

FORCED CONVECTION DRYING OF INDIAN GROUNDNUT: AN EXPERIMENTAL STUDY

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Abstract. *In this paper, convective and evaporative heat transfer coefficients of the Indian groundnut were computed under indoor forced convection drying (IFCD) mode. The groundnuts were dried as a single thin layer with the help of a laboratory dryer till the optimum safe moisture storage level of 8 – 10%. The experimental data were used to determine the values of experimental constants C and n in the Nusselt number expression by a simple linear regression analysis and consequently, the convective heat transfer coefficient (CHTC) was determined. The values of CHTC were used to calculate the evaporative heat transfer coefficient (EHTC). The average values of CHTC and EHTC were found to be 2.48 W/m²°C and 35.08 W/m²°C, respectively. The experimental error in terms of percent uncertainty was also estimated. The error bars for convective and evaporative heat transfer coefficients are also shown for the groundnut drying under IFCD condition.*

Key Words: *Groundnut/peanut, Convective Heat Transfer Coefficient, Evaporative Heat Transfer Coefficient, Indoor Forced Convection Drying*

1. INTRODUCTION

Groundnut or peanut (*Arachis hypogaea*) is a perishable oilseed crop grown in tropic and sub-tropic countries [1]. It is rich in proteins (20 – 50%) and edible oil (40 – 50%) which makes it very popular all over the world [2]. It is also known by various names such as monkey nut, wonder nut, earth nut, cashew nut of poor men and so on [3]. It came into existence in India in the 16th century. The worldwide production of groundnuts has

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reached about 40 million tons [4]. It is grown on 24 million hectares land throughout the world [4]. China with 16.70 metric million tons is the largest groundnut producing country followed by India with a production of 5 metric million tons [4]. In India about three quarters of groundnut is harvested in the Kharif season (June – September) and the remaining quarter in the Rabi season (November – March). Indian groundnut is famous for its flavor, aroma and crunchiness. Export of Indian groundnuts has reached the record of 7 Lac tons in 2014 – 2015 [5].

Drying of agricultural products is the simplest traditional food preservation method which involves the removal of the water present in the product to stop fungus or bacteria growth [6]. Groundnuts, just after being dug out from the ground, are required to dry to their safe moisture content of 8 – 10%. In the developing countries, poor farmers dry groundnuts under open sun drying (OSD) mode which takes four to five days to dry the groundnuts to their safe moisture level. Although the OSD is unquestionably the cheapest post-harvest method, it involves many disadvantages such as deterioration of products due to dust, dirt, uncontrolled heating and discoloring of products because of Ultra-Violet rays, animals, microorganisms and so on. Post-harvest losses of the agricultural products are estimated to be about 30 – 40% due to an improper method of drying [7-8]. Moreover, farmers are also lacking behind with the better drying facilities. Hence, the need is felt to adopt such a method which gives continuous and controlled drying.

The convective heat transfer coefficient (CHTC) for the drying of groundnut is an important and critical parameter required for the proper design of a dryer. It is governed by the temperature difference between groundnut surface and air, and the physical properties of the humid air which surrounds the groundnut surface. The researchers who have worked on the drying of various commodities under the forced convection drying mode are summarized in Table 1. Some authors who have also studied the drying of groundnuts under the forced mode are summarized in Table 2.

Table 1 Summary of drying of various commodities

S. No.	Researcher	Ref.	Commodity	Mode of drying	Conclusion/Remarks
1	Akpinar (2004)	[9]	Apple, strawberry, eggplant, garlic, mulberry, onion, pumpkin, potato	Indoor forced convection drying (IFCD)	The value of CHTC was reported to lie within the range of 0.64 – 7.12 W/m ² °C
2	Kumar et al. (2011)	[10]	Papad	OSD and IFCD	The values of CHTC were found to be 3.54 W/m ² °C and 1.56 W/m ² °C under OSD and IFCD modes, respectively
3	Anwar and Singh (2012)	[11]	Indian gooseberry	IFCD	The values of CHTC were observed to vary from 18.67 to 116.55 W/m ² °C
4	Sahdev et al. (2012)	[12]	Vermicelli	IFCD	The value of CHTC was reported to vary from 0.98 to 1.10 W/m ² °C
5	Sahdev et al. (2013)	[13]	Corn kernels	IFCD	The value of CHTC was found to vary from 1.02 to 1.04 W/m ² °C.
6	Kumar (2014)	[14]	Khoa	IFCD	The values of CHTC and evaporative heat transfer coefficient (EHTC) were observed to vary from 1.93 to 2.51 W/m ² °C and 1.94 to 2.49 W/m ² °C, respectively

Table 2 Summary of groundnuts drying under forced mode

S. No.	Researcher	Ref.	Mode of drying	Conclusion/Remarks
1	Ahmed et al. (1967)	[15]	OSD and accelerating drying	Carried out the Comparative study
2	Blankenship and Chew (1979)	[16]	Trailer drying	Presented single and double trailer drying
3	Troegeer and Butler (1980, 1980a)	[17-18]	Solar drying	Dryer used solar heated air, solar heated water and LPG gas
4	Nawungkalatusart and Tamtawatchai (1989)	[19]	Continuous drying	Proposed 55 °C suitable for the germination of groundnut seeds
5	Premkumar (1990)	[20]	Various dryers	Proposed forced air oven drying as superior than batch type rotary and conduction dryer
6	Gowda et al. (1991)	[21]	Forced drying	Investigated the drying at different temperatures
7	Noomhorn et al. (1992, 1994)	[22-23]	Conduction dryer (CD)	Proposed the CD for drying groundnuts
8	Syarief et al. (1996)	[24]	Convection dryer	Peanut seeds were investigated in dryer which used coconut as a fuel
9	Tumbel et al. (1997)	[25]	Rack dryer	Presented the rack type dryer for drying groundnuts
10	Ertas et al. (1999)	[26]	Trailer dryer	Proposed semi-trailer dryer for drying peanuts at constant temperature of 35 °C
11	Jain et al. (2004)	[27]	Solar dryer	Proposed forced solar dryer for groundnut drying
12	Palacios et al. (2004)	[28]	Batch dryer	Studied the remoistened peanut in batch type dryer
13	Tarigan and Tekasakul (2005)	[29]	Indirect Solar Dryer (ISD)	ISD efficiency was reported to be 23%
14	Ezekoya and Eneba (2006)	[30]	Modified Solar Dryer (MSD)	Dryer efficiency was found to be 10%
15	Ahmed and Mirani (2012)	[31]	Mobile flat-bed dryer	Moisture was maintained up-to 14%
16	Mennouche et al. (2014, 2015)	[32-33]	Direct Solar Dryer (DSD) and ISD	Yield of oil in DSD and ISD dried peanuts were found to be higher

The above-listed literature leads to observation that different agricultural products have been dried under IFCD conditions to reduce the drying time and increase the quality. The values of CHTC and EHTC for the drying of various products under IFCD mode are reported to vary from 0.16 to 116.55 W/m² °C and 1.94 to 2.49 W/m² °C, respectively. Although groundnuts/peanuts have also been dried by different artificial and mechanical dryer to improve the quality and storage life. Studies to evaluate the important parameters such as CHTC and EHTC for designing a dryer for groundnut drying have not been found. Therefore, the present study has been undertaken to determine the CHTC and EHTC of groundnut drying under IFCD mode. This study would be helpful in designing a better dryer for drying groundnut to its safe moisture storage level.

2. MATERIALS AND METHODS

2.1. Experimental set-up

The groundnut sample of 180 g was kept in a wire mesh tray (rectangular shape of $0.15 \times 0.25 \text{ m}^2$ size) over the digital weighing balance of 6 kg capacity (least count = 0.1 g). A heat convector (Model FH-812T, Usha Shriram, made in India) was used for blowing hot air over the groundnut surface. The temperature of groundnut surface (T_g) was measured by calibrated copper constantan thermocouples connected to a 12-channel digital temperature indicator (least count = 0.1 °C). The thermocouples were calibrated with respect to the ZEAL thermometer which gives accurate readings. Relative humidity (γ) and temperature of exit air (T_e) was measured by a digital hygrometer (Lutron – HT 315, least count: 0.1% RH and 0.1 °C temperature). Air velocity (V_a) over the groundnut surface was measured with a digital anemometer (Lutron, AM – 4201, Taiwan, least count: 0.1 m/s, accuracy $\pm 2\%$ on the full scale range of 0.2 – 30.0 m/s). The schematic view and photograph of the experimental set up are shown in Figs. 1 and 2, respectively.

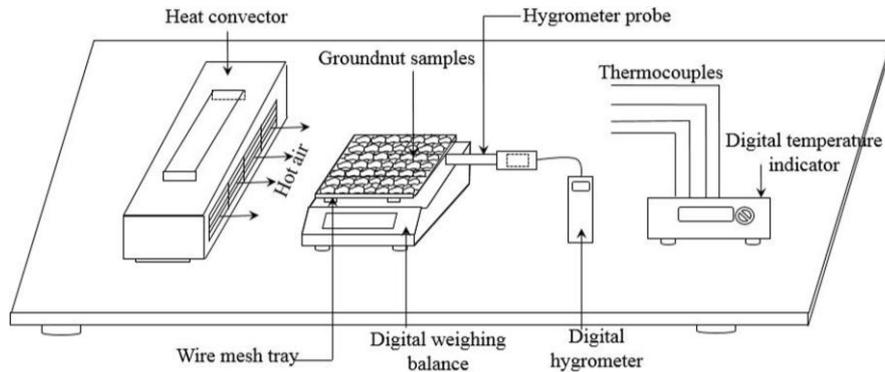


Fig. 1 Schematic view of the experimental set up under IFCD Mode

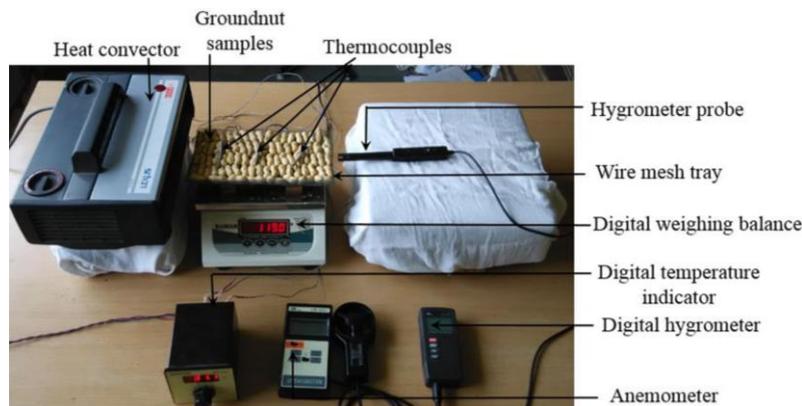


Fig. 2 Experimental set up under IFCD Mode

2.2. Sample preparation and experimental procedure

Fresh groundnuts were purchased directly from the farmer and cleaned to remove immature and broken pods. Groundnuts were remoistened by soaking in water for 12 hours. Then the samples were conditioned in shed for one hour so that the extra moisture was removed. Then the groundnut sample was used for experimentation.

The experiment was performed in February, 2016 in the climatic conditions of Rohtak, India (28°54'0''N 76°34'0''E). The groundnut sample in a thin layer was kept in a wire mesh tray of size 0.25×0.15 m² directly over the digital weighing balance. The difference in weight between two consecutive 30 min. time interval observed readings directly gave the moisture evaporation during the observed time interval. The 30 min. data for the moisture removal, groundnut surface and ambient temperatures, relative humidity and temperature just above the groundnut surface were recorded. The groundnut sample was dried to its optimum safe moisture level of 8 – 10%.

2.3. Thermal modeling

The CHTC under IFCD can be evaluated by using following Eq. [1]:

$$Nu = \frac{h_c X}{K_v} = C(RePr)^n \quad (1)$$

where Nu is the Nusselt number, h_c is the convective heat transfer coefficient, X is the characteristic dimension, K_v is the thermal conductivity of the humid air, C and n are the experimental constants, Re is the Reynolds number and Pr is the Prandtl number. From Eq. (1) one can write:

$$h_c = \frac{K_v}{X} C(RePr)^n \quad (2)$$

The rate of heat utilized to evaporate moisture, Q_e , is given by Eq. (3) [34]:

$$Q_e = 0.016 h_c [P(T_g) - \gamma P(T_e)] \quad (3)$$

where $P(T_g)$ and $P(T_e)$ are partial vapor pressures at temperatures T_g and T_e , respectively.

Substituting the value of CHTC i.e. h_c from Eq. (2), Eq. (3) becomes

$$Q_e = 0.016 \frac{K_v}{X} C(RePr)^n [P(T_g) - \gamma P(T_e)] \quad (4)$$

The moisture evaporated, m_{ev} , is determined by dividing Eq. (4) by latent heat of vaporization, λ , and multiplying by tray area A_{tray} , and time interval, t .

$$m_{ev} = \frac{Q_e}{\lambda} t A_{tray} = 0.016 \frac{K_v}{X \lambda} C(RePr)^n [P(T_g) - \gamma P(T_e)] t A_{tray} \quad (5)$$

Let
$$0.016 \frac{K_v}{X \lambda} [P(T_g) - \gamma P(T_e)] t A_{tray} = Z$$

$$\therefore \frac{m_{ev}}{Z} = C(RePr)^n \quad (6)$$

Taking logarithm on both sides of Eq. (6), we get

$$\ln \left[\frac{m_{ev}}{Z} \right] = \ln C + n \ln(RePr) \quad (7)$$

Eq. (7) is the form of a linear equation:

$$y = mx + c \quad (8)$$

where $y = \ln \left[\frac{m_{ev}}{Z} \right]$, $m = n$, $x = \ln(RePr)$, $c = \ln C$. Thus, $C = e^c$

The values of m and c in Eq. (8) are obtained by using simple linear regression formulae. The EHTC, h_e , is evaluated as [35]

$$h_e = 0.016 h_c \left[\frac{P(T_g) - \gamma P(T_e)}{T_g - T_e} \right] \quad (9)$$

2.4. Physical properties of the humid air

The thermo-physical properties of the humid air, namely, thermal conductivity, K_v , dynamic viscosity, μ_v , density, ρ_v , specific heat, C_v , and partial vapor pressure $P(T)$ were calculated for the mean temperature $T_i = [(T_g + T_e)/2]$ by using the following Eqs. (10 – 14) [36]:

$$K_v = 0.0244 + 0.7673 \times 10^{-4} T_i \quad (10)$$

$$\mu_v = 1.718 \times 10^{-5} + 4.620 \times 10^{-8} T_i \quad (11)$$

$$C_v = 999.2 + 0.1434 T_i + 1.101 \times 10^{-4} T_i^2 - 6.7581 \times 10^{-8} T_i^3 \quad (12)$$

$$\rho_v = \frac{353.44}{T_i + 273.15} \quad (13)$$

$$P(T) = \exp \left[25.317 - \frac{5144}{T + 273.15} \right] \quad (14)$$

2.5. Experimental error and external uncertainty

The experimental error was determined in terms of percent uncertainty (internal + external) for the mass of moisture evaporated. Eqs. (15) to (17) were used to calculate internal uncertainty [37]:

$$U^* = \frac{\sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 + \dots + \sigma_n^2}}{N} \quad (15)$$

where σ is the standard deviation and is by Eq. (16):

$$\sigma = \sqrt{\frac{\sum (X_i - \bar{X}_i)^2}{N_o}} \quad (16)$$

where X_i is the moisture evaporated and $(X_i - \bar{X}_i)$ is the deviation of the observations from the mean value, N and N_o are the number of sets and number of observations in each set respectively. The percent uncertainty was evaluated as:

$$\%internaluncertainty = \frac{U^*}{Average\ of\ total\ number\ of\ observations} \times 100 \quad (17)$$

The external uncertainty is the least count of all the instruments.

2.6. Computation technique

The average of groundnut surface temperature (T_g) and exit air temperature (T_e) after the groundnut surface were determined at 30 minutes time interval for corresponding moisture evaporation. The physical properties of the humid air were evaluated for the mean temperature [$T_i = (T_g + T_e)/2$] using Eq. (10) to (14). These properties of the humid air and air velocity were used to calculate the Prandtl number (Pr) and Reynolds number (Re). The values of experimental constants C and n in Eq. (1) were determined by using the linear regression technique analysis, and hence the value of CHTC (h_c) was evaluated. Then, the value of EHTC (h_e) was calculated by using Equation (9).

3. RESULTS AND DISCUSSION

The experimental data obtained for groundnut drying under IFCD mode is given in Table 3. The data given in Table 3 were used to determine the values of the experimental constant ‘ C ’ and exponent ‘ n ’ in the Nusselt number expression by simple linear regression. Then the values of constants C and n in Eq. (2) were used to evaluate the CHTC (h_c). Further, the value of EHTC (h_e) was calculated by substituting the value of h_c in Eq. (9). The computed values of constants C and n , h_c , and h_e for groundnut drying under IFCD are summarized in Table 4. The values of Reynolds Number (Re) and Prandtl number (Pr) are also given. The product of Re and Pr were observed to be less than 10^5 , (i.e. $RePr \leq 10^5$). This indicated that the entire groundnut drying under IFCD mode lies within the laminar region [38].

Table 3 Experimental data for groundnut drying under IFCD condition

Drying time (min)	T_g (°C)	T_e (°C)	m_{ev} ×10 ⁻³ (kg)	γ (%)	Re ×10 ⁴	Pr
30	29.9	25.83	24.3	38.78	1.87	0.6982
60	44.5	35.33	11.7	22.75	1.74	0.6963
90	45.7	36.52	8.1	19.88	1.73	0.6961
120	46.5	36.98	4.5	19.12	1.72	0.6960
150	46.8	37.42	3.2	18.42	1.72	0.6959

Table 4 Values of C , n , h_c , and h_e

C	n	h_c (W/m ² °C)	$h_{c, avg}$ (W/m ² °C)	h_e (W/m ² °C)	$h_{e, avg}$ (W/m ² °C)
0.98	0.31	2.45 – 2.49	2.48	28.08 – 38.73	35.08

From Table 3, it is observed that the rate of moisture removal is faster in the initial stage and decreases with the increase in drying time. The values of convective heat transfer coefficient (h_c) are observed to vary from 2.45 to 2.49 $\text{W}/\text{m}^2\text{ }^\circ\text{C}$. Its average value is found to be 2.48 $\text{W}/\text{m}^2\text{ }^\circ\text{C}$. Variation of h_c with respect to time is illustrated in Fig. 3. It is observed from Fig. 3 that the value of h_c does not vary much and is almost constant throughout the experiment. The values of evaporative heat transfer coefficient (h_e) are observed to vary from 28.08 to 38.13 $\text{W}/\text{m}^2\text{ }^\circ\text{C}$. The average value of h_e for groundnut drying is found to be 35.08 $\text{W}/\text{m}^2\text{ }^\circ\text{C}$. The variability in h_e is observed to be 37.93% which is more than the variability in h_c . The variation of h_e with time is shown in Fig. 4. The photographs of groundnut drying before and after drying are shown in Fig. 5. The computed values of experimental error in terms of percent uncertainty (internal + external) are given in Table 5. The error in the experimental measurements of CHTC and EHTC is shown by the error bar which shows the graphical representation of the variability of data. The variability of CHTC and EHTC from its true value is shown by the error bars, with 95% confidence level, in Fig. 6 which is drawn with the help of SPSS software (version 24).

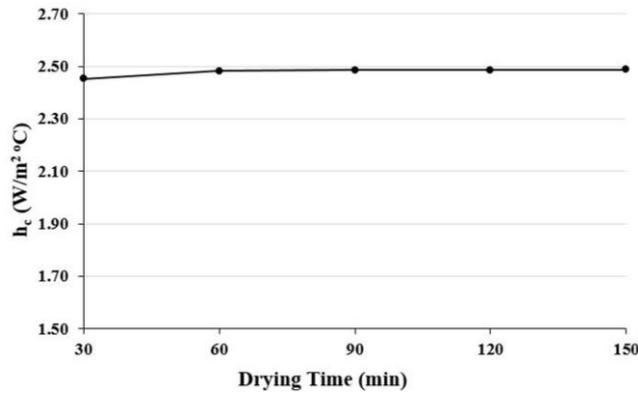


Fig. 3 Variation of h_c with time

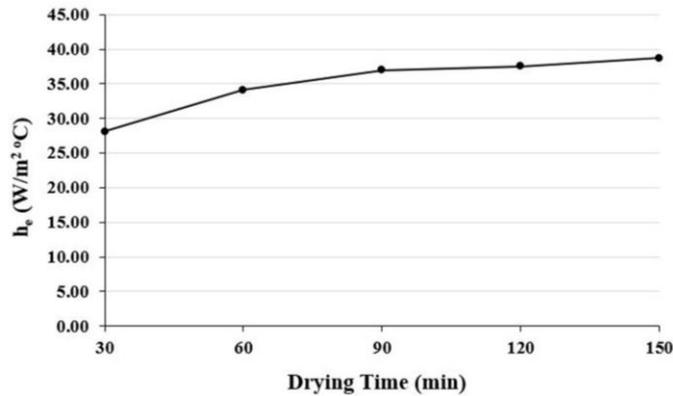


Fig. 4 Variation of h_e with time



Fig. 5 Photograph of groundnut sample before and after drying

Table 5 Experimental percent uncertainties for groundnut drying under IFCD mode

Internal uncertainty (%)	External uncertainty (%)	Total uncertainty (%)
42.05	0.5	42.55

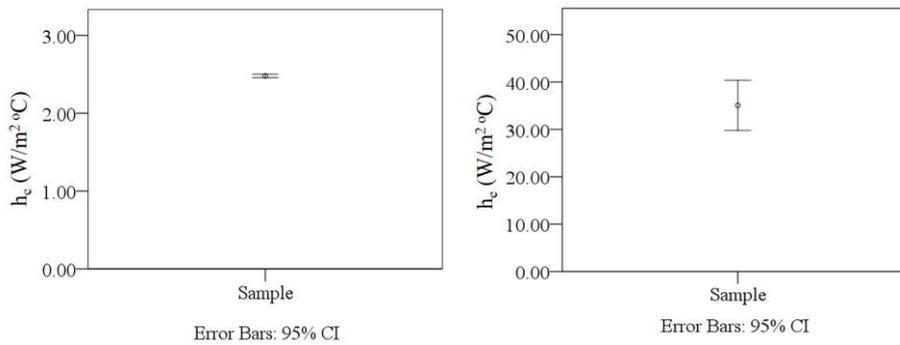


Fig. 6 Error bars for CHTC and EHTC

4. CONCLUSIONS

The following conclusions are made from the present study in which convective heat transfer coefficient (CHTC) and evaporative heat transfer coefficient (EHTC) for groundnut drying under indoor forced convection drying (IFCD) mode are evaluated.

1. The value of CHTC for the drying of groundnut drying under IFCD mode is found to vary from 2.45 to 2.49 $\text{W/m}^2 \text{ } ^\circ\text{C}$. The average value of the CHTC for the drying of groundnut is observed to be 2.48 $\text{W/m}^2 \text{ } ^\circ\text{C}$. The CHTC is observed to be almost constant throughout the experiment.
2. The value of EHTC for the drying of groundnuts under IFCD mode is found to vary from 28.08 to 38.73 $\text{W/m}^2 \text{ } ^\circ\text{C}$. The average value of EHTC for drying of groundnut under IFCD mode is observed to be 35.08 $\text{W/m}^2 \text{ } ^\circ\text{C}$. The variability of h_e is observed to be more than the CHTC.

3. The experimental error in terms of percent uncertainty (internal + external) for the drying of groundnuts under IFCD mode is computed as 42.55%.
4. This research work will be helpful in designing a better dryer for drying groundnuts to retain their quality during storage so that the farmers in the developing countries can increase the storage life of groundnuts.

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