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Influence of Drying Temperatures on Effective Diffusivity of Custard Apple Pulp

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Abstracts: Fresh custard apple pulp was dehydrated using convective drying method to study the effect of drying temperatures on effective diffusivity of custard apple pulp. Dehydration characteristics of custard apple pulp for the convective drying experiment were studied. Moisture diffusivity (D_{eff}) at 50, 55, 60 and 65° C temperatures was ranged from 3.20 x10^{-9} m^2/s to 4.80 x 10^{-9} m^2/s and activation energy was found 29.436 kJ/mol at air velocity of 2 m/s. The average drying time was decreased 16.67, 10.00 and 22.22 for per 5 °C temperature increase. It was also found that greater drying effect of 22 per cent reduction in drying time was observed for 60 to 65 °C temperature increase. During the drying experiment and data were recorded, it was found that highest drying rate during the drying process was about thrice of the average drying time. It can be deduced from the study that drying process was fast at higher temperature and as the drying temperature increased the effective moisture diffusivity was also increased.

Keywords: Convective dehydration, Dehydration characteristics, Custard apple powder, Activation energy.

I. INTRODUCTION

Custard apple (*Annona squamosa* L.) commonly known as *sitaphal,* is one of the most important multipurpose plant species of Indian sub-continent and known by several vernacular names such as *sugar apple, sweet sop, sitaphal* and *sharifa* in different part of the country (Khodifad and Kumar, 2019). The fruit is rich in free sugars, minerals and vitamins and contains about fifty three compounds including limonene, alpha-pinene, beta-pinene, germacrene D and bornyl acetate (Pino, 2010). Custard apple has medicinal and industrial applications due to properties like anti-oxidant, anti-diabetic, hepato-protective, cyto-toxic, geno-toxic, anti-tumor and anti-lice agent (Sharma and Panesar, 2018). Custard apple pulp is being used for production of soft drinks, ice-creams and certain food products. Fruits have short shelf-life and spoiled because of non-availability of proper post-harvest technology. Dehydrated custard apple powder will inhibit the quality deterioration, browning of pulp and fruit, microbial contamination and increase in shelf life. Spray drying of custard apple pulp was studied by Shashirekha *et al.*, (2018) and reported that spray dried powder was free of bitterness, discoloration and off-flavour. Patil, (2011) reported that 20 % level of maltodextrin and 1 % tricalcium phosphate is optimum for maximum yield of custard apple powder by spray drying. Vaccum storage of freeze dried custard apple powder in polyethelene bags was reported optimum by Sondarva *et al.*, (2016). Natural circulation solar drying of custard apple pulp was performed by Ojha *et al.*, (2018) and reported that whole drying took placed in falling rate only and in 29 hours. Dehydration of custard apple pulp in thin layer foam mats was done by Khodifad and Kumar, (2019) and found that 2 mm pulp thickness took drying time 100 to 140 min at 60–75° C temperatures.

The present investigation was focused on the thin-layer drying characteristics of custard apple pulp in a tray dryer over 50 to 65° C temperature ranges at 2 m/s air velocity.

II. MATERIALS AND METHODS

Fresh and mature custard apple fruits were procured from the local market of Udaipur. The procured mass has been thoroughly washed to remove dirt, dust and other impurities, then each fruit was cut into two halves manually with wearing gloves. Pulp encapsulated with seeds was then scooped from each half of the fruit with help of stainless steel spoon. This scooped pulp was then subjected to seed separation with depulper developed at MPUAT, Udaipur and the drying experiments were performed.

A. Drying Characteristics

The observed drying data *i.e.* change of weight of the sample with time during convective drying of custard apple pulp were used to evaluate the moisture content, drying rates and the moisture ratio, as discussed hereunder.

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B. Moisture Content

Moisture content of custard apple pulp was found by oven drying method (Ranganna, 2002) and was expressed as g water/g dry matter using Eq. 1.

$$Moisture\ content = \frac{M_w}{M_d}\ g\ water/g\ dry\ matter \quad \ldots (1)$$

Where-

M_w - Weight of water in sample, g

M_d - Weight of dry matter in sample, g

C. Moisture Ratio

The moisture content level at which drying rate ceases and drying experiment cannot be processed further was considered as equilibrium moisture content of custard apple pulp. The moisture ratio (MR) at each moisture content level was calculated by the Eq. 2 (Brooker *et al.*, 1974; Mudgal and Pande, 2007):

$$MR = \frac{M - M_e}{M_0 - M_e} \quad \ldots (2)$$

Where-

MR - Moisture ratio | M - Moisture content at any time (db)

M_o - Initial moisture content (db) | M_e - Equilibrium moisture content (db)

D. Drying Rate

The moisture content data recorded during experiments was analysed to determine the moisture lost from the dehydrated samples of custard apple pulp in a given period. The drying rate of sample was calculated using Eq. 3 (Kohli *et. al.*, 2018; Brooker *et al.*, 1974).

$$R = \frac{WML}{Time\ interval \times DM} \quad \ldots (3)$$

Where-

R -Drying rate at time t, kg water/kg dry matter/s

WML -Initial weight of sample – Weight of sample after time t, kg

DM -Dry matter, kg

E. Estimation of Moisture Diffusivity

Diffusivity is defined as the moisture flow, in falling rate period water transported from interior to surface of custard apple pulp. Fick's diffusion equation was used to describe falling rate period, Crank (1975) suggested solution for Fick's diffusion model for different regular shapes *viz.* rectangular, cylindrical and spherical. Assuming uniform initial moisture distribution with negligible external resistance the form of Eq. 4 can be applicable for custard apple pulp particles with slab geometry.

$$MR_i = \frac{8}{\pi}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}e^{\left(-\frac{(2n+1)^2\pi^2 D_{eff}t}{4L_0^2}\right)} \quad \ldots (4)$$

Where-

D_{eff} - Effective moisture diffusivity, m^2/s

L_0 - Half thickness of slab, m

T - Drying time, s

The equation 4 was further simplified for longer drying period (Tutuncu and Labuza, 1996) and can be written in a logarithmic form as Eq. 5.

$$\ln MR = \ln\frac{8}{\pi^2} - \frac{\pi^2 D_{eff}}{4L_0^2} \quad \ldots (5)$$

Diffusivities for each drying experiment was determined by plotting graph between *ln MR* against drying time. The slope of line (m from; y = mx + c) obtained from the graph using Microsoft excel software and multiplied with $\left(\frac{4L_0^2}{\pi^2}\right)$. Result was termed as diffusivity.

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F. Calculation Of Activation Energy

The temperature dependence of the diffusivity was described by an Arrhenius-type relationship (Akgun and Doymaz, 2005; Kohli *et al.* 2018) as Eq. 6.

$$D_{eff} = D_0 e^{\left(-\frac{E_a}{RT}\right)} \quad \text{... (6)}$$

Where-

D_{eff}	-Effective moisture diffusivity, m^2/s
D_0	-Pre-exponential factor of the Arrhenius equation, m^2/s
E_a	-Activation energy, kJ/mol
R	-Universal gas constant kJ/mol K, and
T	-Absolute temperature, K

Activation energy is the minimum energy required to initiate the moisture diffusion process. Its knowledge is necessary for designing and modelling the mass transfer processes such as dehydration and moisture adsorption during storage of any food product. Activation energy for the drying of custard apple pulp of 4 mm thickness at 2 m/s air velocity at temperatures of 50, 55, 60 and 65 °C was calculated with help of slope of line obtained by graph between natural logarithmic of effective moisture diffusivity and inverse of absolute temperature as per Eq. 7.

$$\ln D_{eff} = \ln D_0 - \frac{E_a}{RT} \quad \text{... (7)}$$

III. RESULTS AND DISCUSSION

A. Drying Characteristics

The dehydration characteristics of convective drying process was described in terms of moisture content versus drying time, moisture content versus drying rate, logarithmic moisture ratio versus drying time for (effective moisture diffusivity) and logarithmic diffusivity versus inverse of temperature for (activation energy) of custard apple pulp at selected temperature is shown in Fig. 1, 2, 3 and 4.

The custard apple pulp was dried in a thin layer of 4 mm thickness, at temperatures of 50, 55, 60 and 65 °C at air velocity of 2 m/s in a tray dryer. The initial moisture content of custard apple pulp was found to be 5.55 g water/g dry matter and final moisture content was found to be as 0.11, 0.09, 0.08 and 0.07 g water/g dry matter for 50, 55, 60 and 65 °C respectively. In the drying process, the moisture content of custard apple pulp was found to be reducing with time at all the temperatures.

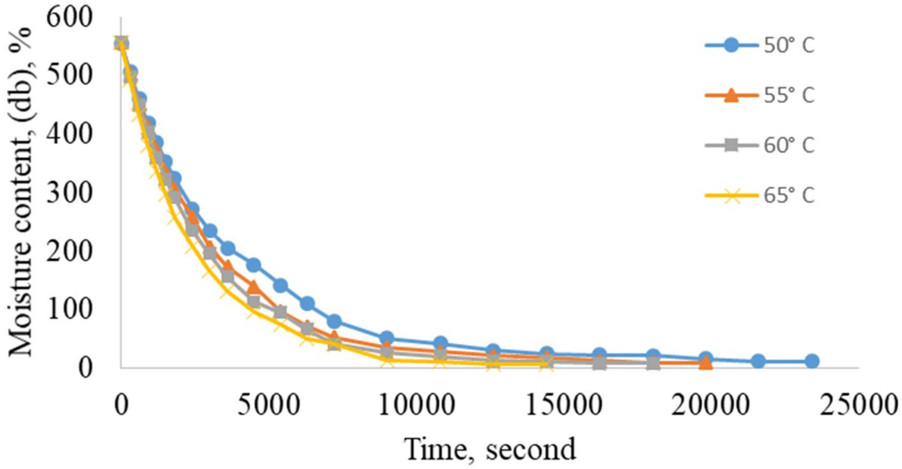

Fig. 1 Variation in moisture content of custard apple pulp with time at various temperatures

The drying time taken for drying of custard apple pulp with 2 m/s air velocity were 21600, 18000, 16200 and 12600 s at 50, 55, 60 and 65 °C air temperatures, respectively. The average drying time was decreased 16.67, 10.00 and 22.22 for per 5 °C temperature increase. It was also found that greater drying effect of 22 per cent reduction in drying time was observed for 60 to 65 °C temperature increase.

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Furthermore, it was recorded that drying time at 65 °C was nearly two third of drying time taken for dehydration of custard apple pulp at 50 °C. It was inferred from Fig. 1 that the moisture content reduced faster initially, further with increase in time and became very slow in the last phase of drying operation. This may be due to complete exposure of custard apple pulp to the drying environment and high moisture migration in less thickness. As the vapour pressure difference between pulp layer and the drying air inside the dryer is high so the air picks moisture from the pulp fast in initial stage of drying but as the time increased vapour pressure difference decreased which resulted slower drying process.

Similar results have been reported by Kumar *et al.* (2015) for tray drying of custard apple pulp and Khodifad and kumar (2019) for drying of foamed custard apple pulp. Drying at higher temperature provided more driving forces for heat transfer, which eventually related to mass transfer (Chantaro *et al.* 2008).

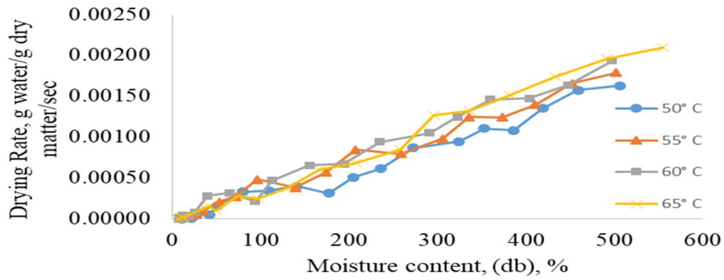

Fig. 2 Variation in drying rate of custard apple pulp with moisture content at various temperatures

The drying rate for the pulp was estimated from the change in its moisture content in a known time period and expressed as g water evaporated/g dry matter per second. It was observed that drying rate of custard apple pulp was high at higher moisture content *i. e.* at the begening of drying process and it decreased as moisture content reduced. At the initial stage of drying, moisture content of custard apple pulp was high and more moisture was evaporated from the upper surface of custard apple pulp in further steps. As the drying process proceeded, the moisture on the surface decreased and hence drying rate reduced with moisture content as shown in Fig 6.6. This trend was observed at other tempereture also The drying curves mostly displays a falling rate period only. It was observed that the maximum drying rate was almost double than the average drying rate at initial stage of drying.

The average drying rates for convective tray drying of custard apple pulp at 2 m/s air velocity with 50, 55, 60 and 65 °C temperatures were 0.00052, 0.0006, 0.00066 and 0.0008 g water/g dry matter per sec, respectively. During the drying experiment and data were recorded, it was found that highest drying rate during the drying process was about thrice of the average drying time.

It can be inferred from Fig. 6.6 that drying of custard apple pulp occurred in falling rate period, except a short accelerating period at the begining. It can be due to fast moisture removal from thin surface of pulp. It can be observed that drying rates were significantly higher at higher temperature and moisture content while at lower values of moistue content dryng rates were very low towards end of drying. The main reason of lower drying rates at the end of process was lower moisture migration rate from the inner layer to surface at final stage of drying process.

B. Effective Moisture Diffusivity

The results indicated that internal mass transfer resistance controlled the drying time due to which falling rate drying period dominated the drying process. Effective moisture diffusivity (D_{eff}) at various drying temperatures were calculated using Eq. 7 and found to vary from 3.20 x10^{-9} m^2/s to 4.80 x 10^{-9} m^2/s. Table 1 shows the effect of drying air temperature on diffusivity.

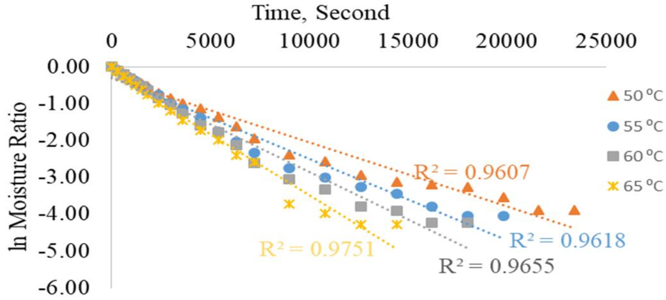

Fig. 3 Variation in moisture ratio with drying time at various drying temperature

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Table 1 Effect of drying air temperature on diffusivity

S. No.	Temperature °C	Effective moisture diffusivity (m^2/s)	Linear Relationship	R^2 Value
1	50	3.20 x 10^{-09}	y = -0.0002x - 0.3139	0.9607
2	55	3.20 x 10^{-09}	y = -0.0002x - 0.2948	0.9618
3	60	4.80 x 10^{-09}	y = -0.0003x - 0.2574	0.9655
4	65	4.80 x 10^{-09}	y = -0.0003x - 0.1667	0.9751

It was inferred from Fig. 3 and Table 1 that as the drying temperature increased the effective moisture diffusivity also increased. This could be because of increase in diffusion with the increase in sample temperature (Daimante, 1991).

C. Activation Energy

Linear relationship obtained between reciprocal of absolute temperature and logarithm of diffusivity at selected temperatures viz. 50, 55, 60 and 65 °C were described in Fig. 4. The activation energy was calculated using Eq. 7. The value of activation energy for the convective tray drying experiment of custard apple pulp was found as 29.436 kJ/mol at an air velocity of 2 m/s.

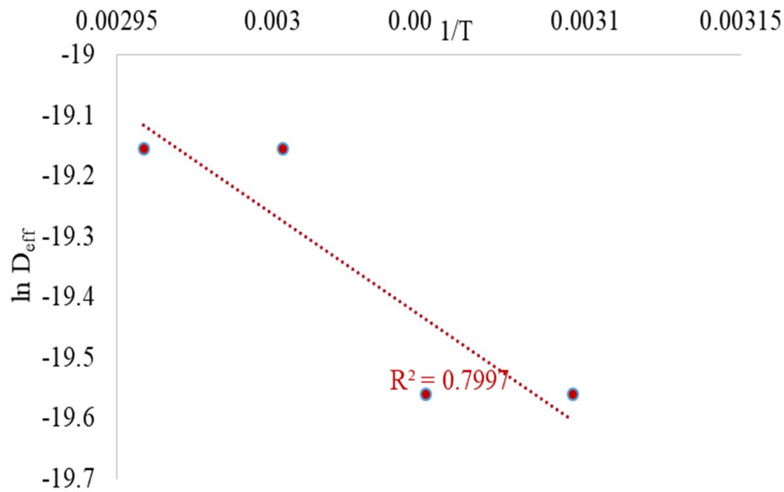

Fig. 4 Variation in effective moisture diffusivity with absolute temperature and 2 m/s velocity of drying air

IV. CONCLUSIONS

During the drying process of custard apple pulp moisture content reduced faster initially, further with increase in time and became very slow in the last phase of drying operation. This may be due to complete exposure of custard apple pulp to the drying environment and high moisture migration in less thickness. As the vapour pressure difference between pulp layer and the drying air inside the dryer is high so the air picks moisture from the pulp fast in initial stage of drying but as the time increased vapour pressure difference decreased which resulted slower drying process. The drying time taken for drying of custard apple pulp with 2 m/s air velocity were 21600, 18000, 16200 and 12600 s at 50, 55, 60 and 65 °C air temperatures, respectively. The average drying rates for convective tray drying of custard apple pulp at 2 m/s air velocity with 50, 55, 60 and 65 °C temperatures were 0.00052, 0.0006, 0.00066 and 0.0008 g water/g dry matter per sec, respectively. Dssrying of custard apple pulp occurred in falling rate period, except a short accelerating period at the beginning. It can be due to fast moisture removal from thin surface of pulp. It can be observed that drying rates were significantly higher at higher temperature and moisture content while at lower values of moistue content dryng rates were very low towards end of drying. The main reason of lower drying rates at the end of process was lower moisture migration rate from the inner layer to surface at final stage of drying process.

V. ACKNOWLEDGEMENTS

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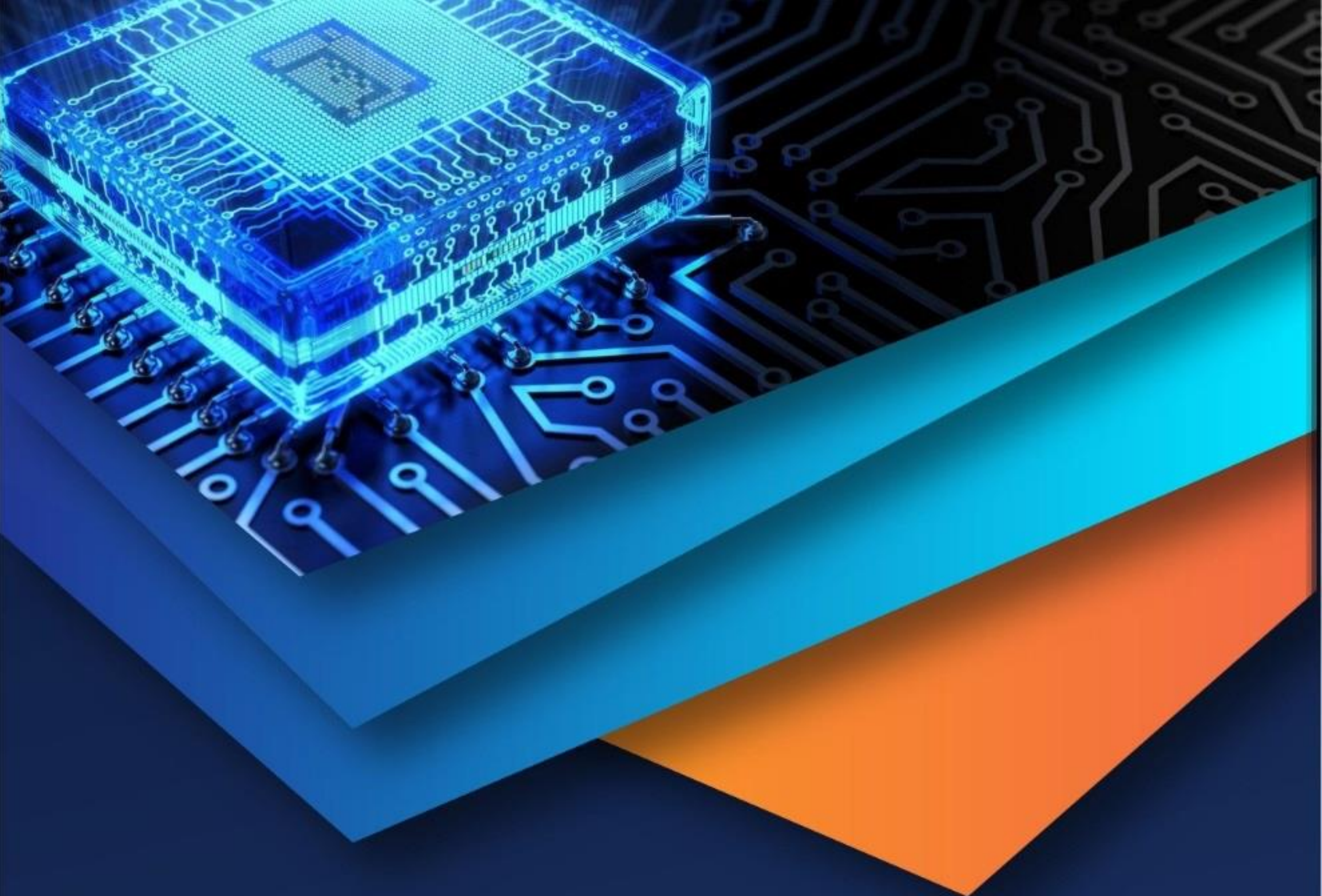

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