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Drying characteristics of osmo-convectively dried sapota slices

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ABSTRACT : Sapota is a highly productive, nutritious and tropical fruits of India contributing 1424 MT, on 160 ha area with the productivity of 8.9 MT/ha. In India, sapota is generally consumed fresh. Ripened sapota cannot be stored more than a day or two. However, it is highly perishable in nature, ripens faster and becomes unfit for consumption very soon. The post-harvest losses in sapota fruits is in the ranged from 25-30%. These losses mainly occur due to high ethylene evaluation and metabolic activity. To avoid the huge wastage, the surplus could be processed and preserved properly. Wastage of large quantities of sapota fruits before it reaches the consumer is due to poor quality transportation as well as storage facilities. One effective method of reducing this huge loss would be by converting it into various commercial sapota products like slices, powder, juice, concentrate, etc. Therefore, it is necessary to produce the final product with wholesome, soft and of acceptable quality. The products may be dehydrated, canned and refrigerated. Dehydrated fruit products have inherent advantages, such as prolong shelf-life, higher degree of resistance to bacterial attack and lower transportation, handling and storage costs. The use of faulty dehydration process causes quality defects of dehydrated fruits as tough woody texture, slow or incomplete rehydration, loss of juiciness and shrinkage. Osmotic dehydration is less energy intensive technique than air or vacuum drying process, since it can be conducted at low or ambient temperature. It is the process of water removal from a product by immersion in concentrated aqueous solution. The osmotic process prior to convective drying can be used as a pre-treatment for the dehydration of food prior to further processing such as freezing, vacuum drying, etc. Therefore, a study was proposed to investigate osmotic behaviour and drying characteristic of sapota slices under osmo-convective drying process. The optimum conditions for osmotic treatment were determined with the values of 27.72% WR and 8.25% SG for process parameters, syrup temperature of 47.36 °C, and sugar concentration of 53.53 °B for 167.85 min duration. After optimization, osmotically treated samples were dried in convective dryer at temperature 40, 50 and 60 °C. The convective drying behavior and drying characteristics was investigated for osmo-dehydrated sapota samples, at air temperature of 40, 50 and 60 °C. It was observed that the moisture content of the product was reduced exponentially with drying time and no constant rate period was observed. To determine the most suitable drying equation the the moisture ratio data of osmosed sapota dried at various air temperatures were fitted into the six thin-layer drying models. Among those two term model as best fitted for drying data. This indicated that the total mass transfer resistance was primarily due to the internal moisture diffusion within the sample

KEY WORDS : Sapota, Osmotic, Convective drying, Diffusivity, Drying rate, Moisture ratio

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Sapota is a highly productive, nutritious and tropical fruits of India contributing 1424 MT, on 160 ha area with the productivity of 8.9 MT/ha In India, sapota is generally consumed fresh (Indian Horticulture database). Ripened sapota cannot be stored more than a day or two (Jain and Jain, 1998). However, it is highly perishable in nature, ripens faster and becomes unfit for consumption very soon. The post-harvest losses in sapota fruits is in the ranged from 25-30 %.(National Horticulture Board, 2008) These losses mainly occur due to high ethylene evaluation and metabolic activity. To avoid the huge wastage, the surplus could be processed and preserved properly. Wastage of large quantities of sapota fruits before it reaches the consumer is due to poor quality transportation as well as storage facilities. One effective method of reducing this huge loss would be by converting it into various commercial sapota products like slices, powder, juice, concentrate, *etc.* (Ganjyal *et al.*, 2005). Therefore, it is necessary to produce the final product with wholesome, soft and of acceptable quality. The products may be dehydrated, canned and refrigerated. Dehydrated fruit products have inherent advantages, such as prolong shelf-life, higher degree of resistance to bacterial attack and lower transportation, handling and storage costs. Maguer (1988) enumerated the quality defects of dehydrated fruits as tough woody texture, slow or incomplete rehydration, loss of juiciness and shrinkage. These are mainly due to faulty dehydration process. Osmotic dehydration is less energy intensive technique than air or vacuum drying process, since it can be conducted at low or ambient temperature. It is the process of water removal from a product by immersion in concentrated aqueous solution. The driving force for water removal is the concentration gradient between the solution and the intercellular fluid of the product. The osmotic dehydration process may not yield a product of low moisture content enough to make it shelf stable and therefore further processing, such as air drying, vacuum drying or freeze drying is necessary (Ponting *et al.*, 1966 and Jayaraman and Das Gupta, 1992). Osmotic dehydration of fruit has several advantages *viz.*, better product quality and stability during storage and it is energy efficient process. The limitation of the osmotic dehydration process is the increase in sweetness and decrease in acidity of the product. However, it may be possible to control the rate of solute diffusion and optimize the process (Rahman and Lamb, 1991). The advantage of osmotic dehydration process for sapota necessitates the study of osmotic kinetics and air drying behaviour of osmosed product. Also, there is a need to investigate the osmo-air drying process in order to get shelf stable quality dehydrated products. Air drying leads to physical and biochemical change in the food. These changes are frequently disastrous for the product quality (browning reaction and vitamin destruction). So, to improve the product quality it is important to optimize the drying conditions. The quality of the product needs to be evaluated for the acceptance of the consumer. The functional characteristics of the final dehydrated product such as rehydration, carotene and ascorbic acid retention are essential to get better picture about the product. Hence, a new method of drying in combination of osmosis (in which partial dehydration of the fruit and to a lesser extent to vegetables) has received attention in recent years as a technique for production of intermediate moisture foods and shelf-stable foods or as a pre-treatment prior to drying in order to reduce energy consumption and heat damage. The osmotic dehydration process has been studied for many fruits and vegetables, such as apple, banana, carrot, cherry, citrus fruits, grape, guava, mango, papaya, onion, etc. The osmotic process prior to convective drying can be used as a pre-treatment for the dehydration of food prior to further processing such as freezing, vacuum drying, etc. Therefore, a study was proposed to investigate osmotic behaviour and drying characteristic of sapota slices under osmo-convective drying process to obtain quality dried products with overall following specific objectives as to study convective drying behaviour of osmotically dehydrated sapota.

■ METHODOLOGY

Convective drying of osmotically dehydrated sapota :

Osmotically dehydrated product, generally, may not have moisture content low enough to be considered as shelf stable. It is, therefore, needed it to be further air dried to obtain a shelf stable product *i.e.* stable with respect to prevention of microbial growth and enzymatic colour changes (Islam and Flink, 1982; Kim and Toledo, 1987). Hence, the product obtained from the optimized levels of the osmotic dehydration *i.e.*, with the values of 27.72% WR and 8.25% SG for process parameters, syrup temperature of 47.36 °C, and sugar concentration of 53.53 ^{o}B for 167.85 min duration was then air-dried in conventional tray drier as explained below:

Experimental setup :

A convective tray dryer was used in the dehydration experiment in this study. Tray drier consists of drying chamber, blower, heaters and thermostat. The insulating chamber consisted of air circulating fan that moved air through heaters. The drying chamber size was 150 x 100 x 40 cm accommodating 12 aluminum trays. Trays were arranged one above the other with the clearance of 3 cm in between two successive trays to permit air circulation.

Before starting an experiment, the initial moisture content of sample was determined. The instrumentation system was checked carefully and dryer was started one hour before experiments in order to reach steady state of temperature. The sapota samples were tapped manually and spread in stainless steel plates having flat surface placed in the drying trays before loading into the tray dryer. The drying temperatures were taken as 40, 50, and 60 °C at constant drying air velocity of 1.5 m/s in drying chamber. During drying, the samples were weighed at an interval of 20 minutes until the samples attained constant moisture content (EMC). At the completion of each experiment, the final moisture content of dried sample was considered as EMC.

The osmotically dehydrated sapota slices were loaded on the drying trays and inserted into the dryer. Drying data were recorded at 20 minute interval until completion of experiment.

Drying characteristics:

Drying rate :

The moisture content data recorded during the experiments were analyzed to determine the moisture lost from the samples of sapota slices in particular time interval. The drying rate of sample was calculated by following mass balance equation (Brooker *et al.*,1974).

$$\mathbf{R} = \frac{\mathbf{WML\ (kg)}}{\mathbf{Time\ interval\ (min)\ x\ DM\ (kg)}} \qquad (1)$$

where,

R = Drying rate at time θ, g w/ g, dm

WML = Initial weight of sample – Weight of sample after time θ

Moisture content during drying :

The moisture content of sapota slices during experiment at various times was determined by oven method on the basis of dry matter of sapota slices (Eqn.2) (AOAC, 1984)

$$\mathbf{MC\ (\%\ wb)} = \frac{\mathbf{W_1 - W_2}}{\mathbf{W_1}}\ \mathbf{x\ 100} \qquad (2)$$

Moisture diffusivity :

In drying, diffusivity is used to indicate the rapidness of flow of moisture or moisture out of material. In falling rate period of drying, moisture is transferred mainly by molecular diffusion. Diffusivity is influenced by shrinkage, case hardening during drying, moisture content and temperature of material (Singh and Tomar, 2000)

The falling rate period in drying of biological materials is best described by simplified mathematical Fick's second law diffusion. (Crank, 1975) as given below.

$$\frac{\partial \mathbf{M}}{\partial} = \mathbf{D}\frac{\partial^2 \mathbf{M}}{\partial \mathbf{x}^2} \qquad (3)$$

where

D = Diffusion co-efficient, m^2/s

M = Moisture content, gw/ g dm

X = Characteristic dimension *i.e.* distance from the center of the line and

t = Time elapsed during the drying, min.

For infinite plate shape geometry; The sapota slices were considered as infinite slab (as the thickness of the slices was 2.2 mm) in order to solve Eqn.3 Certain assumptions were considered in estimation of moisture diffusivity during drying process, which are given herewith as follows (Crank, 1975).

- Moisture is initially uniformly distributed throughout the mass of sample
- Mass transfer is symmetric with respect to the centre
- Surface moisture content of the sample instantaneously reaches equilibrium with the condition of surrounding air
- Resistance to the mass transfer at the surface is negligible compared to internal resistance of the sample
- Moisture transfers are by diffusion only
- Diffusion co-efficient is constant and shrinkage is negligible.

Eqn.3 can be written for infinite slab as follows;

$$\mathrm{MR} = \frac{M - M_e}{M_o - M_e} = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \exp\left[\frac{-(2n+1)^2 \pi^2 D_{eff}^t}{L^2}\right] \qquad (4)$$

where

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

MR = Moisture ratio, dimensionless

M = Moisture content, g water/g dry matter

M_0 = Initial moisture content, g water/g dry matter

M_e = Equilibrium moisture content, g water/g dry matter

L = Characteristic dimension *i.e.* thickness of slab

t = Time elapsed during the drying (s).

The equation can be simplified to the first term of the series only and results into eqn.5

$$\mathrm{MR} = \left(\frac{M - M_e}{M_o - M_e}\right) = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \exp\left(-\pi^2 \frac{D_{eff}^t}{L^2}\right) \qquad (5)$$

where,

MR = Moisture ratio, dimensionless

M = Moisture content at any time, g /g dm

M_0 = Initial moisture content, g w/g dm

M_e = Equilibrium moisture content, g w/g dm

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

L = Thickness of slab, 0.002 m

t = Time, min

Taking logarithm and rearranging the equation (Eqn.5) as.

$$\ln \mathrm{MR} = \ln\left(\frac{M - M_e}{M_o - M_e}\right) = \ln \frac{8}{\pi^2} \left(-\pi^2 \frac{D_{eff}^t}{L}\right) \qquad (6)$$

$$\ln(\mathrm{MR}) = -0.21 - \left(-\pi^2 \frac{D_{eff}^t}{L^2}\right) \qquad (7)$$

where, A is constant and B is slope.

A general form of above Eqn. could be written in semi-logarithmic form, as follows.

$$\ln(\mathrm{MR}) = A - B_t \qquad (8)$$

The experimental values of the effective diffusivity are typically calculated by plotting experimental drying data in terms of ln (*MR*) versus drying time t. It gives a straight line and the slope of the line would be used to measure the moisture diffusivity (Eqn. 9). This approach was a simplified one and shrinkage of the material was not taken into consideration, *i.e.* thickness of the material L was assumed constant throughout the drying process.

$$\mathrm{Slope} = \frac{\pi^2 D_{eff}}{L^2} \qquad (9)$$

Modeling of convective drying of sapota :

To determine the most suitable drying equations, the experimental drying data were fitted in the six thin layer-drying equations (Table A). Non-linear regression analysis was performed for the drying data by using software STATISTICA. The models were tested on the basis of co-efficient of determination (R^2) (Ozdemir and Onur Devres, 1999; Yaldiz *et al.*, 2001; Erenturk *et al.*, 2004) chi-square (χ^2), and mean bias error (M_{BE}) and root mean square error (RMSE). The R^2value should be higher for quality fit, whereas, χ^2, MBE and E_{RMS} values should be lower (Togrul and Pehlivan, 2002).The above mentioned parameters can be calculated as follows.

$$\chi^2 = \frac{\sum_{i=1}^{N} \left[\mathrm{MR}_{exp,i} - \mathrm{MR}_{pre,i}\right]^2}{N - n} \qquad (10)$$

$$E_{RMS} = \left[\frac{1}{N} \sum_{i=1}^{N} (\mathrm{MR}_{exp,i} - \mathrm{MR}_{pre,i})^2\right]^{\frac{1}{2}} \qquad (11)$$

$$M_{BE} = \frac{1}{N} \sum_{i=1}^{N} (\mathrm{MR}_{exp,i} - \mathrm{MR}_{pre,i}) \qquad (12)$$

where,

MR_{pre} = Moisture ratio of predicted data

MR_{exp} = Moisture ratio of experimental data

N = Number of observations

n = Number of model constants

Table A : Mathematical model used

Sr. No.	Name of the model	Model /equation	References
1.	Lewis	MR = Exp(-k*t)	Lui and Bakker-Arkema (1997)
2.	Page	MR = exp(–kt^n)	Page (1949)
3.	Henderson and Pabis	MR = a*Exp(-k*t)	Rahman *et al.* (1998)
4.	Logarithmic	MR = a*Exp(-k*t) +c	Doymaz (2004)
5.	Two- term	MR = a*Exp(-k*t) + b*Exp(-n*t)	Demir *et al.* (2004)
6.	Wang and Sing	MR = 1+ (a*t) + (b*(t**2))	Ertekin and Yaldiz (2004)

a, b, c, k and n = Model co-efficients t = Drying time, min

In above stated equations k, n, a, b, and c are the model co-efficients. Non-linear regression method was utilized to fit the data to the selected drying models. For evaluating the goodness of fit, three statistical indicators were used in addition to R^2. The model having the highest R^2 and the lowest root mean squares error (E_{RMS}), $\chi^2$and mean bias error (M_{BE}) was thus determined as the best model.

■ RESULTS AND DISCUSSION

The results obtained from the present investigation as well as relevant discussion have been summarized under following heads :

Convective drying of osmotically dehydrated sapota slices :

This section deals with results of various investigations pertaining to convective drying behaviour of osmotically dehydrated sapota slices. The investigations were carried out on (i) drying characteristics and (ii) estimation of effective moisture diffusivity and (iii) modelling of convective drying.

Drying characteristics :

The convective drying behaviour was investigated for osmo-dehydrated sapota slices dried at air temperature of 40, 50, and 60 ^{o}C. The experimental data are presented in Table 1-2. The variation in moisture content of osmotically dehydrated sapota slices with drying time, drying rate and effective moisture diffusivities were calculated and presented in following sections.

Variation in moisture content with time :

The typical curves showing variation in moisture content with drying time for osmotically dehydrated sapota slices dried with air temperature of 40, 50 and 60^{o}C are shown in Fig. 1. The initial moisture content of the osmotically dehydrated sapota slices was ranging 44.42 to 45.08 % (wb) for all the samples investigated and after drying upto (nearly) constant weight, the moisture content was reduced in the range of 12.06 to 25.20 % (wb) (Fig.1) (Table 1-3). It can also be observed from these curves that moisture content of sapota slices decreased exponentially with drying time under all drying conditions. Similar types of results have been reported by various researchers (Pokharkar *et al.*, 1994 and Jain

Table 1 : Drying air temperature 40 ^{o}C, IMC = 73.14%, EMC= 20.20%, Dm = 53.72 g

Time, min	Wt. of sample, g	MC (db) %	MC(wb) %	gw/g dm	MR	Ln(MR)	dM/Dt
0	200.0	272.3	73.14	2.72	1	0	1.295
20	186.1	246.4	71.14	2.46	0.897	-0.109	1.206
40	173.1	222.3	68.98	2.22	0.801	-0.222	0.992
60	162.5	202.4	66.94	2.02	0.722	-0.326	0.840
80	153.4	185.6	65.00	1.86	0.655	-0.423	0.824
100	144.6	169.2	62.85	1.69	0.590	-0.528	0.767
120	136.3	153.8	60.61	1.54	0.529	-0.637	0.721
140	128.6	139.4	58.24	1.39	0.471	-0.752	0.674
160	121.3	125.9	55.75	1.26	0.418	-0.873	0.593
180	115.0	114.1	53.30	1.14	0.370	-0.993	0.569
200	108.9	102.7	50.67	1.03	0.325	-1.123	0.557
220	102.9	91.60	47.81	0.92	0.281	-1.270	0.541
240	97.12	80.79	44.69	0.81	0.238	-1.436	0.468
260	92.09	71.43	41.67	0.71	0.201	-1.606	0.456
280	87.19	62.30	38.39	0.62	0.164	-1.806	0.411
300	82.77	54.08	35.10	0.54	0.132	-2.028	0.302
320	79.53	48.05	32.45	0.48	0.108	-2.229	0.299
340	76.32	42.07	29.61	0.42	0.084	-2.479	0.212
360	74.04	37.83	27.44	0.38	0.067	-2.703	0.141
380	72.53	35.01	25.93	0.35	0.056	-2.886	0.134
400	71.09	32.33	24.43	0.32	0.045	-3.098	0.123
420	69.77	29.88	23.00	0.30	0.035	-3.342	0.087
440	68.83	28.13	21.95	0.28	0.028	-3.562	0.084
460	67.93	26.45	20.92	0.26	0.022	-3.829	0.062
480	67.26	25.20	20.13	0.25	0.017	-4.088	-0.053

et al., 2010) for air drying of osmotically dehydrated pineapple and papaya, respectively.

The drying data of convective drying at 20 min interval was recorded, Table 1-3. It can be seen that there was a wide variation in drying time required for convective drying *i.e.* 300, 380 and 480 min at drying air temperature 40, 50 and 60 ^{o}C, respectively. It can also be seen that minimum time in drying was observed for higher air temperature (60 ^{o}C) and maximum time was recorded for low air temperature (40 ^{o}C).

The convective drying of osmotically dehydrated sapota slices followed a typical trend. As the drying air temperature increased, the drying curves exhibited steeper slope indicating that the drying rate increased with increase in drying air temperature. This resulted into substantial decrease in drying time. This is according to kinetic theory, due to the increased energy of water molecules as temperature is increased. Hence escaping of molecules becomes easier from the medium and faster. Higher temperature provide a larger water vapour pressure deficit (the difference between the saturated water vapour pressure and partial pressure of water vapour in air at a given temperature) (Prabhanjan *et al.*, 1995), which is one of the driving forces for the outward moisture diffusion process (drying).Similar behaviours were observed by Vergara *et al.* (1997) for osmotically dehydrated apple, Pokharkar (1994) for pine apple and Jain *et al.* (2011) for papaya. It can be observed from

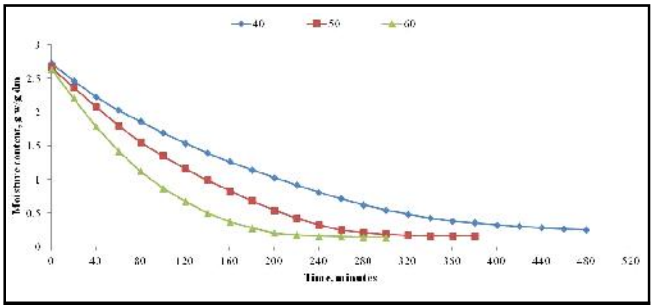

Fig. 1 : Variation in moisture content with drying time

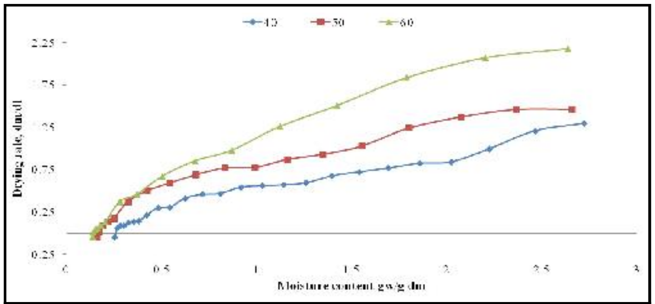

Fig. 2 : Variation of drying rate with moisture content

Table 2 : Drying air temperature 50 ^{o}C, IMC= 72.67%; FMC= 13.85%, Dm= 54.69 g

Time, min	Weight of sample, g	MC (db) %	MC (wb) %	gw/g dm	MR	Ln(MR)	dM/Dt
0	200.1	265.9	72.67	2.66	1	0	1.463
20	184.1	236.6	70.3	2.37	0.884	-0.123	1.459
40	168.1	207.4	67.48	2.07	0.768	-0.264	1.37
60	153.1	180	64.3	1.8	0.659	-0.416	1.239
80	139.6	155.3	60.83	1.55	0.561	-0.578	1.028
100	128.3	134.7	57.4	1.35	0.48	-0.735	0.93
120	118.2	116.1	53.74	1.16	0.406	-0.902	0.869
140	108.7	98.77	49.69	0.99	0.337	-1.088	0.775
160	100.2	83.27	45.44	0.83	0.275	-1.29	0.769
180	91.82	67.89	40.44	0.68	0.214	-1.54	0.688
200	84.29	54.12	35.12	0.54	0.16	-1.834	0.592
220	77.82	42.29	29.72	0.42	0.113	-2.182	0.5
240	72.35	32.29	24.41	0.32	0.073	-2.615	0.375
260	68.25	24.79	19.87	0.25	0.043	-3.137	0.174
280	66.35	21.32	17.57	0.21	0.03	-3.519	0.133
300	64.89	18.65	15.72	0.19	0.019	-3.961	0.089
320	63.92	16.88	14.44	0.17	0.012	-4.422	0.021
340	63.69	16.46	14.13	0.16	0.01	-4.572	0.022
360	63.45	16.02	13.81	0.16	0.009	-4.756	0.012
380	63.32	15.78	13.63	0.16	0.008	-4.872	-0.042

the Fig. 2 that as the drying proceeds, the moisture content of the sample decreased and the rate of drying also decreased. It can also be seen from the figure that the rate of drying was higher for high temperature of drying air. This is expected also because high temperature of drying will remove moisture quickly from the sample which resulted in high drying rate. Further, it can be seen from the figures that no constant rate period was found during convective drying of osmotically dehydrated sapota and entire drying has taken place in falling rate period.

Moisture diffusivity of sapota slices :

The moisture loss data from convective drying were analyzed and moisture ratios at 20 min time interval were determined. The moisture ratio (MR) was plotted with drying time on in order to find out moisture diffusivity for osmotically dehydrated sapota slices Fig. 3, respectively.

The variation in ln (MR) with drying time of sapota slices have been presented in Fig.3. The variation in ln (MR) with drying time for each case was found to be linear with inverse slope. At all levels straights lines were fitted satisfactory with co-efficient of determination $R^2 > 0.90$. The slope became steeper with increase in drying air temperature. Moisture diffusivities were calculated by using Eq.(7) from the slopes of these straight lines are presented in Table 4. The moisture diffusivity varied in the range of 5.39×10^{-9} m²/s to 9.80×10^{-9} m²/s. during convective drying of osmotically dehydrated sapota slices depending on drying air temperature (Table 4). These values are within the general range of 10^{-08} to 10^{-12}m²/s.

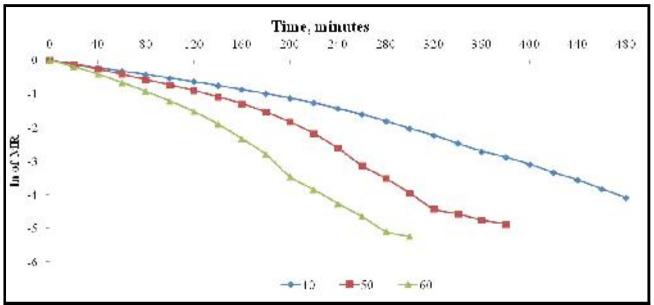

Fig. 3 : Variation in ln (MR) with drying time at different air drying temperature

Table 3 : Drying air temperature 60 °C, IMC=72.51%, EMC= 12.38, Dm= 54.99 g							
Time, min	Wight of sample, g	MC (db) %	MC (wb) %	g w / g dm	MR	Ln(MR)	dM/Dt
0	200	263.8	72.51	2.64	1	0	2.178
20	176.1	220.2	68.78	2.2	0.827	-0.19	2.069
40	153.3	178.8	64.14	1.79	0.662	-0.412	1.835
60	133.1	142.1	58.71	1.42	0.516	-0.661	1.505
80	116.6	112	52.85	1.12	0.397	-0.925	1.258
100	102.7	86.92	46.5	0.87	0.296	-1.216	0.979
120	92.02	67.34	40.24	0.67	0.219	-1.521	0.852
140	82.65	50.3	33.47	0.5	0.151	-1.892	0.673
160	75.25	36.84	26.92	0.37	0.097	-2.33	0.457
180	70.22	27.7	21.69	0.28	0.061	-2.798	0.37
200	66.15	20.29	16.87	0.2	0.031	-3.459	0.127
220	64.75	17.75	15.07	0.18	0.021	-3.847	0.091
240	63.75	15.93	13.74	0.16	0.014	-4.26	0.056
260	63.13	14.8	12.89	0.15	0.01	-4.642	0.044
280	62.65	13.93	12.23	0.14	0.006	-5.089	0.011
300	62.53	13.71	12.06	0.14	0.005	-5.241	-0.046

Table 4 : Effective moisture diffusivity of sapota slices during convective drying				
Convective drying temperature, °C	Equation of straight line	Slope (m)	Diffusivity, m²/s	R^2
40	y = -0.011x + 0.511	-0.0011	5.39×10^{-9}	0.917
50	y = -0.015x + 0.750	-0.0015	7.35×10^{-9}	0.921
60	y = -0.020x + 0.873	-0.02	9.80×10^{-9}	0.901

for drying of food materials.(McMinn and Magee, 1999)

Modelling of drying curve :

To determine the most suitable drying equation the moisture ratio data of osmosed sapota slices dried at various air temperatures were fitted into the seven thin-layer drying models (Lewis model, Page, Henderson and Pabis, Logarithmic, Two term model and wang and Singh model) in their linearized form using regression technique (Table 5). Among all these models, the best model suitable to fit the data were selected on basis of highest values of R² and the lowest value of reduced mean square of the deviation (χ^2) bias error (M_{BE}) and root mean square error (E_{RMS}), which were calculated using Eqn. (10, 11 and 12) Table 5.

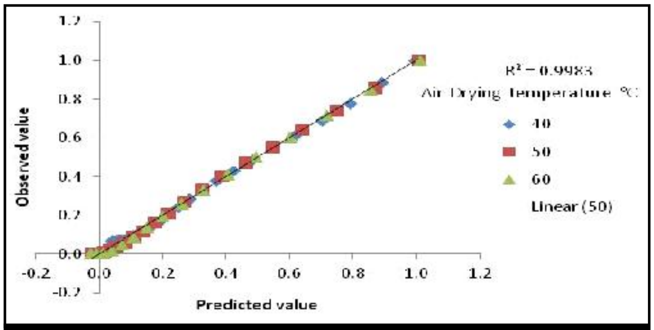

Fig. 4 : Observed verses predicted values of two - term model at various temperature

The overall statistical parameters for different models used for osmo-convective dried sapota have been presented in Table 6. The results show that the highest values of co-efficient of determination (R²) and the lowest values of root mean square error (E_{RMS}), reduced

Table 5 : Values for model constant and statistical parameters used in convective drying of osmotically dehydrated sapota fruit slices

Name of model	Air Temp. (°C)	Drying constant						Statistical parameters			
		K	N	a	B	C	d	R²	χ^2 X10^3	M_{BE}	E_{RMS} x 10^2
Lewis model	40	0.01						0.998	290.5	-0.0	0.00
	50	0.01						0.997	1508	-0.0	0.00
	60	0.01						0.989	2304	0.0	3.10
Page	40	0.00	1.06					0.998	151.6	0.0	0.00
	50	0.00	1.23					0.997	494.4	0.0	0.00
	60	1.28	0.00					0.552	2304	0.0	0.00
Hendersion and pebis	40	0.01		1.02				0.926	13354	0.0	11.19
	50	0.01		1.05				0.992	1302	0.0	4.67
	60	0.01		1.05				0.990	1943	0.0	5.40
Logarithmic	40	0.00		-188.08		188.8		0.926	13354	0.0	11.18
	50	0.01		1.13		-0.12		0.998	205.1	0.0	0.93
	60	0.01		1.18		-0.17		0.998	237.2	6.9	1.16
Two - term model	40	0.01	0.01	-3.27	4.27			0.998	116.1	0.00	1.04
	50	0.00	0.00	4.31	-3.30			0.999	149.7	0.00	0.53
	60	0.01	0.00	3.67	-2.67			0.999	179.9	-5.1	0.86
Wang and singh model	40			-0.004	6.16			0.997	431.3	0.0	2.01
	50			-0.006	0.00			0.998	232.0	0.00	0.00
	60			-0.08	0.0			0.999	75.25	0.0	0.00

Table 6 : Overall values for model constant and statistical parameters used in convective drying of osmotically dehydrated sapota sample

Name of model	Drying constant						statistical parameters			
	k	n	A	b	C	d	R2	χ^2 X10^3	E_{RMS} x 10^2	M_{BE} x 10^3
Lewis model	0.00						0.99	1368	1.03	8.16
Page	0.42	0.76					0.85	983.6	0	4.08
Henderson and pebis	50.0		1.03				0.97	5533	7.08	4.01
Logarithmic	0.00		-61.9		62.8		0.975	4599	4.42	3.6
Two - term model	0.00	0.00	1.56	-0.56			0.999	148.6	0.81	2.9
Wang and singh model			-0.00	2.05			0.999	246.2	0.67	3.46

mean square of the deviation (χ^2) and bias error was obtained for two – term model. Hence, two- term model was found to be the most satisfactory among the models to represent the thin-layer drying of sapota slices.

The selected Logarithmic model for osmo-convective drying studies was validated by comparing the predicted and observed values of moisture ratio in all drying experiment. The predicted and observed values of moisture ratio were plotted as shown in (Fig. 4) (Togrul and Pehlivan, 2002 and Erketin *et al.*, 2004)

Data sheet on convective drying of osmotically dehydrated sapota (Wankhade, 2013).

Conclusion :

With the above results it was concluded that moisture content of the product was reduced with drying time in falling rate period and moisture diffusivity varied in the range of 5.39 x 10^{-9} to 9.80 x 10^{-9} m^2/s depending on the temperature. Drying time was observed less for higher air temperature of 60 °C (300 min) and maximum in lower temperature of 40 °C (480 min). The two term model was found most satisfactory among the all this model to represent the thin layer drying of sapota slices. Sapota fruit osmotically treated at syrup temperature of 47 °C, sugar concentration of 54 °B and 168 min duration and convectively dried sample at 50 °C temperature gives highly acceptable sapota product.

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