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Thin Layer Drying Kinetics of Osmotic Treated Coconut Slices by Using Sugar Solution.

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ABSTRACT

In this study ,the eight thin layer drying models was applied to determine the suitable best model to describe the thin layer drying kinetics of both untreated osmotic dehydration of coconut slices and osmotic dehydrated coconut slices in hypertonic sugar solution. The coconut slices for both untreated osmotic dehydration of coconut slices and osmotic dehydrated coconut slices in hypertonic sugar solution were dried at various temperatures such as 50^0c, 60^0c and70^0c in a forced convection tray drier. The experimental data obtained through the experimental studies were fitted to eight thin layer drying models. The Midilli model was found to be the most appropriate one for describing the thin layer drying kinetics of the coconut slices for both untreated osmotic dehydration and osmotic dehydrated coconut slices in hypertonic sugar solution. The Fick's second law was applied to calculate the effective moisture diffusivity (D_{eff}), which varied from 6.42352x10-10 to 1.11144x 10-09 m^2/s for untreated osmotic dehydration of coconut slices and for osmotic dehydrated coconut slices in hypertonic sugar solution was found to be varied from 8.409739x10-10 to 1.295155x10-09 m^2/s. The Arrhenius type equation was used to describe the relation between moisture diffusivity and drying temperature .The D_0 and E_a for untreated osmotic dehydration was $7.907*10^{-6}$ m^2/s and 25.288 KJ/g mol and for osmotic dehydrated coconut slices in hypertonic sugar , it was $1.307*10^{-6}$ m^2/s and 19.769 KJ/g mol.

Keywords: drying kinetics, coconut slices, sugar, osmosis.

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INTRODUCTION

Drying is one of the oldest and widely used techniques for the preservation of fruits and vegetables. Drying fruit and vegetable products have certain advantages such as enhancing resistance to degradation by reducing the water activity ,increasing the shelf life ,product diversity , substantial volume reduction ,since reduce the transport cost and enhance the product quality[1-2]. Drying high moisture content material such as fruits and vegetables is a complicated process involving simultaneous heat and mass transfer [3]. Simulation models of the drying process are used for designing new, improving existing drying systems predicting the air flow over the product or even control of the product [4].

Thin layer drying models that describe the drying phenomenon of agricultural products mainly fall in to three categories, namely Theoretical, Semi theoretical and Empirical models. The first category, theoretical models include only the internal resistance to moisture transfer between product and heating air while other two categories such as semi theoretical and empirical models only take external resistance to moisture transfer between product and heating air[5]. Theoretical model requires some assumptions of geometry of a typical food, its mass diffusivity and conductivity [6]. Empirical model refuse the fundamentals of drying process and create a direct relationship between average moisture content and drying time by means of regression analysis [7]. Semi theoretical model is derived from simplification of second law of Fick's diffusion or modification of simplified models generally derives semi theoretical models .Among semi theoretical drying models ,the Newton model, Lewis , page, modified page , Henderson and pabis, logarithmic two term , approximation of diffusion , verma and midilli-kucuk models are widely used. Several researchers have investigated the drying kinetics of various agricultural products in order to evaluate different mathematical models for describing the thin layer drying characteristics. Unshelled peanuts [8], rough rice [9].

Recently many researchers investigated the thin layer drying characteristics of coconut slices in sugar solution .The present investigation was focussed on thin layer drying characteristics of coconut slices in a forced convection tray drier for both untreated and osmotic dehydrated coconut slices. In addition, the effective diffusivities and activation energy in the convective drying process of coconut slices were also calculated

MATERIALS AND METHODS

The Mature coconuts of 10 month after flowering were purchased from local market in India. The average moisture content of coconut was found to be 125.359 ± 0.003 % on dry basis. The kernel portion of coconut was taken and washed with water to remove other impurities. The kernel was cut into pieces of 5 mm thickness and 20 mm length. The cane sugar was purchased from local supermarket. Distilled water was used to prepare the osmotic medium. The concentration of sugar solution was measured by using refractometer. The initial moisture content of the coconut slices was measured by drying coconut slices in hot air oven at 105 ^{0} c for 24 hours.

Coconut slices were weighed (100 g) and then blanched at 90 °C for 2 minutes and then immersed in 2% citric acid solution to increase the shelf life of the coconut slices. The coconut slices after pre treatment it was dried in Tray drier for without treatment of osmotic dehydration of coconut slices. The coconut slices were dried in Tray drier until the constant weight is obtained. Similarly for osmotic dehydration, the coconut slices after pre treatment it was subjected to osmotic treatment in sugar solution .After treatment with osmotic sugar solution it was subjected to drying process through conventional forced convection tray drier.

Osmotic treatment with hypertonic sugar solution

The coconut slices after pre treatment steps such as blanching and immersing in 2% citric acid solution, it was partially dehydrated by osmotic dehydration process .The coconut slices were immersed in a 500 ml Erlenmeyer flask containing osmotic sugar solution. Osmotic dehydration process was performed under 61.189 wt/wt % of sugar concentration, 34.915 °C for 3.084 hours. The osmotic solution to sample ratio was maintained as 5:1. A constant agitation of 200 rpm was performed, to maintain a constant uniform temperature throughout the experiment. After osmotic dehydration, the samples were removed from osmotic sugar solution and blotted with adsorbent paper to remove the excess solution. The Experimental values obtained at this process parameter condition for response variable such as WR, SG and WL was found to be 20.852±0.051, 2.267± 0.054 and 23.119±0.085 respectively.

Drying equipment

Drying experiment was performed in a forced convection tray drier at 50, 60 and70 °C. The tray drier was operated at air velocity of 1.5 m/s which was measured using anemometer. The dryer was run without sample for about 30 minutes to set desired conditions for each drying experiment. After pre-treatment of coconut slices they were subjected to hot air drying in forced convection tray drier at 50, 60 and70 °C for without treatment of osmotic dehydration of coconut slices. Similarly, after pre treatment of coconut slices they were osmotic dehydrated in osmotic sugar solution .Then osmotic dehydrated coconut slices were also subjected to hot air drying at 50, 60 and 70 °C. Moisture loss was measured using digital balance and recorded each 5 minute interval with an accuracy of ±0.001 g for all temperature range selected for this work. Air drying was continued until the constant weight of coconut slices was obtained and there would not change any more in moisture content. The experiments were conducted with 3 replicates and average values were taken in to account.

Mathematical modelling

The development of model is essential to investigate the drying characteristics of coconut slices. In this work, the experimental drying data obtained for both without treatment of osmotic dehydration and treated with osmotic dehydration of coconut slices in sugar solution were fitted to commonly use eight thin layer drying models and listed in Table (1). The eight thin layer drying models were investigated to find the most appropriate one. In these thin layer drying models, the experimental moisture content were made non-dimensional using the equation.

$$MR = (M_t - M_e)/(M_0 - M_e) \text{----------} (1)$$

Where MR represents the dimensionless Moisture Ratio, M_t is the moisture content at any time t, M_0 is the initial moisture content and M_e is the equilibrium moisture content. In these eight thin layer drying models, for the analysis it was assumed that the equilibrium moisture content, M_e , was equal to zero .where M_e is relatively small compared to M_t or M_0.

In this present study, the non linear regression analysis was performed using the software **MAT LAB 7.0**.Totally three criteria has been applied to find the goodness of the fit of each thin layer drying models. The statistical parameters such as correlation coefficient (R^2) Chi- squared (χ^2) and the root mean square error (RMSE) were used to determine the quality and goodness of the fit. The fit showing the higher R^2 and reduced values of χ^2 and RMSE was considered as the best model to represent the experimental data . [10-13]. The χ^2 and RMSE values were evaluated as,

$$\chi 2 = \frac{\sum_{i=1}^{n}(MR_{exp,i} - MR_{pre,i})}{N - Z} \qquad \text{-----------} \quad (2)$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(MR_{exp,i} - MR_{pre,i})2}{N}} \qquad \text{------------} (3)$$

Where MR_{exp} is the i^{th} experimentally observed moisture ratio, MR_{pred} is the i^{th} predicted moisture ratio, N is the number of observations and z is the number of constants in models.

Calculation of Effective diffusivity and Activation energy

It has been accepted that the drying characteristics of fruit and vegetable products in falling rate period could be explained by Fick's diffusion equation. Crank found solution to the Fick's diffusion equation and it could be used for various regularly bodies such as rectangular, cylindrical and spherical product. The equation (4) can be applicable for particles with slab geometry by assuming uniform initial moisture distribution and for long drying time.

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

The Eq(4) can be simplified further to retain only the first term of the series and can be written as Eq.(5).

$$MR = \frac{8}{\pi^2}\exp\left[\pi^2\ \frac{D_{eff}\ t}{4L_0^2}\right] \quad \text{------------------ (5)}$$

Where D_{eff} is the effective diffusivity (m^2/s); L is the half thickness of slab (m). It could be rewritten in logarithmic form as follows .

$$MR = ln\left[\frac{8}{\pi^2}\right] - \left[\pi^2\ \frac{D_{eff}}{4L_0^2}\ t\right] \quad \text{------------------------ (6)}$$

The effective moisture diffusivity (D_{eff}) could be determined by plotting Experimental drying data in terms of ln MR versus drying time(t) in eq (6).

Calculation of activation energy

A simple Arrhenius equation was used to relate the effective moisture diffusivity with temperature and the equation is given below [14-15].

$$D_{eff} = D_O\ exp\left[-\frac{E_a}{RT}\right] \quad \text{-------------------------- (7)}$$

Where D_{eff} is the effective moisture diffusivity, E_a is the activation energy (kJ/mol), D_0 is the constant equivalent to the diffusivity at infinitely high temperature (m^2/s) , R is the universal gas constant (8.314 J/ (mol K) and T is the absolute temperature. After linearization of equation (6) .The activation energy and the constant (D_0) could be determined by plotting logarthermic effective moisture diffusivity ln($D_{eff)}$ versus inverse of absolute temperature (1/T). E_a and D_0 could be determined from the slope and intercept value obtained from the plot.

RESULTS AND DISCUSSION

The conventional forced convection tray drier was used to dry the coconut slices (100 g) of about 5 mm thickness. The initial average moisture content of the coconut slice was about 123.359±0.037 % on Dry basis. The changes in moisture content with time for every five minutes were recorded till attaining constant weight of the coconut slices at three different drying air temperatures such as 50 ^{0}c, 60 ^{0}c and 70 ^{0}c for both untreated coconut slices and treated with osmotic dehydration of coconut slices in sugar solution. The work is aimed to determine the most appropriate thin layer drying model and to calculate the effective moisture diffusivity and activation energy for the untreated coconut slices and osmotic dehydrated coconut slices at three different temperature such as 50 ^{0} c, 60 ^{0} c and 70 ^{0}c.The final moisture content obtained for the untreated coconut slices was about 4.317, 4.318 and 4.317 % (Db) at 50 ^{0}c, 60^{0}c and 70 °C respectively. The changes in moisture content with drying time for the untreated coconut slices at three different drying temperatures were shown in Fig (1). The drying time required for untreated coconut slices to reach the equilibrium moisture content was about 195, 155 and 120 minutes at 50 ^{0}c, 60^{0} c and 70 °C. The moisture ratio versus drying time was shown in Fig. (2).The equilibrium moisture content was approached fast at higher temperature 70 ^{0}c when compared with other two drying temperatures 50 ^{0}c and 60 ^{0}c with respect to drying time. Hence reduced drying time was observed with increase in drying temperature to approach equilibrium moisture content. It may be due to water vapour pressure within the coconut slices was increased at higher temperature.

The drying curve for osmotic treated coconut slices in sugar solution at selected temperature such as 50, 60 and 70 °C was shown in fig (4). The drying time for osmotic treated coconut slices in sugar solution to approach the equilibrium moisture content was found to be 125, 100 and 80 minutes at 50, 60 and 70 °C respectively. The final moisture content of osmotic treated coconut slices in sugar solution was found to be

4.802, 4.788 and 4.806 % for 50, 60 and 70 °C respectively. The Equilibrium moisture content was approached fast at higher temperature with less drying time and shown in fig (5) Moisture ratio versus drying time. Obviously, when increasing drying temperature it accelerates the drying process and hence shortens the drying time. Drying of coconut slices for both untreated osmotic dehydration of coconut slices and osmotic dehydrated coconut slices in hypertonic sugar solution occurred in falling rate period and due to fast removal of moisture, no constant rate period was observed .Similar findings have been reported by many researchers for the drying of apricots [16] and drying of red chillies [17].

Further it can be observed that the drying temperature has an important effect on the drying rate and the total drying process was found to be occurred in falling rate period only. Therefore diffusion governed for drying behaviour of coconut slices. To remove the first half of moisture at 50, 60, 70 °C, it took about 70, 50, 40 minutes for untreated coconut slices. For treated coconut slices, it took about 50, 25, 20 minutes respectively. To remove moisture further it took longer time due to slower diffusion. The rate of migration of moisture from the inner surface to outer surface decreases and hence lowers the drying rate.

When compared with untreated coconut slices and treated with osmotic dehydrated coconut slices. The drying time required to reach the equilibrium moisture content was less in osmotic treated coconut slices and shown in fig (2 & 5)

Fitting of models to the drying curves

The moisture content data obtained from the drying experiment at selected temperatures were converted into moisture ratio (MR) and fitted to the eight thin layer drying models listed in table (1).The criteria used to evaluate goodness of the fit is based on the Parameter values of R^2, χ^2 and RMSE and the drying model coefficients. The corresponding parameter values were listed in Table (2-7). It is assumed that the model which has highest R^2 and the lowest χ^2 and RMSE could be considered as the best fit. In all cases, highest R^2 values and the lowest χ^2 and RMSE values were obtained for Midilli model. The Midilli model was found to be the best one. The predicted data of moisture ratio obtained through Midilli model for drying coconut slices for both without treatment of osmotic dehydration of coconut slices and for osmotic dehydration of coconut slices in sugar solution were shown in Fig (3&6). From the figure (2,3) and (5,6),it was observed that there is good agreement between experimental values and predicted values found from Midilli model.

Determination of Effective diffusivities

The internal mass transfer resistance have ability to control the drying time therfore the falling rate drying period dominating entire process.The effective diffusivity of untreated and osmotically treated coconut slices at different temperatures was evaluated by plotting ln(MR) versus drying time and experimental data was presented in Table (8-9). The values varied from 6.42352x10-10 to 1.11144x 10-09 m^2/s for untreated coconut and for osmotically treated coconut 8.409739x10-10 to 1.295155x10-09 m^2/s. It could be obviously found that effective diffusivity increased with increase in temperature. The logarithm of D_{eff} is a reciprocal of function of temperature was plotted and shown in figure (13 &14). The results showed a linear relationship between $\ln(D_{eff})$ versus 1/T showing an Arrhenius type relationship between the diffusion coefficient and temperature. The activation energy was then found from the slope of the line .The calculated values of activation energy for untreated and osmotic treated coconut slices were evaluated as 25.288 kJ/gmol and 19.769 kJ/gmol. The R^2 for the regression was found to be 0.9988 for untreated coconut slices and treated with osmotic dehydration of coconut slices was found to be 0.9815 as shown in Fig. D_0 for untreated and treated coconut slices were found to be 7.907×10^{-6} m^2/s and 1.307×10^{-6} m^2/s.

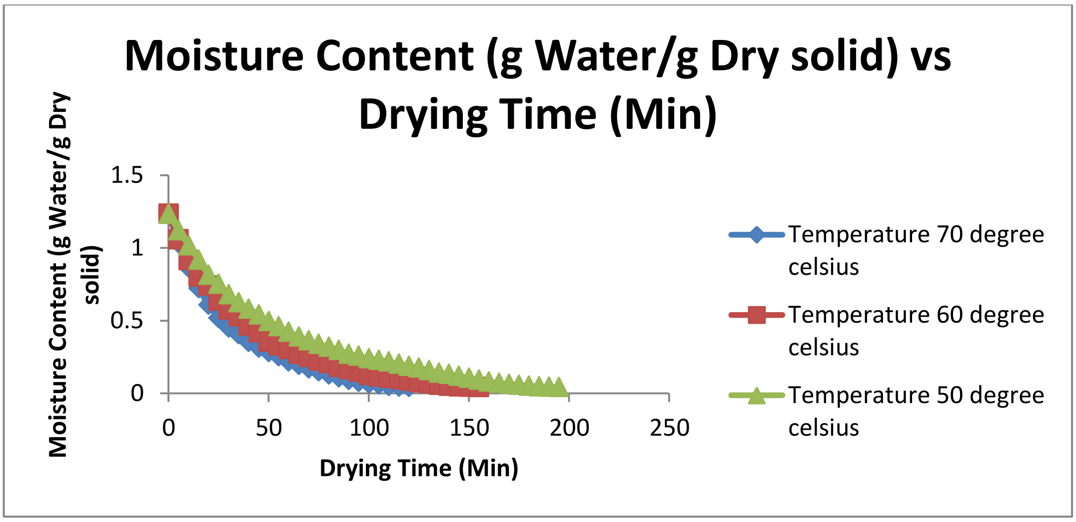

Figure 1: Thin layer drying curves for untreated coconut slices at different Temperatures.

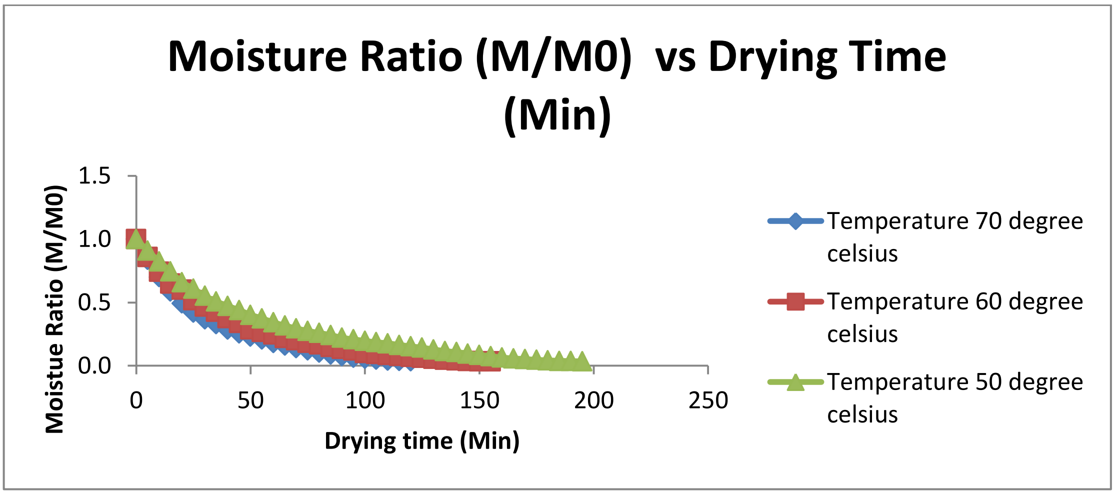

Figure 2: Experimental values of Moisture ratio versus drying time for untreated coconut slices at different temperatures.

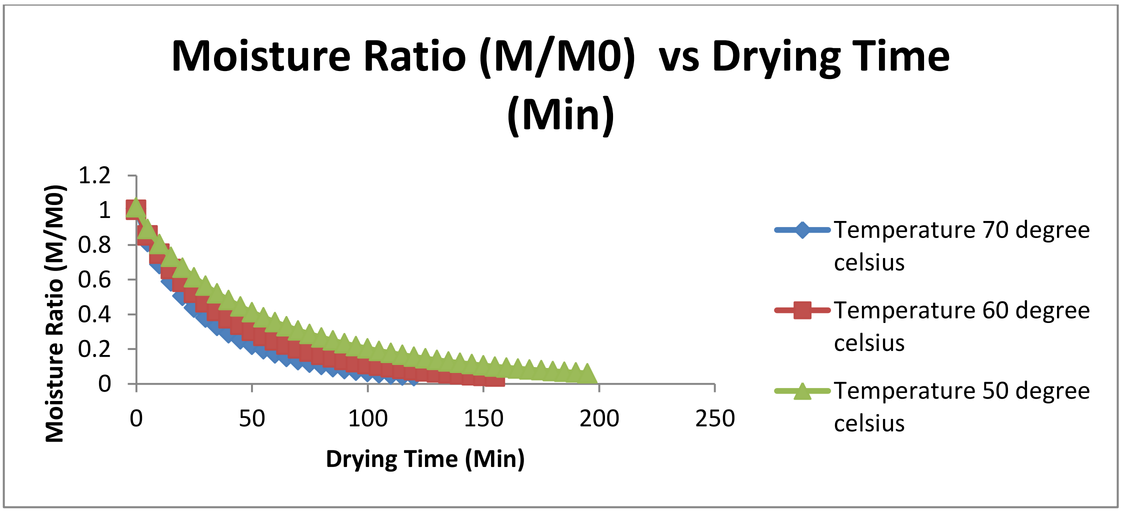

Figure 3: Predicted values of Moisture ratio versus drying time for untreated coconut slices at different temperatures

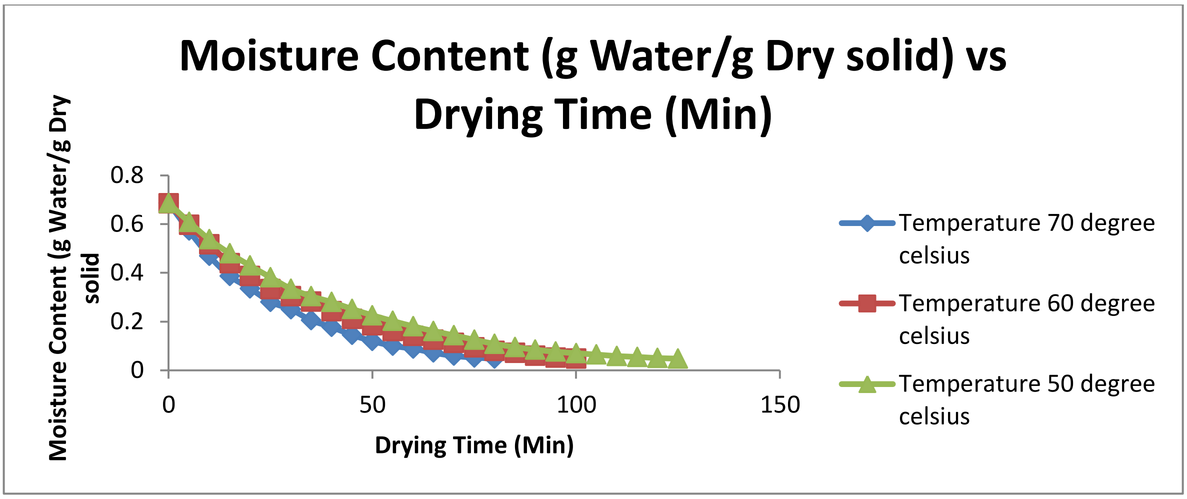

Figure 4: Thin layer drying curves for osmotic dehydrated coconut slices at different Temperatures.

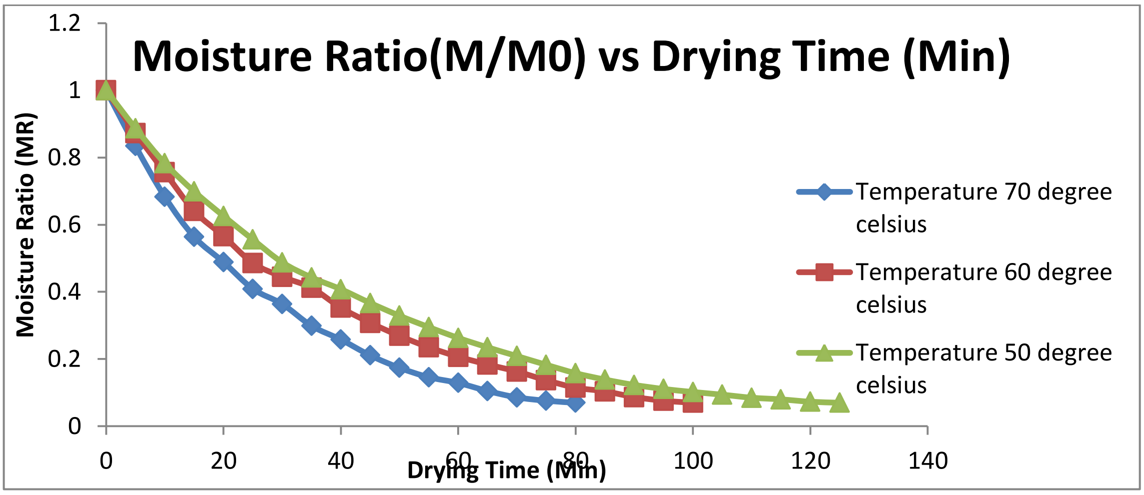

Figure 5: Experimental values of Moisture ratio versus drying time for osmotic dehydrated coconut slices at different temperatures.

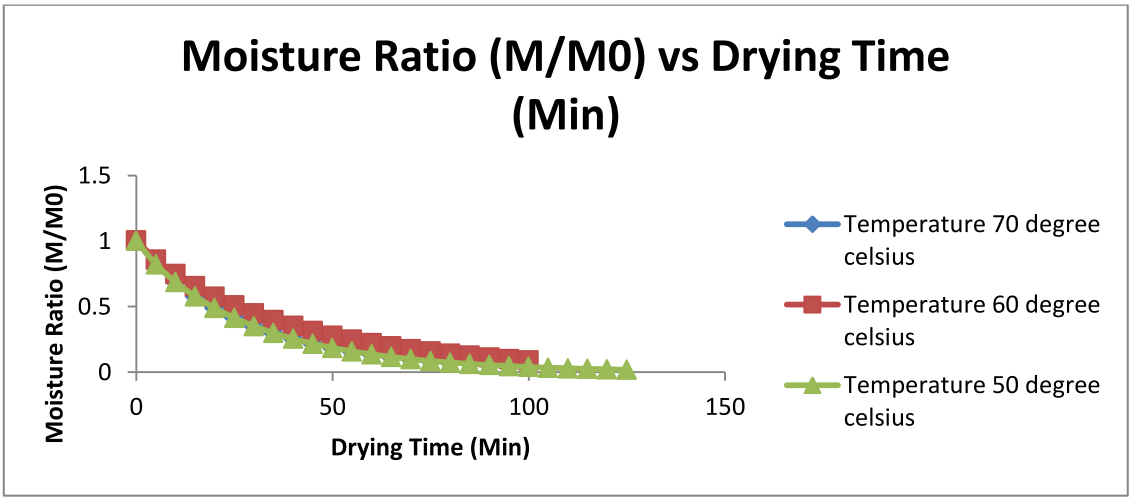

Figure 6: Predicted values of Moisture ratio versus drying time for osmotic dehydrated coconut slices at different temperatures.

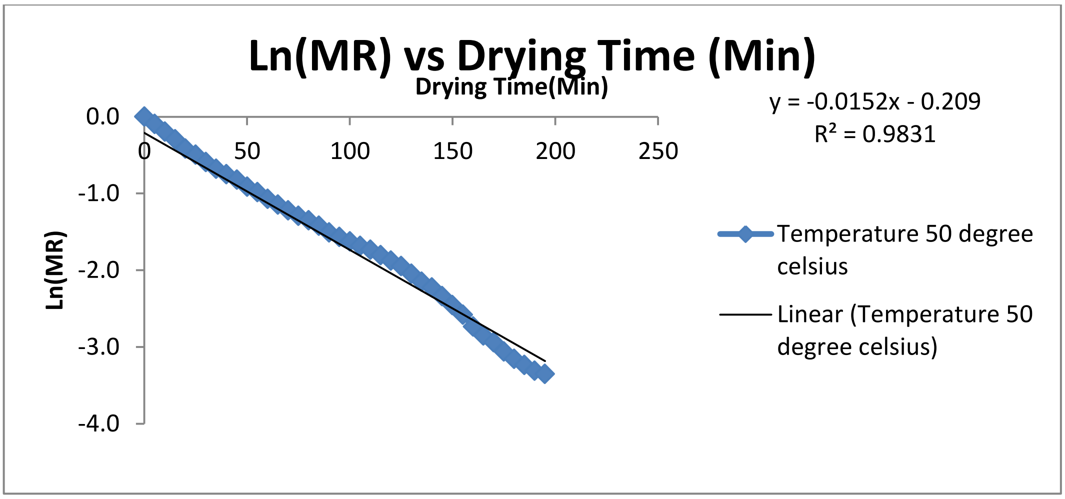

Figure 7: Logarthemic Moisture ratio vs Drying Time at 50 ^{0} c temperature for untreated coconut slices.

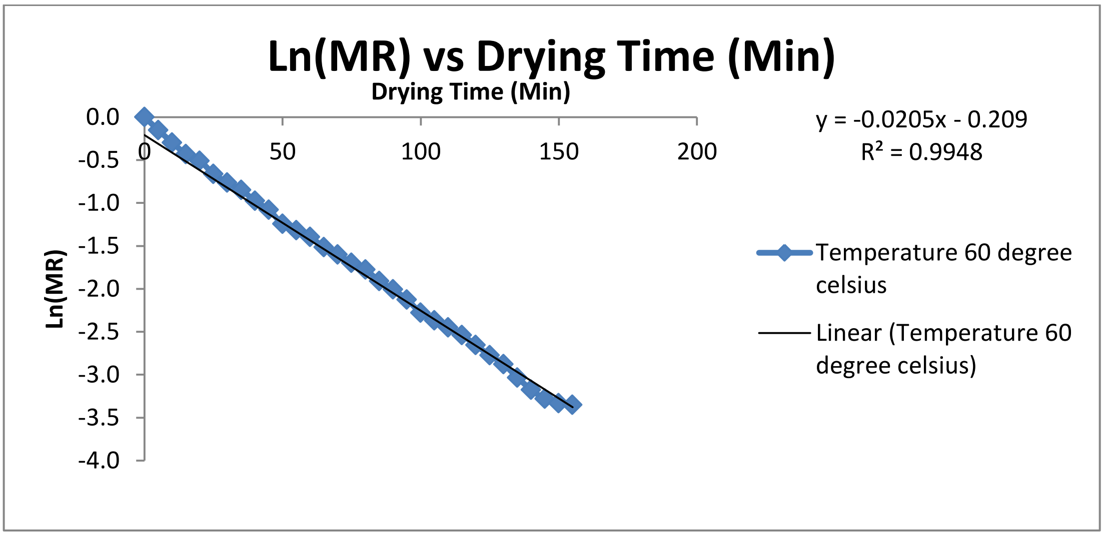

Figure 8: Logarthemic Moisture ratio vs Drying Time at 60 ^{0} c temperature for untreated coconut slices.

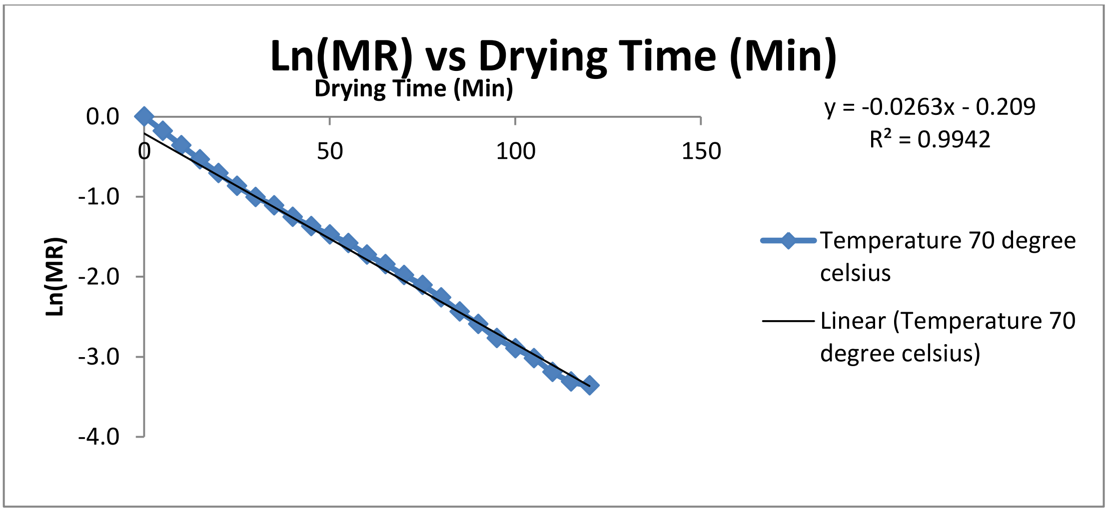

Figure 9: Logarthemic Moisture ratio vs Drying Time at 70 ^{0} c temperature for untreated coconut slices .

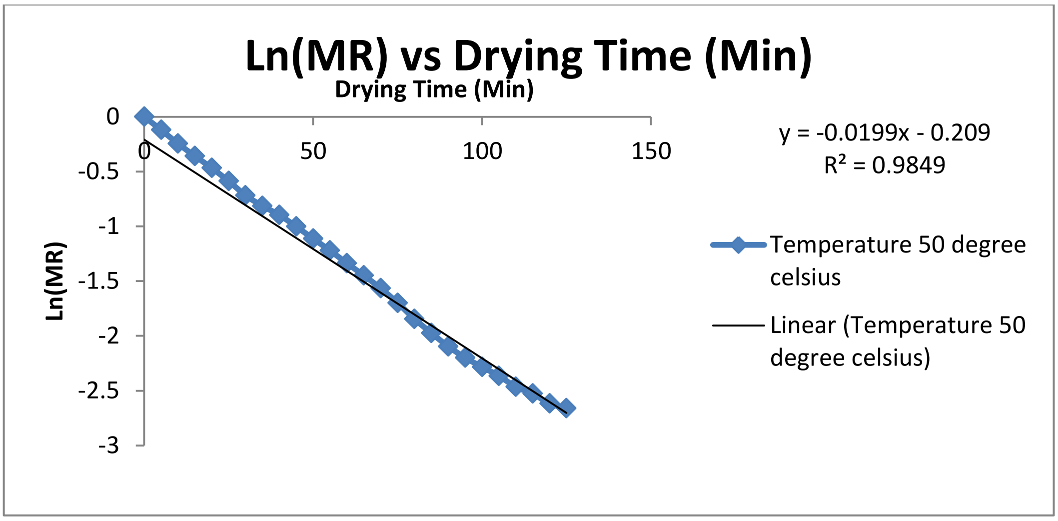

Figure 10: Logarthemic Moisture ratio vs Drying Time at 50 ^{0} c temperature for osmotic dehydrated coconut slices.

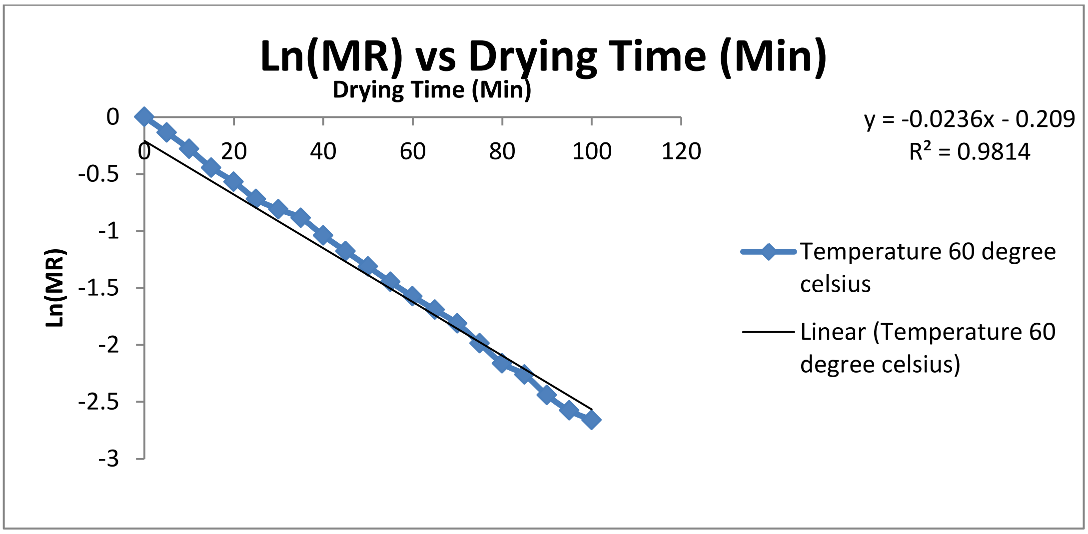

Figure 11: Logarthemic Moisture ratio vs Drying Time at 60 ^{0} c temperature for osmotic dehydrated coconut slices.

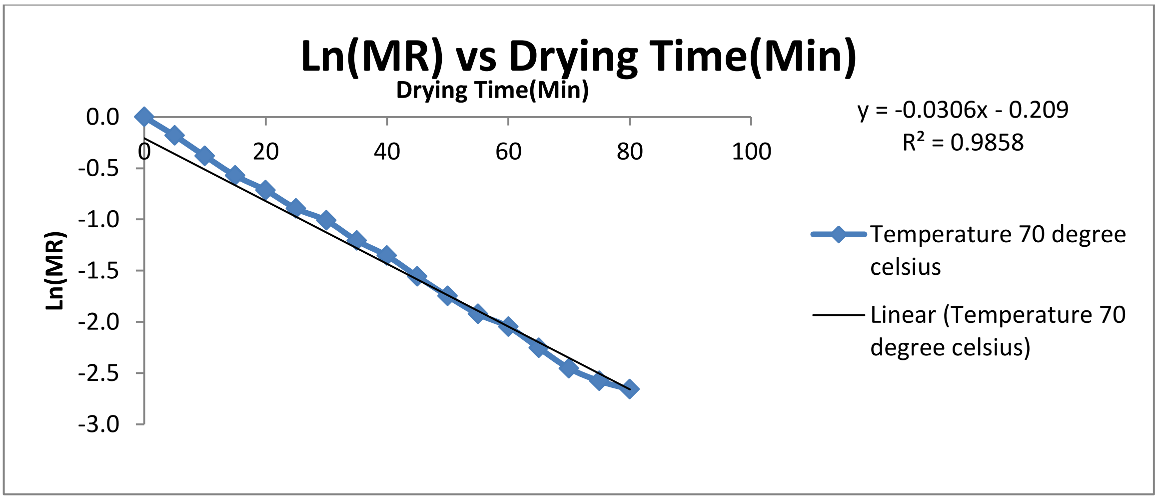

Figure 12: Logarthemic Moisture ratio vs Drying Time at 70 ^{0} c temperature for osmotic dehydrated coconut slices .

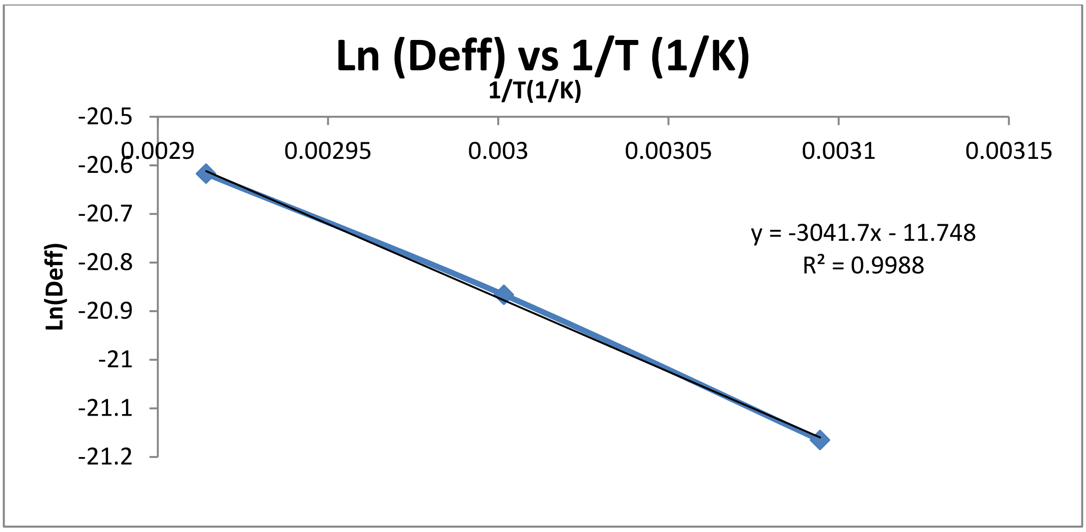

Figure 13: Arrhenious type relationship between effective diffusivity and drying temperature for untreated coconut slices .

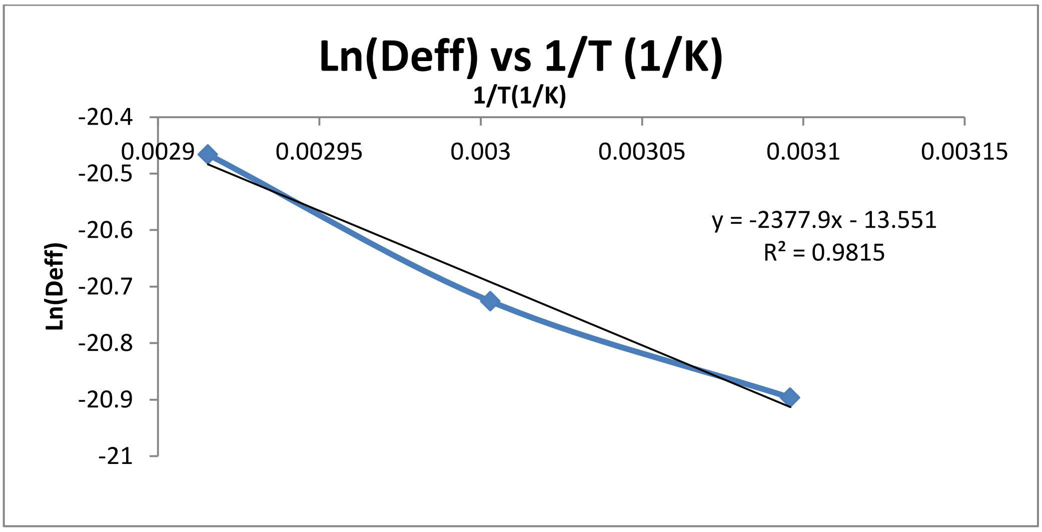

Figure 14 : Arrhenious type relationship between effective diffusivity and drying temperature for untreated coconut slices .

Table 1: Eight Thin layer Drying Models

Model name	Equation	Reference
Newton	$MR = \exp(-kt)$	[18]
Henderson	$MR = a\exp(-kt)$	[19]
Page	$MR = \exp(-kt^n)$	[20]
Wang & Singh	$MR = 1+at + bt^2$	[21]
Modified Page model	$MR = \exp(-kt)^n$	[22]
Logarthemic model	$MR = a \exp(-kt)+c$	[23]
Two term model	$MR = a \exp(-k_0 t)+b \exp(-k_1 t)$	[24]
Midilli model	$MR = a \exp(-kt^n)+bt$	[25]

Table -2: Thin layer Drying models for untreated coconut slices dried at 50 °C Temperature

Model	a	b	c	D	R^2	Chi - sq	RMSE
Newton	0.01739				0.9937	0.000272	0.01631
Henderson	0.959	0.01664			0.9959	0.000296	0.01679
Page	0.02689	0.8975			0.9983	0.000119	0.01066
Wang & Singh	-0.01254	4.123e-005			0.9476	0.003779	0.05992
Modified Page model	0.3963	0.04388			0.9937	0.000451	0.02072
Logarthemic model	0.9501	0.01784	0.02118		0.9966	0.000261	0.01554
Two term model	0.8427	0.01495	0.1668	0.06608	0.9988	0.000097	0.009353
Midilli model	1.017	0.03407	0.8356	-0.0001443	0.9989	0.000087	0.008888

Table -3: Thin layer Drying models for untreated coconut slices dried at 60 °C Temperature

Model	a	b	c	D	R^2	Chi - sq	RMSE
Newton	0.02396				0.9948	0.000360	0.0187
Henderson	0.9552	0.02283			0.9973	0.000200	0.0137
Page	0.03653	0.8932			0.9995	0.000040	0.006156
Wang & Singh	-0.01665	7.11E-005			0.9429	0.004265	0.06324
Modified Page model	0.1774	0.135			0.9948	0.000385	0.01901
Logarthemic model	0.9468	0.02451	0.02062		0.9982	0.000145	0.01149
Two term model	0.8733	0.02111	0.1269	0.1173	0.9996	0.000036	0.005659
Midilli model	1.001	0.03889	0.873	-7.268e-005	0.9996	0.000036	0.005619

Table -4: Thin layer Drying models for untreated coconut slices dried at 70 °C Temperature

Model	a	b	c	D	R^2	Chi - sq	RMSE
Newton	0.03123				0.9926	0.000543	0.02284
Henderson	0.9577	0.02983			0.9948	0.000414	0.01953
Page	0.04938	0.8755			0.9988	0.000094	0.009305
Wang & Singh	-0.02152	0.0001188			0.9346	0.005215	0.06927
Modified Page model	0.1765	0.1769			0.9926	0.000591	0.02333
Logarthemic model	0.9453	0.03322	0.03069		0.9968	0.000280	0.0157
Two term model	0.7586	0.02495	0.2476	0.09013	0.9993	0.000067	0.007529
Midilli model	1.009	0.05383	0.8507	-7.663e-005	0.9989	0.000102	0.009265

Table -5: Thin layer Drying models for osmotic dehydrated coconut slices dried at 50 °C Temperature

Model	a	b	c	D	R^2	Chi - sq	RMSE
Newton	0.02277				0.9991	0.000068	0.008096
Henderson	0.9882	0.02249			0.9993	0.000057	0.007279
Page	0.02562	0.9701			0.9995	0.000045	0.006498
Wang & Singh	-0.01769	8.524e-005			0.9853	0.001234	0.03376
Modified Page model	0.537	0.0424			0.9991	0.000073	0.008263
Logarthemic model	0.9838	0.02297	0.007596		0.9994	0.000057	0.007136
Two term model	0.9687	0.02207	0.03251	0.1436	0.9995	0.000049	0.006463
Midilli model	0.9995	0.02614	0.9628	-3.902e-005	0.9995	0.000052	0.006695

Table -6: Thin layer Drying models for osmotic dehydrated coconut slices dried at 60 °C Temperature

Model	a	b	c	D	R^2	Chi - sq	RMSE
Newton	0.02678				0.9981	0.000149	0.01193
Henderson	0.9862	0.02638			0.9984	0.000139	0.01125
Page	0.03115	0.9598			0.9987	0.000111	0.01003
Wang & Singh	-0.02109	0.0001227			0.9832	0.001480	0.0366
Modified Page model	0.4438	0.06033			0.9981	0.000165	0.01224
Logarthemic model	0.9824	0.02681	0.005944		0.9984	0.000153	0.01146
Two term model	0.9497	0.02549	0.05418	0.1364	0.9989	0.000122	0.009938
Midilli model	1.006	0.03596	0.911	-0.0002765	0.999	0.000105	0.009229

Table -7: Thin layer Drying models for osmotic dehydrated coconut slices dried at 70 °C Temperature

Model	a	b	c	D	R^2	Chi - sq	RMSE
Newton	0.03509				0.9985	0.000125	0.01086
Henderson	0.9856	0.03456			0.9988	0.000112	0.009962
Page	0.04129	0.9536			0.9993	0.000067	0.007739
Wang & Singh	-0.02729	0.0002033			0.983	0.001636	0.038
Modified Page model	0.1876	0.187			0.9985	0.000142	0.01121
Logarthemic model	0.9771	0.03588	0.01345		0.999	0.000111	0.009561
Two term model	0.943	0.03321	0.05944	0.17	0.9994	0.000077	0.007722
Midilli model	1.002	0.04385	0.9314	-0.0001507	0.9994	0.000081	0.007899

Table – 8: Effective diffusivities of coconut slices (without treatment of osmotic dehydration) at different temperatures

s.no	Temperature (^{0}C)	Deff (m^2/s)
1	50	6.4235E-10
2	60	8.6633E-10
3	70	1.1114E-09

Table – 9: Effective diffusivities of coconut slices (treatment with osmotic dehydration) at different temperatures

s.no	Temperature(^{0} c)	Deff (m^2/s)
1	50	8.4097E-10
2	60	9.9733E-09
3	70	1.2931E-09

CONCLUSION

Thin layer drying model was applied to the osmotic dehydrated coconut slices in hypertonic sugar solution and for without treatment of osmotic dehydration of coconut slices. Among eight thin layer drying models, the Midilli model was evaluated as appropriate one to describe drying process of the coconut slices for both osmotic dehydrated coconut slices in hypertonic sugar solution and for untreated osmotic dehydration of coconut slices. The effective moisture diffusivities (D_{eff}) was increased with increasing the drying temperature and it varied from 6.42352x10-10 to 1.11144x 10-09 m^2/s for untreated osmotic dehydration of coconut slices and for osmotic dehydrated coconut slices in hypertonic sugar solution , it was varied from 8.409739x10-10 to 1.295155x10-09 m^2/s . The diffusivity constant D_0 was evaluated as 7.907×10^{-6} m^2/s for untreated osmotic dehydration and osmotic dehydrated coconut slices in hypertonic sugar solution was evaluated as 1.307×10^{-6} m^2/s. The activation energy (E_a) for untreated osmotic dehydration of coconut slices and osmotic dehydrated coconut slices in hypertonic sugar solution was evaluated as 25.288 kJ/gmol and 19.769 kJ/gmol.

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