations [8, 11]:

$$Nu = \frac{h_c X}{K_v} = C\left(Gr\Pr\right)^n$$

Or

$$h_c = \frac{K_v}{X} C\left(Gr\Pr\right)^n \tag{1a}$$

And under forced convection

$$h_c = \frac{K_v}{X} C(\mathrm{Re}\,\mathrm{Pr})^n \tag{1b}$$

The rate of heat utilized to evaporate moisture is given as [12]

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

On substituting h_c from Eq. (1a), Eq. (2) becomes

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

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

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

Let

$$0.016 \frac{K_v}{X\lambda} [P(T_k) - \gamma P(T_e)] A_t t = Z$$

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

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

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

This is the form of a linear equation,

$$Y = mX_0 + C_0 \tag{7}$$

Where

$Y = \ln\left[\frac{m_{ev}}{Z}\right]$, $m = n$, $X_0 = \ln(Gr\,\mathrm{Pr})$ and $C_0 = \ln C$

Thus, $C = e^{C_o}$

Similarly in the case of the forced convection drying mode,

$Y = \ln\left[\frac{m_{ev}}{Z}\right]$, $m = n$, $X_0 = \ln(\mathrm{Re}\,\mathrm{Pr})$, $C_0 = \ln C$ and $C = e^{C_o}$

Values of m and C_0 in Eq. (7) are obtained by using the simple linear regression method by using the following formulae

$$m = \frac{N\sum X_0 Y - \sum X_0 \sum Y}{N\sum X_0^{\,2} - \left(\sum X_0\right)^2} \tag{8}$$

and

$$C_0 = \frac{\sum X_0^{\,2} \sum Y - \sum X_0 \sum X_0 Y}{N\sum X_0^{\,2} - \left(\sum X_0\right)^2} \tag{9}$$

Where N is the number of observations in each set of the observation tables. By using the experimental data from Tables 1-3 for T_k, T_e, γ and m_{ev} , the values of Y and X_0 could be determined for different time intervals and then the constant C and exponent n were obtained from the above equations for open sun, natural convection greenhouse and forced convection greenhouse drying modes. Then, the constants C and n were considered further for evaluating the values of convective heat transfer coefficients from Eq. (1).

2.4. Experimental error

The experimental errors were evaluated in terms of percent uncertainty (internal + external) for the moisture evaporated. The following two equations were used for internal uncertainty [13]:

$$U_I = \frac{\sqrt{\sigma_1^{\,2} + \sigma_2^{\,2} + \ldots \sigma_N^{\,2}}}{N_o} \tag{10}$$

Where N_o is the number of sets and σ is the standard deviation and is given as

$$\sigma = \sqrt{\frac{\sum\left(X - \bar{X}\right)^2}{N}} \tag{11}$$

The percent internal uncertainty therefore was determined using the following expression:

% internal uncertainty = (U_I/mean of the total observations) ×100

For external uncertainty, the least counts and the accuracies of all the instruments used in measuring the observation data were considered [14].

RESULTS AND DISCUSSION

The experimental data obtained for khoa drying under natural convection greenhouse, forced convection greenhouse and open sun drying modes are given in Tables 1-3. These data were used to determine the values of the constant C and exponent n in the Nusselt expression by simple linear regression analysis. Then the values of the constant C and exponent n were used further for determining the values of the convective heat transfer coefficient by Eq. (1). The values of C, n and h_c for khoa drying under different modes are summarized in Tables 1-3. The range of Grashof numbers and Reynolds numbers for each case has also been given. The product of Grashof and Prandtl number indicates that the entire drying for open sun and natural greenhouse modes falls within a laminar flow, because $Gr\,\mathrm{Pr} \le 10^7$. In the case of the forced greenhouse drying the nature of heat transfer was also observed under laminar regime, since $\mathrm{Re}\,\mathrm{Pr} \le 10^5$ [15]. It has been observed from Tables 1-3 that the values of h_c are almost constant for forced convection greenhouse drying mode. However convective heat transfer coefficient varies for open sun and greenhouse drying under the natural convective mode. Further it is important to note that the convective heat transfer coefficient is more in forced mode as compared to natural greenhouse as well as open sun drying modes. This may be due to a decrease in relative humidity inside the greenhouse resulting in increased partial pressure difference. The convective heat transfer coefficient in the open sun drying mode is more than the natural greenhouse drying mode. This may be due to the wind effect outside the greenhouse. It has been observed from Tables 1-3 that in all the drying modes, the rate of moisture removal increases initially and then decreases for a given day, also the total moisture removal decreases with day of drying progression from first day to the third day. This can be explained in terms of the convective

Table 1: Experimental data for khoa drying under natural greenhouse mode during November 3-5, 2010

Day of drying	Time	T_k (°C)	T_e (°C)	$m_{ev} \times 10^{-3}$ (kg)	γ (%)	$Gr \times 10^5$	Pr	C	n	h_c
1st	10-11am	36.4	33.8	3.6	36.6	1.65×10^5	0.697	0.92	0.17	0.90
	11-12	41.6	37.8	2.4	30.9	1.59×10^5	0.696			0.91
	12-1pm	46.8	41.8	1.7	27.8	0.962×10^5	0.696			0.84
	1-2pm	51.2	42.2	1.1	23.2	0.803×10^5	0.695			0.82
2nd	10-11am	37.6	34.4	3.8	42.6	2.17×10^5	0.697	0.83	0.16	0.76
	11-12	42.8	38.7	3.1	36.1	1.42×10^5	0.696			0.72
	12-1pm	47.0	41.4	1.4	29.8	0.963×10^5	0.696			0.68
	1-2pm	49.4	41.5	0.3	25.1	0.688×10^5	0.695			0.65
3rd	10-11am	38.6	32.5	4.1	41.0	1.83×10^5	0.697	0.85	0.15	0.67
	11-12	42.6	38.0	1.7	29.2	1.30×10^5	0.696			0.65
	12-1pm	45.6	40.6	0.8	25.1	0.889×10^5	0.696			0.62
	1-2pm	43.4	38.7	0.5	18.6	0.412×10^5	0.696			0.54

Table 2: Experimental data for khoa drying under forced greenhouse mode during November 6-8, 2010

Day of drying	Time	T_k (°C)	T_e (°C)	$m_{ev} \times 10^{-3}$ (kg)	γ (%)	$Re \times 10^3$	Pr	C	n	h_c
1st	10-11am	32.4	30.0	2.1	25.1	2.57×10^3	0.698	0.99	0.28	1.08
	11-12	37.6	34.2	2.8	23.6	2.50×10^3	0.697			1.09
	12-1pm	42.8	37.2	2.4	18.4	2.45×10^3	0.696			1.09
	1-2pm	43.2	39.4	1.6	17.1	2.43×10^3	0.696			1.09
2nd	10-11am	31.3	28.1	2.1	29.3	2.59×10^3	0.698	0.99	0.26	0.93
	11-12	36.6	33.1	2.8	23.3	2.52×10^3	0.697			0.93
	12-1pm	41.8	36.3	2.1	19.9	2.46×10^3	0.696			0.94
	1-2pm	42.2	38.6	0.7	16.0	2.44×10^3	0.696			0.94
3rd	10-11am	31.8	27.0	1.6	28.9	2.60×10^3	0.698	0.99	0.25	0.86
	11-12	37.9	31.8	2.4	23.0	2.51×10^3	0.697			0.87
	12-1pm	42.8	35.0	1.8	21.0	2.46×10^3	0.696			0.87
	1-2pm	43.2	38.2	1.2	20.3	2.43×10^3	0.696			0.87

Table 3: Experimental data for khoa drying under open sun mode during November 9-11, 2010

Day of drying	Time	T_k (°C)	T_e (°C)	$m_{ev} \times 10^{-3}$ (kg)	γ (%)	$Gr \times 10^5$	Pr	C	n	h_c
1st	11.00am	37.0	33.0	3.0	39.9	0.125×10^5	0.697	1.54	0.13	0.68
	11.30am	41.9	37.5	1.1	34.5	0.677×10^5	0.696			0.86
	12.00	44.8	39.0	1.2	31.4	1.33×10^5	0.696			0.94
	12.30pm	47.8	41.3	1.0	28.8	1.94×10^5	0.695			0.99
	1.00pm	51.9	44.0	0.8	25.5	2.37×10^5	0.695			1.03
2nd	11.00am	38.4	35.4	3.0	37.6	0.17×10^5	0.697	1.50	0.12	0.63
	11.30am	42.9	36.9	1.4	33.2	1.23×10^5	0.696			0.80
	12.00	45.4	37.8	1.5	30.8	1.57×10^5	0.696			0.83
	12.30pm	48.4	41.4	1.1	26.6	1.78×10^5	0.695			0.85
	1.00pm	49.4	40.7	0.3	26.4	2.44×10^5	0.695			0.89
3rd	11.00am	33.0	29.8	1.9	44.1	0.053×10^5	0.697	1.65	0.11	0.54
	11.30am	36.5	31.4	1.6	40.0	0.762×10^5	0.697			0.74
	12.00	39.6	34.6	1.3	35.1	1.07×10^5	0.697			0.77
	12.30pm	39.9	34.6	0.1	34.5	0.944×10^5	0.697			0.76
	1.00pm	39.6	33.1	0.3	35.4	1.15×10^5	0.697			0.78

Table 4: Experimental percent uncertainty under different modes of drying

Mode of drying	Uncertainty (%)		
	Internal	External	Total
Greenhouse natural	31.11	1.33	32.44
Greenhouse forced	16.55	1.45	18.00
Open sun	27.73	1.33	29.06

Table 5: Coefficients of exponential model and results of statistical analyses under different modes of drying

Day	a	b	r	χ^2	MBE	$RMSE$
Greenhouse natural						
1st	0.7953	-0.0466	0.9987	0.1342	-0.1269	0.1427
2nd	0.5668	-0.0973	0.9943	0.3479	-0.2043	0.2285
3rd	0.4629	-0.1309	0.9865	0.4264	-0.2262	0.2534
Greenhouse forced						
1st	1.1436	0.0181	0.9992	0.0639	0.0876	0.0997
2nd	0.8980	-0.0113	0.9992	0.0204	-0.0495	0.0571
3rd	0.7966	-0.0267	0.9971	0.0794	-0.0976	0.1115
Open sun						
1st	0.8712	0.0779	0.9793	0.0408	0.0673	0.1007
2nd	0.7604	0.0201	0.9718	0.0016	-0.0135	0.0746
3rd	0.6669	-0.0101	0.9518	0.0234	-0.0509	0.1022

heat transfer coefficient. In order to compare, the convective Experimentally, it is found that initially the rate of moisture removal in the case of open sun and natural greenhouse convection modes is more when compared to the forced convection mode after each hour. This is because of the high temperature difference between the khoa and the surroundings as compared to the forced convection mode, in which temperature difference is reduced due to the continuous removal of air by the fan from the greenhouse. heat transfer coefficient for different drying modes, the average values of convective heat transfer coefficients were calculated for each day. These results are plotted in Fig. 4, from which it can be seen that the convective heat transfer coefficients for khoa drying under different modes decreases as the day of drying progresses from the first day to the third day. From Fig.4 it can also be seen that the convective heat transfer coefficient is more in the forced greenhouse drying for all the drying days which is followed by the open sun and natural greenhouse drying modes respectively.

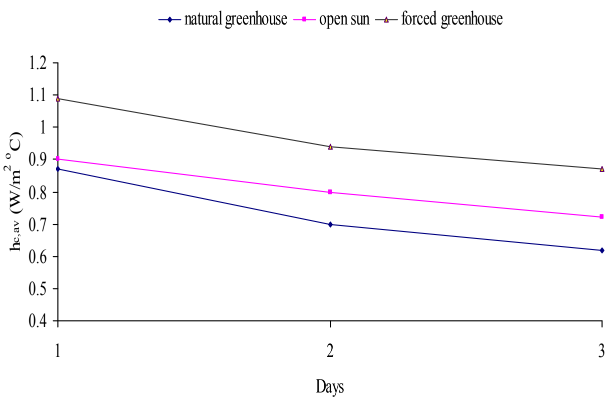

Fig. 4: Variation in convective heat transfer coefficient for different modes of drying

Experimentally, it is found that initially the rate of moisture removal in the case of open sun and natural greenhouse convection modes is more when compared to the forced convection mode after each hour. This is because of the high temperature difference between the khoa and the surroundings as compared to the forced convection mode, in which temperature difference is reduced due to the continuous removal of air by the fan from the greenhouse. The percent uncertainty (internal + external) was found to be with in 32.44%, 18% and 29.06%, for the natural greenhouse, forced greenhouse and open sun drying modes respectively and the different values of h_c were found to be within this range. The experimental percent uncertainties for khoa under different drying modes are reported in Table 4. When the convective heat transfer coefficients of khoa were analyzed under different drying modes, it is found that the changes in the convective heat transfer coefficient may be expressed best by an exponential equation as a function of the drying time interval.

$$h_c = a.\exp(b.t) \tag{13}$$

Where a and b are the constants which were calculated by linear regression analysis and t is the drying time interval in hour. The correlation coefficient (r) was one of the primary criteria to decide the fitness of the developed model. In addition to the correlation coefficient, the various statistical parameters like reduced chi-square (χ^2), mean bias error (MBE) and root mean square error ($RMSE$) were used to know the quality of the fit. These parameters are given below [16]:

$$r = \frac{N\sum_{i=1}^{N} h_{\exp,i}\,h_{pre,i} - \left(\sum_{i=1}^{N} h_{\exp,i}\right)\left(\sum_{i=1}^{N} h_{pre,i}\right)}{\sqrt{N\sum_{i=1}^{N} h_{\exp,i}^{\ 2} - \left(\sum_{i=1}^{N} h_{\exp,i}\right)^2}\sqrt{N\sum_{i}^{N} h_{pre,i}^{\ 2} - \left(\sum_{i=1}^{N} h_{pre,i}\right)^2}} \tag{14}$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(h_{\exp,i} - h_{pre,i}\right)^2}{N-n} \tag{15}$$

$$MBE = \frac{1}{N}\sum_{i=1}^{N}\left(h_{pre,i} - h_{\exp,i}\right) \tag{16}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(h_{pre,i} - h_{\exp,i}\right)^2\right]^{1/2} \tag{17}$$

Where $h_{\exp,i}$ is the ith experimentally determined convective heat transfer coefficient and $h_{pre,i}$ is the ith predicted heat transfer coefficient for the developed model. N and n are the number of observations and number of constants respectively. The results of r, χ^2, MBE and $RMSE$ selected to assess the consistency of the developed model are reported in Table 5. The high values of r and the low values of χ^2, MBE and $RMSE$ indicate that the developed model for the convective heat transfer coefficient is statistically accurate. Thus, these relations can be used with an acceptable accuracy to determine the convective heat transfer coefficient for khoa drying under open sun and greenhouse drying modes. Further the developed model can be used for designing a greenhouse dryer for khoa to retain its quality for storage.

Conclusions

The following conclusions were made from the present research work in which the convective heat transfer coefficient for khoa drying were investigated.

1. The convective heat transfer coefficient inside the greenhouse under forced mode was higher than for other modes and it was least for the natural greenhouse mode.
2. The convective heat transfer coefficient was observed to vary from 0.86-1.09 W/m^2 °C, 0.54-0.91 W/m^2 °C and 0.54-1.03 W/m^2 °C for forced greenhouse, natural greenhouse and open sun drying modes respectively.
3. For all the drying modes the convective heat transfer coefficient decreases as the day of drying progresses to the next day. This is because of the decrease in total moisture removal with the drying day progression from first to the third day.
4. The convective heat transfer coefficient could be expressed exponentially as a function of the drying time interval. The statistical parameters like r, χ^2, MBE and $RMSE$ have also confirmed the suitability of the models developed.
5. Experimental errors in terms of percent uncertainty were found with in 32.44%, 18% and 29.06%, for the natural greenhouse, forced greenhouse and open sun drying modes respectively.

Nomenclature

A_t	Area of tray, m^2
C	Experimental constant
C_v	Specific heat of humid air, J/kg ^oC
g	Acceleration due to gravity, m/s^2
Gr	Grashof number $= \beta g X^3 \rho_v^2 \Delta T / \mu_v^2$
h_c	Convective heat transfer coefficient, $W/m^2\ ^oC$
$h_{c,av}$	Average convective heat transfer coefficient, $W/m^2\ ^oC$
K_v	Thermal conductivity of humid air, W/m ^oC
m_{ev}	Mass evaporated, kg
n	Experimental constant
Nu	Nusselt number $= h_c X / K_v$
$\Pr$	Prandtl number $= \mu_v C_v / K_v$
$P(T)$	Partial vapor pressure at temperature T, N/m^2
$\dot{Q}_e$	Rate of heat utilized to evaporate moisture, $J/m^2\ s$
Re	Reynolds number $= \rho_v V X / \mu_v$
T_k	Temperature of khoa surface, ^oC
T_e	Temperature just above the khoa surface, ^oC
t	Time, s
ΔT	Effective temperature difference, ^oC
V	Air velocity inside greenhouse, m/s
X	Characteristic dimension, m
	Greek symbols
β	Coefficient of volumetric expansion (K^{-1})
γ	Relative humidity (%)
λ	Latent heat of vaporization, J/kg
μ_v	Dynamic viscosity of humid air, N s/m^2
ρ_v	Density of humid air, kg/m^3

APPENDIX A

The following expressions were used for determining the values of the thermal physical properties of humid air, such as specific heat (C_v), thermal conductivity (K_v), density (ρ_v), viscosity (μ_v), and partial vapor pressure, $P(T)$ [17]:

$$C_v = 999.2 + 0.1434 T_i + 1.101\times10^{-4} T_i^2 - 6.7581\times10^{-8} T_i^3 \quad (18)$$

$$K_v = 0.0244 + 0.7673\times10^{-4} T_i \quad (19)$$

$$\rho_v = \frac{353.44}{(T_i + 273.15)} \quad (20)$$

$$\mu_v = 1.718\times10^{-5} + 4.620\times10^{-8} T_i \quad (21)$$

$$P(T) = \exp\left[25.317 - \frac{5144}{(T_i + 273.15)}\right] \quad (22)$$

Where $T_i = (T_k + T_e)/2$

REFERENCES

[1] Pal, D, (2008), 'New innovations in the processing of traditional Indian dairy products', Indian Dairyman, 60(3), pp 127-131.

[2] De, S, 'Outlines of Dairy Technology', Oxford University Press, Great Clarendon street, Oxford, 1980, pp 385-399.

[3] Bhat, JV, Sethna, K and Fernandes, F, (1948), 'Chemical and microbiological studies on mawa', Indian J. Dairy Sci., 1, pp 49-58.

[4] Kumar, CN, Kumaresan, G and Saravanan, K, (1996), 'Incidence of moulds in khoa', Indian J. Dairy Sci., 49, pp 462-464.

[5] Rajarajan, G, Kumar, CN and Elango, A, (2007), 'Distribution pattern of moulds in air and khoa samples collected from different sections of khoa plants', Indian J. Dairy Sci., 60(2), pp 133-135.

[6] Chavan, KD and Kulkarni, MB, (2006), 'Solar radiation- an effective approach for khoa preservation', J. Dairying, Foods & H.S., 25(3/4), pp 182-185.

[7] Tiwari, GN, 'Greenhouse technology for controlled environment', New Delhi, Narosa Publishing House, India, 2003, pp 135-161.

[8] Anwar, SI, and Tiwari, GN, (2001), 'Evaluation of convective heat transfer coefficient in crop drying under open sun drying conditions', Energy Conversion Management, 42(5), pp 627-637.

[9] Tiwari, GN, Kumar, S and Prakash, O, (2004), 'Evaluation of convective mass transfer coefficient during drying of jaggery', Journal of Food Engineering, 63, pp 219-227.

[10] Kumar, A and Tiwari, GN, (2006), 'Effect of shape and size on convective mass transfer coefficient during greenhouse drying of jaggery', Journal of Food Engineering, 73, pp 121-134.

[11] Tiwari, GN, 'Solar Energy Fundamentals, Design, Modelling and Applications', Narosa Publishing House, New Delhi, 1997, pp 58-74.

[12] Malik, MAS, Tiwari, GN, Kumar, A and Sodha MS, 'Solar distillation', Oxford Pergamon press, New York, 1982, pp 1-58.

[13] Nakra, BC and Chaudhary, KK, 'Instrumentation, measurement and analysis', Tata McGraw Hill, New Delhi, 1985, pp 33.

[14] Kumar, M, Prakash, O and Kasana, KS, (2011), 'An experimental study on pool boiling of milk', Heat Transfer- Asian Research, 40(2), 2011, pp 159-170.

[15] Holman, J P, 'Heat transfer', Tata McGraw Hill, New Delhi, 2004, pp 205-263.

[16] Chapra, SC and Canale, RP, 'Numerical methods for Engineers', McGraw Hill Company, New Delhi, 1989, pp 37.

[17] Kumar, A and Tiwari, GN, (2007), 'Effect of mass on convective mass transfer coefficient during open sun and greenhouse drying on onion flakes', Journal of Food Engineering 79, pp 1337-1350.

****