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PARAMETRIC EFFECT STUDY ON HEAT TRANSFER RATE DURING AERATION OF APPALA IN HOTHOUSE

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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 Appala (Papad) by variable diameter and thickness under hothouse natural convection mode. Three sets of experiments with 130, 150 and 180 mm diameter of appala were down. Experimental data obtained from natural convection hothouse drying mode for appala was used to find out 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 coefficients were found to vary from 0.70 $W/m^2\,^oC$ to 1.93 $W/m^2\,^oC$ by varying thickness 0.6, 0.8 and 1.2 mm of appala sample.

Keywords- Hothouse aeration of appala, Heat transfer rate for appala, Natural convection drying foodstuff.

1. INTRODUCTION

In recent years, there is a universal concern for the foodstuff and energy protection of emergent world population. For foodstuff protection, either the crop production should enhance or post harvest sufferers should reduce or both. The conservative energy sources e.g. coal, wood, oil, gas etc. should be conserved for energy protection i.e. we must investigate the renewable energy sources. If lunar energy, one of the renewable energy sources, is effectively used for aeration of crops, it will help in both foodstuff as well as energy security [1].

Appala is a public food item of the Indian diet since more than half centuries [2, 3]. It is a cookie like product, circular in shape, epithetical clams of powdered pulses, spices and salt, etc. It is groomed by rolling dough into a round 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]. Aeration reduces the moisture content of a product by which its shelf life can be distended. In the aeration process, the product is extend in a thin layer on the earth surface and exposed directly to the solar energy. The product aeration rate depends on diverse parameters like solar radiation, wind velocity, relative humidity, air and earth warmth, variety of product, initial wetness content, product absorptive, and mass of product per unit exposed area [6, 7]. In the most of emergent countries, people have been drying appala and other foodstuff products for decades by placing on ground exterior in open air. Generally, open sun dried products do not meet the global quality standards and therefore, it cannot be sold in the worldwide market. The main disadvantages of open sun drying are poisoning, extortion or ruin by birds, rats or insects; slow or occasional drying, no safeguard from rain or dew that wets the stock, encourages blight surge and may go related high last-minute mist composition; low and fickle excellence of produce due to over or lower drying; hefty area of land desired for the empty beds of drying merchandises; mean liability to dawn reduces the excellence of appala [8]. The substitute factor for drying of some of the farming and food products in emergent countries may be provided by well-designed lunar dryers. The acquirement and operational costs of dryers existing in the market considerably increase the costs of the dehydrated products. Therefore, in the recent work hothouse type dryer is to be used to arid appala. Hothouse 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 appala drying under hothouse natural convection drying mode. These values would be helpful in designing a dryer for dry appala to its optimum storage moisture level of 15% to 20%.

2. EXPERIMENTAL SET-UP AND PROCEDURE

A hothouse is made of three main elements: the apparent cover, structure material and captivating or soil surface. The apparent sheets are fixed on steel frame carry with bolts, nuts, and rubber packing to prevent sultry air leaking into chamber. The apparent (polyethylene or PVC) film cover acts an interface between indoor and outer climate conditions and the soil surface as an interface between indoors and ground earth surface. Air flows through bottom side by natural convection through the material and finally vegetation through the air vent provided at the upper part of the hothouse.

Hothouse prevents the contamination by rainwater, insects, microorganisms, and bacteria. Hothouse works on natural as well as forced convection modes. The schematic diagrams for natural convection hothouse dryer exposed in Figure 2.1. A hothouse has been fabricated for appala drying under natural convection mode. The important dimensions of hothouse 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

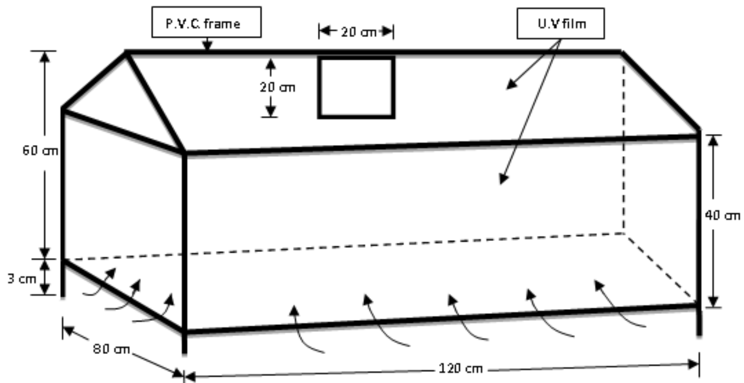

Fig. 2.1 Schematic Diagram of Hothouse Drying Under Natural Convection

All the crucial equipments required for determining the convective heat transfer coefficient for appala drying in hothouse are given blow:

- A digital weighing balance (model TJ-6000) of 6 kg capacity, having a least count of 0.1 g.
- One circular shaped wire mesh tray of diameter 150 mm has been used to contain the appala 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 hothouse 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 appala surface.
- A digital humidity meter (model HT-315) has been used to measure the relative humidity and temperature of air just above the appala surface. Every time, it was kept on 2 min before recording observations.

The schematic vision of the experimental set-up for hothouse drying under natural convection is publicized in the Figure 2.2. Hothouse indoor temperatures T_1 and T_2 at diverse 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 appala 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 hothouse drying of appala 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 2016 in the climatic conditions of NIT, Jalandhar.

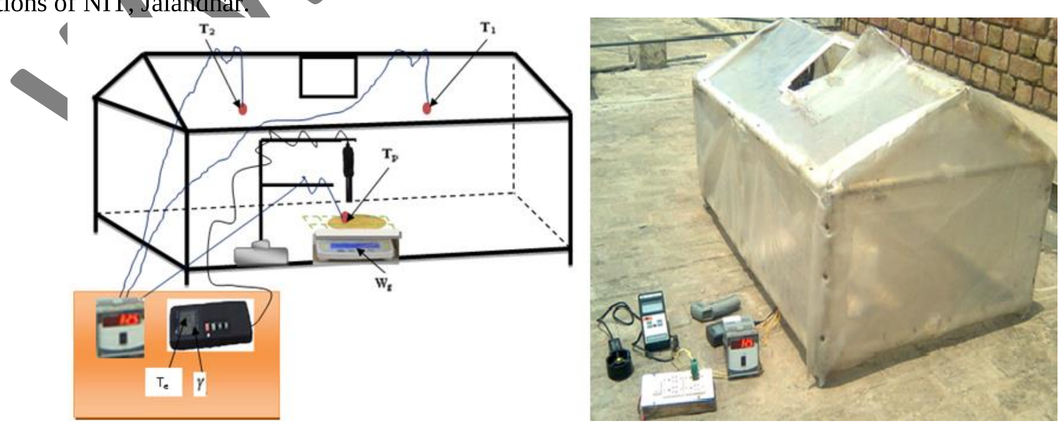

Fig. 2.2 Experimental Set Up Diagram and Photographic View of Hothouse Drying Under Natural Convection

Three globular shaped wire mesh trays of diameter 0.130, 0.150 and 0.180 m have been used to accommodate the appala. The appala was set aside on the weighing balance using the wire mesh tray. A digital hygrometer has been set aside just above the appala surface with its probe facing downwards towards the appala surface. Each time, it has been start on 2 minute before recording observations. All the observations have been recorded at every 10 minute time intervals. The whole entity has been kept in hothouse with negligible wind velocity. The schematic and photographic views of experimental set-up appala drying under natural convection hothouse are shown in the Figure 2. The difference in weight directly gave the amount of water evaporated during that time era. All experiment has been recurring two times for more correct outcome.

3. APPALA SAMPLE PREPARATION

Appala has been newly 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 130, 150 and 180 mm with the help of pastry-board and pastry-roller as shown in figure 3.1. A very minute amount of mustard oil was applied on surface of pastry-board and pastry-roller so that appala does not fuse to it.

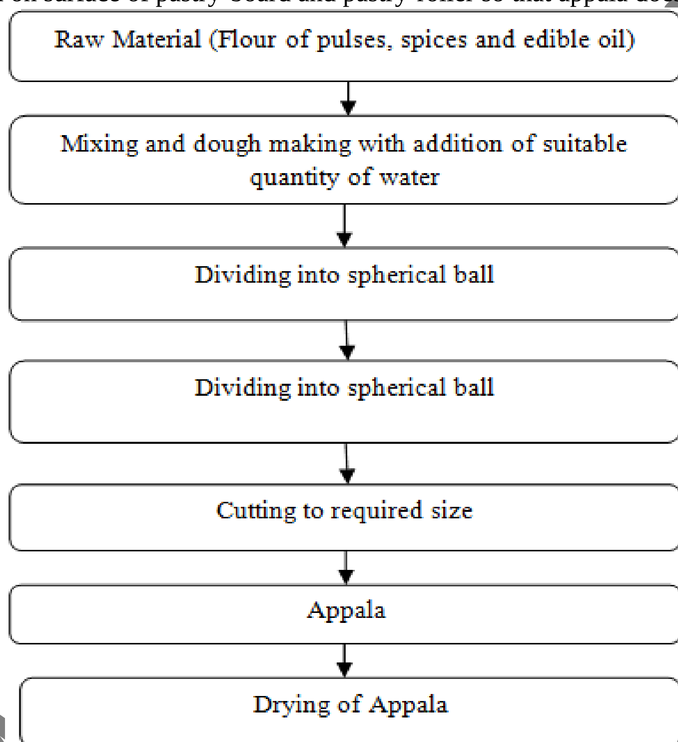

Fig. 3.1 Flow Diagram of Appala Manufacturing Process

4. THERMAL MODELING

The convective heat transfer coefficient in hothouse drying under natural convection can be intended using following relations [11]

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

or

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

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

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

on substituting h_c above Eq. and find

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

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

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

Let

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

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

Taking logarithm of both sides of Equation (6),

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

This is in the form of liner equation,

$$y_i = mx_i + C$$

Where

$$Y_i = \ln\left[\frac{m_{ev}}{Z}\right], \quad m = n, \qquad X_i = \ln(Gr\ \mathrm{Pr}), \qquad C_0 = \ln C,$$

Thus

$$C = e^{C_0}$$

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

$$y_i = mx_i + C$$

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

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

The minimum occurs when the partial derivatives of *S* with respect to m and c are both zero. This gives

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

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

These equations may be simplified and expressed as

$$\sum y_i x_i - \sum Cx_i - \sum mx_i^{\,2} = 0$$

$$\sum y_i - C - \sum mx_i = 0$$

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

$$\sum x_i y_i = C\sum x_i + m\sum x_i^{\,2}$$

$$\sum y_i = nC + m\sum x_i$$

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

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

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

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

4. 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:

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

$$K_v = 0.0244 + 0.7673\times10^{-4}T_i$$

$$\rho_v = \frac{353.44}{T_i + 273.15}$$

$$\mu_v = 1.718\times10^{-5} + 4.620\times10^{-8}T_i$$

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

$\mu_v = 1.718 \times 10^{-5} + 4.620 \times 10^{-8} T_i$ Where

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

$C_0 = \frac{\sum X^2 \sum Y - \sum X - \sum X_0 Y}{N \sum X^2 - (\sum X_0)^2}$ Finally the convective heat transfer coefficient (h_c) can be calculated by using above Equation for hothouse drying under natural convection condition.

5. RESULTS AND DISCUSSIONS

The average of appala surface temperature $(\overline{T}_p)$, exit air temperature $(\overline{T}_e)$ and exit air relative humidity $(\overline{\gamma})$ 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 have been obtained by linear regression analysis, and, thus the values of h_c have been determined for hothouse drying under natural convection condition. The values of constants and the average values of convective heat transfer coefficients for varying diameter and thickness of appala under natural convection hothouse drying condition are presented in Table 6.4.

Table-5.1 Observations for Natural Convection Hothouse Drying of Appala Sample for Diameter = 130 mm

For thickness = 1.2 mm

Sr. No.	Time	t (min.)	T_p (°C)	T_e (°C)	$m_{ev} \times 10^{-3}$ (kg)	γ (%)
1.	1.35 pm	0	38.0	46.4	-	15.7
2.	1.45 pm	10	46.1	46.5	2.4	15.0
3.	1.55 pm	20	46.8	47.5	2.4	14.9
4.	2.05 pm	30	47.0	48.0	1.8	14.4
5.	2.15 pm	40	48.1	49.3	1.7	12.6
6.	2.25 pm	50	49.0	49.8	0.6	11.1
7.	2.35 pm	60	51.0	52.2	0.7	10.9
8.	2.45 pm	70	52.0	51.2	0.6	10.9
9.	2.55 pm	80	49.0	50.7	0.2	11.2

For thickness = 0.8 mm

Sr. No.	Time	t (min.)	T_p (°C)	T_e (°C)	$m_{ev} \times 10^{-3}$ (kg)	γ (%)
1.	10.30 am	0	39.5	41.5	-	21.6
2.	10.40 am	10	42.1	42.5	1.4	20.6
3.	10.50 am	20	45.5	45.3	1.3	17.3
4.	11.00 am	30	44.3	46.6	1.3	16.5
5.	11.10 am	40	46.3	46.6	1.3	15.7
6.	11.20 am	50	46.8	47.4	1.2	14.1
7.	11.30 am	60	48.6	48.3	0.7	12.8
8.	11.40 am	70	49.7	49.5	0.7	11.8
9.	11.50 am	80	50.9	50.0	0.3	11.4

For thickness = 0.6 mm

Sr. No.	Time	t (min.)	T_p (°C)	T_e (°C)	$m_{ev} \times 10^{-3}$ (kg)	γ (%)
1.	10.50 am	0	40.1	37.3	-	25.3
2.	11.00 am	10	45.2	42.1	1.8	23.5
3.	11.10 am	20	46.9	45.6	1.2	22.4
4.	11.20 am	30	47.8	43.5	1.1	21.9
5.	11.30 am	40	48.0	48.6	0.9	21.1
6.	11.40 am	50	49.6	46.9	0.6	18.1
7.	11.50 am	60	49.7	48.8	0.5	17.0
8.	12.00 pm	70	50.8	48.2	0.4	17.0
9.	12.10 pm	80	49.6	48.1	0.3	17.0

Table-5.2 Observations for Natural Convection Hothouse Drying of Appala Sample for Diameter = 150 mm

For 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

For 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

For 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
1.	10.05 am	0	40.8	43.5	-	20.3

Table-5.3 Observations for Natural Convection Hothouse Drying of Appala Sample for Diameter = 180 mm

For thickness = 1.2 mm

Sr. No.	Time	t (min.)	T_p (°C)	T_e (°C)	$m_{ev} \times 10^{-3}$ (kg)	γ (%)
1.	10.10 am	0	41.5	41.4	-	23.6
2.	10.20 am	10	44.6	43.3	2.3	20.4
3.	10.30 am	20	44.0	43.2	1.7	19.8
4.	10.40 am	30	43.4	44.4	1.4	17.7
5.	10.50 am	40	46.7	46.2	0.7	17.5
6.	11.00 am	50	45.8	43.9	0.6	18.5
7.	11.10 am	60	48.1	44.4	0.7	17.5
8.	11.20 pm	70	46.4	46.3	0.5	16.8
9.	11.30 pm	80	46.3	47.1	0.3	14.9

For thickness = 0.8 mm

Sr. No.	Time	t (min.)	T_p (°C)	T_e (°C)	$m_{ev} \times 10^{-3}$ (kg)	γ (%)
1.	1.50 pm	0	39.2	48.3	-	15.1
2.	2.00 pm	10	48.5	54.1	2.2	10.2
3.	2.10 pm	20	50.0	54.5	2.0	8.0
4.	2.20 pm	30	53.3	57.7	1.5	6.2
5.	2.30 pm	40	54.7	58.2	1.2	5.9
6.	2.40 pm	50	52.8	57.7	0.8	5.8
7.	2.50 pm	60	50.9	54.3	0.6	6.9
8.	3.00 pm	70	51.3	54.9	0.5	6.3

For 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	46.5	50.8	-	15.3
2.	10.15 am	10	47.9	52.9	2.2	11.4
3.	10.25 am	20	46.4	53.4	1.8	9.2
4.	10.35 am	30	49.4	52.6	1.4	9.5
5.	10.45 am	40	47.1	53.5	1.1	8.4
6.	10.55 am	50	47.2	51.4	0.8	8.5
7.	11.05 am	60	50.2	54.5	0.5	7.5
8.	11.15 pm	70	51.7	55.9	0.2	6.8

Table-5.4 Values of *C*, *n* and h_c Under Natural Convection Hothouse Drying of Appala Samples with Three Diameter and Thickness

Diameter of Papad (mm)	Thickness of Papad (mm)	C	n	h_c (W/m^2 °C)	$h_{c, avg.}$ (W/m^2 °C)
130	1.2	1.28	0.14	1.48 - 1.93	1.70
	0.8	1.45	0.13	1.19 - 1.70	1.53
	0.6	1.01	0.13	1.14 - 1.22	1.19
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
180	1.2	1.16	0.13	0.88 - 1.16	0.98
	0.8	1.07	0.12	0.81 - 0.95	0.89
	0.6	0.89	0.13	0.70 - 0.88	0.77

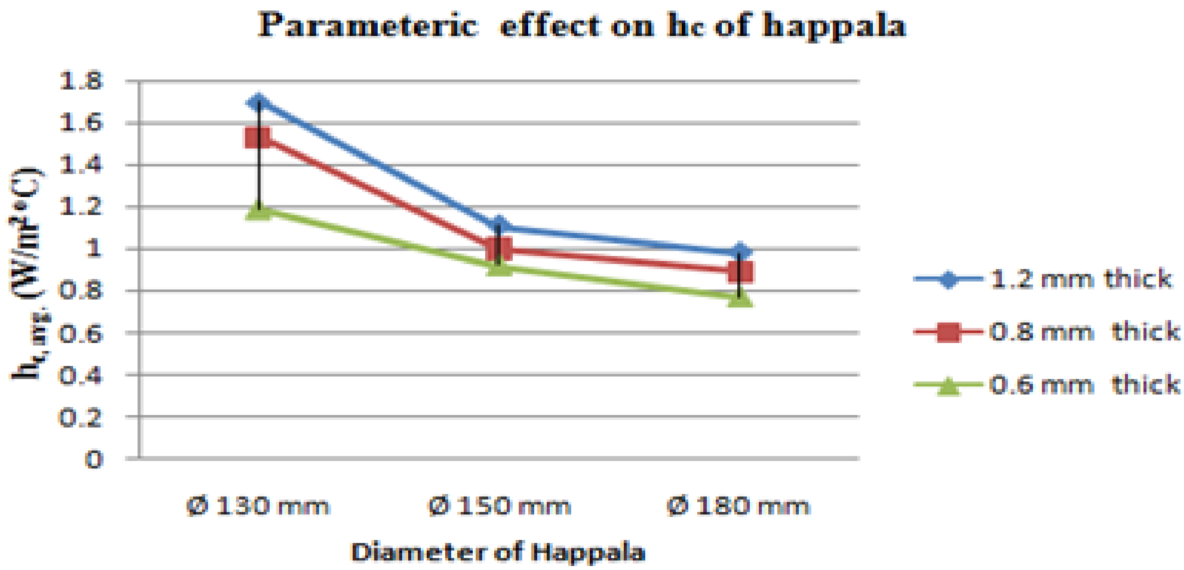

Fig. 5.1 Heat Transfer Coefficient (h_c) *vs* Dia (Ø) of Appala

CONCLUSIONS

The convective heat transfer coefficients for appala under hothouse natural convection modes were resolute using the standards of the constants, 'C' and 'n' in the Nusselt number expression, obtained for appala 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 appala samples of thickness 1.2 mm are found higher than that of samples of thickness 0.8 mm and 0.6 mm respectively for all the mentioned diameter of appala samples.
- The value of convective heat transfer coefficient appala samples of diameter 130 mm are higher than that of samples of diameter 150 mm and 180 mm respectively for all the mentioned thickness of appala samples.
- The values of experimental constants 'C' and 'n' in the Nusselt number expression are observed to vary from 0.89 to 1.45 and 0.12 to 0.14 respectively.

The values of h_c have been observed to vary from 0.70 W/m^2 °C to 1.93 W/m^2 °C.

NOMENCLATURE

C_v - Specific heat of humid air (J/kg°C)
h_c - Convective heat transfer coefficient (W/m^{2}°C)
K_v - Thermal conductivity of humid air (W/m^{2}°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)
$P(T)$ - Partial vapour pressure at temperature T (N/m^2)
t - Time (s)
T_p - Papad surface temperature (°C)
T_e - Exit air temperature (°C)
T_i - Average of papad and humid air temperature (°C)
$\bar{T}_e$ - Average exit air temperature (°C)

$\bar{T}_p$ - Average papad surface temperature (^oC)
Q_e - Rate of heat utilized to evaporate moisture (J/m^2s)
β - Coefficient of volumetric expansion ($1/^oC$)
X - Characteristic dimension (m)
γ - Relative humidity (degree)
$\bar{\gamma}$ - Average relative humidity (degree)
λ - Latent heat of vaporization (J/kg)

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