Effect of thickness on heat transfer rate during aeration of Happala in orangery

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Abstract— **In this research paper, a simulated study has been carried out for the determination of convective heat transfer coefficients of Happala by changeable thickness under orangery natural convection mode. Three sets of experiments with 150 mm diameter of happala were down. Experimental data obtained from natural convection orangery drying mode for happala was used to determine the standards of the constants (C and n) in Nusselt number expression by using linear regression analysis, and consequently convective heat transfer coefficient were evaluated. The average values of convective heat transfer coefficientswere found to be 1.11, 1.00 and 0.92 W/m^{2o}C by varying thickness 1.2, 0.8 and 0.6 mm of happala sample respectively.**

Keywords— **Orangery aeration of happala; Heat transfer rate for happala; Natural convection drying**

I. INTRODUCTION

Solar energy is vast source of energy which could supply all the current and future energy needs of the world. The energy from the sun intercepted by the earth is around 1.8×10^{11} MW, which is many thousands of times larger than the present utilization rate on the earth of all commercial energy sources. Solar drying is a very simple, low cost, most accessible, and widespread technique used to preserve food products [1]. Happala is a popular food item of the Indian diet since more than half centuries [2, 3]. It is a wafer like product, circular in shape, made from dough of powdered pulses, spices and salt, etc. It is prepared by rolling dough into a circular shape whose thickness generally varies from 0.3 mm to 2 mm and is dried by different means to a moisture level of 14% to 15% [4, 5].Drying reduces the moisture content of a product by which its shelf life can be enlarged. In the drying process, the product is spread in a thin layer on the earth surface and exposed directly to the solar radiation. The product drying rate depends on different parameters like solar radiation, wind velocity, relative humidity, air and earth temperature, variety of product, initial moisture content, product absorptive, and mass of product per unit exposed area [6, 7]. In the most of emergent countries, people have been drying happala and other food products for decades by placing on ground surface in open air. Generally, open sun dried products do not meet the international quality standards and therefore, it cannot be sold in the international market. The main disadvantages of open sun drying are contamination, theft or damage by birds, rats or insects; slow or intermittent drying, no protection from rain or dew that wets the product, encourages mould growth and may result in relative high final moisture content; low and variable quality of product due to over or under drying; large area of land needed for the shallow layers of drying products; direct exposure to sunlight reduces the quality of happalas [8]. The alternative means for drying of some of the agricultural and food products in emergent countries may be provided by well-designed solar dryers. The acquirement and operational costs of dryers available in the market considerably increase the costs of the dried products. Therefore, in the current work orangery type dryer is to be used to dry happala. Orangery solar dryers improve the dry products value and their marketability [9, 10].

In this research paper, the convective heat transfer coefficients have been found by determining the standards of the constants (C and n) in the Nusselt number expression for happala drying under orangery natural convection drying mode. These values would be helpful in designing a dryer for dry happala to its optimum storage moisture level of 15% to 20%.

II. EXPERIMENTAL SET-UP AND PROCEDURE

An orangery is made of three main elements: the transparent cover, frame material and absorbing or soil surface. The transparent sheets are fixed on steel frame support with bolts, nuts, and rubber packing to prevent humid air leaking into chamber.The transparent (polyethylene or PVC) film cover acts an interface between inside and outside climate conditions and the soil surface as an interface between inside and bottom earth surface.

Air flows through bottom side by natural convection through

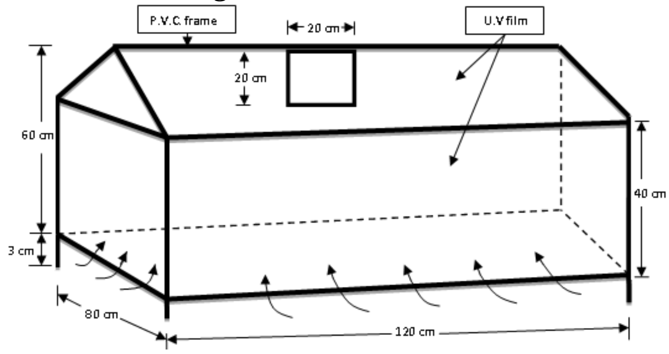

Fig. 1 Schematic diagram of orangery drying under natural convection

the material and finally leaves through the air vent provided at the upper part of the orangery.

Orangery prevents the contamination by rainfall, insects, microorganisms, and bacteria. Orangery works on natural as well as forced convection modes. The schematic diagrams for natural convection orangery dryer shown in Figure 1. A orangery has been fabricated for happala drying under natural convection mode. The important dimensions of orangery structure are given below:

- UV film for Floor coverage 120 x 80 cm^2.
- PVC pipes.
- Central height 60 cm and walls height 40 cm.
- An air vent of area 400 cm^2.

All the necessary equipments required for determining the convective heat transfer coefficient for happala drying in orangery are given blow:-

- A digital weighing balance (model TJ-6000) of 6 kg capacity, having a least count of 0.1g.
- One circular shaped wire mesh tray of diameter 150 mm has been used to accommodate the happala samples.
- A twelve channel digital temperature indicator (0 to 300^{o}C, least count of 0.1 ^{o}C) with K-type thermocouple has been used to measure the orangery temperature.
- A non-contact thermometer (Raytek-MT4), having a least count of 0.2 ^{o}C with accuracy of ± 2% on a full scale range of -1 to 400 ^{o}C has been used to measure the temperature of happala surface.
- A digital humidity meter (model HT-315) has been used to measure the relative humidity and temperature of air just above the happala surface. Every time, it was kept on 2 min before recording observations.

The schematic view of the experimental set-up for orangery drying under natural convection is shown in the Figure 2. Orangery inside temperatures T_1 and T_2 at different locations, have been measured by calibrated K- thermocouples with digital temperature indicator of 0.1 ^{o}C least count. The relative humidity (γ) and temperature above the happala surface (T_e) were measured by a digital humidity/temperature meter (model HT-315). It had a least count of 0.1% relative humidity (RH) and 0.1 ^{o}C temperature. The mass of water evaporated during orangery drying of happala has been measured by an electronic weighing balance (capacity 6 kg; Scaletech, model TJ-6000) having a least count of 0.1g.

Experiments have been conducted in the months of March and April 2017 in the climatic conditions of NIT, Jalandhar. One circular shaped wire mesh tray of diameter 0.150 m has been used to accommodate the happala. The happala was kept on the weighing balance using the wire mesh tray.

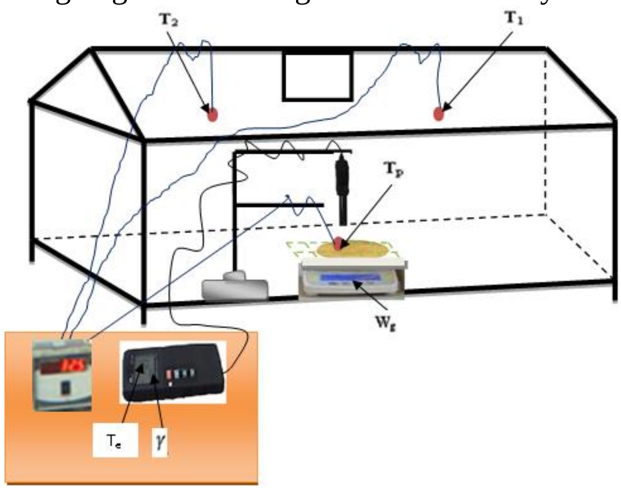

Fig. 2 Experimental set up diagram of orangery drying under natural convection

A digital hygrometer has been kept just above the happala surface with its probe facing downwards towards the happala surface. Every time, it has been start on 2 min before recording observations.All the observations have been recorded at every 10 min time intervals. The whole unit has been kept in orangery with negligible wind velocity. The schematic and photographic views of experimental set-up happala drying under natural convection

Fig. 3 Photographic view of orangery drying under natural convection

Orangery is shown in the Figure 2 and Figure 3 respectively.The difference in weight directly gave the quantity of water evaporated during that time interval. All experiment has been repeated two times for more accurate results.

III. HAPPALA SAMPLE PREPARATION

Happala has been freshly prepared by taking the flour of moong and urad dal mixed with the suitable quantity of water. Dough has been made and rolled in circular shape of thickness varying from 0.6 mm to 1.2 mm and diameter 150 mm with the help of pastry-board and pastry-roller as shown figure 4. A very little amount of mustard oil was applied on surface of pastry-board and pastry-roller so that happala does not stick to it.

IV. THERMAL MODELING

The convective heat transfer coefficient in orangery drying under natural convection can be calculated using following relations [11]:

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

or

$$h_c = \frac{K_v}{X} C(Gr\,\mathrm{Pr})^n \quad (1)$$

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

$$Q_e = 0.016 h_c \left[P(T_p) - \gamma P(T_e)\right] (2)$$

on substituting h_c from Eq. (1), Eq. (2) becomes

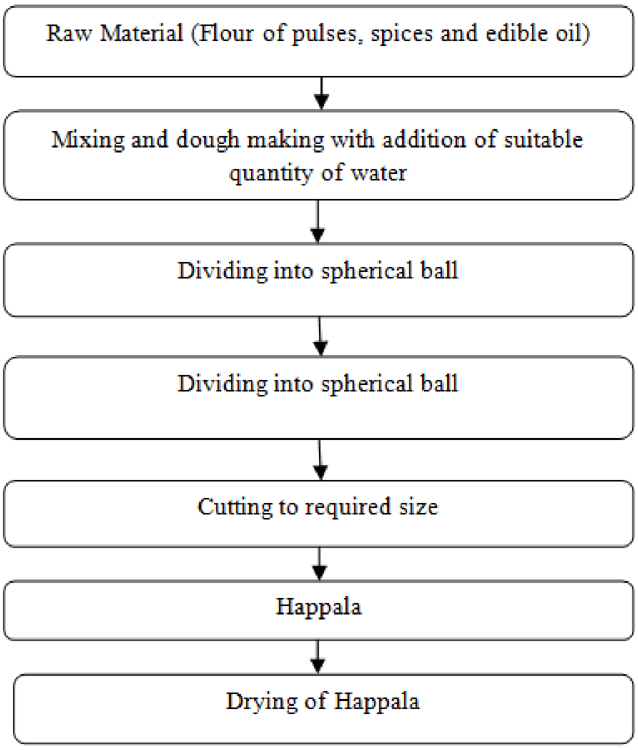

Fig.4Flow diagram of Happala Manufacturing Process

$$Q_e = 0.016 \frac{K_v}{X} C(Gr\,\mathrm{Pr})^n \left[P(T_p) - \gamma P(T_e)\right] (3)$$

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

$$m_{ev} = \frac{Q_e}{\lambda} t A_t = 0.016 \frac{K_v}{X\lambda} C(Gr\,\mathrm{Pr})^n \left[P(T_p) - \gamma P(T_e)\right] t\, A_t$$

(4)

Let

$$0.016 \frac{K_v}{X\lambda} \left[P(T_p) - \gamma P(T_e)\right] t\, A_t = Z \; (5)$$

$$\frac{m_{ev}}{Z} = C(Gr\,\mathrm{Pr})^n \; (6)$$

Taking logarithm of both sides of Equation (6),

$$\ln\left[\frac{m_{ev}}{Z}\right] = \ln(C) + n \ln(Gr\,\mathrm{Pr}) \; (7)$$

This is in the form of liner equation,

$y_i = mx_i + C$ (8)

Where

$Y_i = \ln\left[\frac{m_{ev}}{Z}\right]$,

$m = n$, $X_i = \ln(Gr\ Pr)$, $C_0 = \ln C$, (9)

Thus

$C = e^{C_0}$ (10)

The line of regression of y on x is given by:

$y_i = mx_i + C$ (11)

Where m and C is the coefficients to be determine from the given equation. For a best fit, the sum S is to be minimized, where

$$S = \sum_{i=1}^{n}[y_i - (C + mx_i)]^2 \quad (12)$$

The minimum occurs when the partial derivatives of S with respect to mand care both zero. This gives

$$\frac{\partial S}{\partial m} = \sum_{i=1}^{n}[-2(y_i - C - mx_i)x_i] = 0 \quad (13)$$

$$\frac{\partial S}{\partial c} = \sum_{i=1}^{n}[-2(y_i - C - mx_i)] = 0 \quad (14)$$

These equations may be simplified and expressed as

$$\sum y_i x_i - \sum Cx_i - \sum mx_i^2 = 0 \quad (15)$$

$$\sum y_i - C - \sum mx_i = 0 \quad (16)$$

Which may be written for find the unknown's m and C as

$$\sum x_i y_i = C\sum x_i + m\sum x_i^2 \quad (17)$$

$$\sum y_i = nC + m\sum x_i \quad (18)$$

Where the summations are over the ndata points, from i=1 to i=n. After solving these two simultaneous linear equations the coefficients m and C can be obtained as

$$n = \frac{\sum y_i(\sum x_i)^2 - (\sum X_i Y_i)(\sum x_i)}{n\sum X_i^2 - (\sum X_i)^2}$$

$$C = \frac{\sum x_i^2 \sum y_i - \sum x_i \sum x_i y_i}{n\sum x_i^2 - (\sum x_i)^2} \quad (20)$$

Values of 'n' and 'C' are obtained by using the simple linear regression method.

V. THE PHYSICAL PROPERTIES OF HUMID AIR

The physical properties of humid air, i.e., specific heat (C_v), thermal conductivity (K_v), density (ρ_v), viscosity (μ_v), and partial vapor pressure, P (T) have been determined by using following expressions:

$$C_v = 999.2 + 0.1434T_i + 1.101\times10^{-4}T_i^2 - 6.7581\times10^{-8}T_i^3 \quad (21)$$

$$K_v = 0.0244 + 0.7673\times10^{-4}T_i \quad (22)$$

$$\rho_v = \frac{353.44}{T_i + 273.15} \quad (23)$$

$$\mu_v = 1.718\times10^{-5} + 4.620\times10^{-8}T_i \quad (24)$$

$$P(T) = \exp\left[25.317 - \frac{5144}{(T + 273.15)}\right] \quad (25)$$

Wher

$$T_i = \frac{\overline{T}_p + \overline{T}_e}{2}$$

Finally the convective heat transfer coefficient (h_c) can be calculated by using the Equation (1) for orangery drying under natural convection condition.

TABLE 1
OBSERVATIONS FOR NATURAL CONVECTION ORANGERY DRYING OF HAPPALA SAMPLE FOR DIAMETER = 150 MM; THICKNESS = 1.2 MM

Sr. No.	Time	t (min.)	T_p (°C)	T_e (°C)	$m_{ev} \times 10^{-3}$ (kg)	γ (%)
1.	10.50 am	0	47.1	47.0	-	21.6
2.	11.00 am	10	48.7	49.1	1.9	17.4
3.	11.10 am	20	48.8	50.1	1.8	14.3
4.	11.20 am	30	48.2	48.1	1.5	13.3
5.	11.30 am	40	51.7	50.4	1.2	12.9
6.	11.40 am	50	52.2	51.5	0.9	11.6
7.	11.50 am	60	55.3	53.5	0.8	11.3
8.	12.00 pm	70	55.9	53.6	0.5	11.2
9.	12.10 pm	80	53.8	53.1	0.3	11.6

TABLE 2

OBSERVATIONS FOR NATURAL CONVECTION ORANGERY DRYING OF HAPPALA SAMPLE FOR DIAMETER = 150 MM; THICKNESS = 0.8 MM

Sr. No.	Time	t (min.)	T_p(°C)	T_e (°C)	$m_{ev} \times 10^{-3}$ (kg)	γ (%)
1.	2.15 pm	0	44.3	46.0	-	21.1
2.	2.25 pm	10	46.8	47.5	1.7	20.4
3.	2.35 pm	20	47.5	47.4	1.6	16.8
4.	2.45 pm	30	48.2	47.6	1.5	16.8
5.	2.55 pm	40	48.3	47.9	1.3	16.2
6.	3.05 pm	50	48.1	48.4	1.1	15.6
7.	3.15 pm	60	49.7	50.7	0.7	14.3
8.	3.25 pm	70	48.2	51.2	0.3	12.7
9.	3.35 pm	80	48.6	51.5	0.2	12.6
10.	3.45 pm	90	51.3	54.4	0.1	11.3

TABLE 3
OBSERVATIONS FOR NATURAL CONVECTION ORANGERY DRYING OF HAPPALA SAMPLE FOR DIAMETER = 150 MM; THICKNESS = 0.6 MM

Sr. No.	Time	t (min.)	T_p(°C)	T_e (°C)	$m_{ev} \times 10^{-3}$ (kg)	γ (%)
1.	10.05 am	0	40.8	43.5	-	20.3
2.	10.15 am	10	44.8	46.2	1.6	19.5
3.	10.25 am	20	45.5	46.4	1.0	17.6
4.	10.35 am	30	45.0	47.6	1.0	16.9
5.	10.45 am	40	47.4	49.8	0.6	14.4
6.	10.55 am	50	46.5	48.8	0.7	14.8
7.	11.05 am	60	49.8	53.1	0.3	11.5
8.	11.15 pm	70	50.1	53.9	0.3	10.6
9.	11.25 pm	80	51.6	55.8	0.4	9.5

VI. RESULTS AND DISCUSSIONS

The average of happala surface temperature ($\bar{T}_p$), exit air temperature ($\bar{T}_e$) and exit air relative humidity ($\bar{\gamma}$) have been used to determine the physical properties of the humid air which were further used to calculate the values of Grashof number and Prandtl number. The values of C and n in equation 1 have been obtained by linear regression analysis, and, thus the values of h_c have been determined for orangery drying under natural convection condition. The values of constants and the average values of convective heat transfer coefficients forvarying thickness of happala under natural convection orangery drying condition are presented in Table 4.

TABLE 4
VALUES OF *C*, *N* AND *H_C* UNDER NATURAL CONVECTION ORANGERY DRYING OF HAPPALA SAMPLES FOR 150 MM DIAMETER AND DIFFERENT THICKNESS

Diameter of Papad (mm)	Thickness of Papad (mm)	C	n	h_c (W/m² °C)	$h_{c, avg.}$ (W/m² °C)
150	1.2	0.99	0.14	0.95 - 1.22	1.11
	0.8	1.15	0.12	0.89 - 1.08	1.00
	0.6	1.05	0.13	0.72 - 1.03	0.92

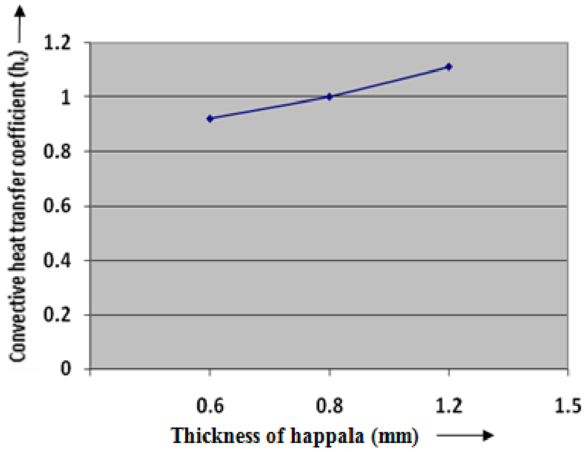

Fig. 5Heat transfer coefficient (h_c) *vs* thickness of happala (mm) samples for 150 mm diameter

V. CONCLUSIONS

Solar drying technique used for happala drying is proved technically and economically feasible. The convective heat transfer coefficients for happala under orangery natural convection modes were resolute using the standards of the constants, 'C' and 'n' in the Nusselt number expression, obtained for happala based on experimental data by using the linear regression technique. From the present research work, following conclusions were drawn:

- The values of convective heat transfer coefficients for happala under natural convection orangery drying condition increase with the increase of thickness, when diameter for happala is kept constant.
- The average values of convective heat transfer coefficientswere found to be 1.11, 1.00 and 0.92 W/m^{2o}C by varying thickness.

NOMENCLATURE

C_v - Specific heat of humid air (J/kg ^{o}C)
h_c - Convective heat transfer coefficient (W/m^2 ^{o}C)
K_v - Thermal conductivity of humid air (W/m^2 ^{o}C)
μ_v - Dynamic viscosity of humid air (kg/m)
ρ_v - Density of humid air (kg/m^3)
m_{ev} - Moisture evaporated (kg)
Gr - Grashof number ($Gr = \beta g X^3 \rho^2 \Delta T/\mu^2$)
Nu - Nusselt number ($Nu = h_c X/K_v$)
Pr - Prandtl number ($Pr = \mu_v C_v/K_v$)
C - Constant
n - Constant
A_t - Area of tray (m^2)
t - Time (s)
T_p - Happala surface temperature (^{o}C)
T_e - Exit air temperature (^{o}C)
T_i - Average of happala and humid air temp. (^{o}C)
$\bar{T}_e$ - Average exit air temperature (^{o}C)
$\bar{T}_p$ - Average happala surface temperature (^{o}C)
Q_e - Rate of heat utilized to evap. moisture (J/m^{2}s)
β - Coefficient of volumetric expansion (1/^{o}C)
X - Characteristic dimension (m)
γ - Relative humidity (degree)
$\bar{\gamma}$ - Average relative humidity (degree)
λ - Latent heat of vaporization (J/kg)
$P(T)$ - Partial v. pressure at temperature T (N/m^2)

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