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Drying Kinetics of *Sandge*, an Indian Traditional Food Adjunct in Air Convective Drying

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Abstract— *Sandge an Indian traditional food adjunct was prepared by using standardized recipe of carrot(80%), okra(9%), green chilies(3.5%), coriander leaves(2%) , sesame seeds(3.5%) and salt (2%) in an air convective dryer. Studies on drying kinetics of sandgewere conducted at 45, 50 & 55ºC.The graph of drying rate and the drying curve revealed that drying took place in the falling rate period and increase in drying temperature accelerated the drying process.The experimental data of drying kinetics was satisfactorily fitted to four different empirical models for thin layer drying: Newton, Page, Logarithmic, Henderson& Pabis.With the selectioncriteria of high values of coefficient of determination (R^2), low values of root mean square error (RMSE) between and chi-square (χ^2), Newton's model was selected as perfect fit. Applying the model of Fickian unsteady state diffusion, effective moisture diffusion coefficient (De) was calculated.The diffusivity varied from 17.5 x $10^{-7} m^2/s$ to 1.75 x $10^{-5} m^2/s$ within the temperature range and fitted the Arrhenius equation. The molecular diffusivity at infinite temperature, Deº was estimated to be 0.038m^2/s and the activation energy for moisture diffusion, E to be 9.57k J/mol.*

Keywords—Food adjunct, drying kinetics, empirical models, molecular diffusivity.

I. INTRODUCTION

Drying is probably the oldest method for preserving foods. Ancient civilizations preserved meat, fish, fruits and vegetables using sun-drying techniques[1].Drying is considered as the complex operation which involves heat and mass transfer along with several rates of processes, like physical or chemical transformations which may result in the product quality changes[2-6].In countries like India where poorly established low temperature distribution and handling facilities are existing, drying is the alternative treatment for post- harvest management. Over 20% of world perishable crops are dried to increase the shelf life and provide food security[7].Currently hot air drying is the most widely used method in post-harvest technology of agricultural products. Using this method, a more uniform, hygienic and attractively colored dried product can be produced rapidly[8].However, this process has adverse effect on colour and quality of the processed products due to the higher temperatures and longer duration of drying[9, 10]. Kinetic parameters, such as reaction order, rate constant and activation energy could be helpful in the prediction of change in colour and quality parameters during thermal processing.The increasing demand for high-quality, shelf-stable dried productsrequires the optimization of the drying process conditions, especially temperature, with the purpose of accomplishing not only the efficiency of the process but also the final quality of the dried products[11].

Drying kinetics data of food materials has been presented by Marinos-Koulis and Maroulis[12] (1995). The effect of air temperature, air velocity, relative humidity and material size have been studied and simulation models proposed by various investigators for thin layer drying of many agricultural products[13-22][Vazquez- Vila *et al*. (2009), Mazza (1983), Bakal*et al*. (2011), Lee and Kim (2009), Abbasi and Anzari (2009), Doymaz (2007), Akpinar (2006), Krokida*et al*. (2003), Ahmed *et al*. (2001)and Kayamak – Ertekin (2002)]. Although the literature on the studies of drying characteristics of raw agricultural products is available, but few studies have been reported on the drying kinetics of processed food products.

Traditional food adjuncts in Indian cuisine include pickle, wet chutney, dry chutney, preserves, dried vegetable products such as*sandge*and*bharwanmirch*,papad, etc. *Sandge*isa dried vegetable product made by mixing grated carrots with okra, coriander leaves, sesame seeds, green chilies and salt; making it into small balls of around 2 inch. diameter and sun dried at 42-45ºC for 2-3 days . The dried balls are then fried and served.

The research was carried out to investigate the drying kinetics of *sandge*in an air convective dryer. The objectives were to study the effect of drying temperature on drying characteristics, selectthe best mathematical model and determine the effective moisture diffusivity and activation energy for*sandge*.

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II. MATERIALS & METHODS

Fresh vegetables e.g. carrot (*Daucuscarota*), coriander leaves(*Coriandrumsativum),* green chilies(*Capsicum annum*), okra (*Abelmoschusesculentus* L. Moench) of uniform maturityand quality were procured from the local vegetable market at Noida, India. All the vegetables were washed under running water till completely free of dirt, the surface water was soaked with a muslin cloth and the vegetables were stored in a refrigerator at 7-10ºC till use. Sesame seeds(*Sesamumindicum*) and common salt (Tata brand) were procured from the supermarket at Noida. Sesame seeds were also cleaned and checked for any impurities.

Dryer Set Up

A laboratory scale batch Tray Dryer (SM Scientech, Kolkata) was used for drying of *sandge* balls. The dryer contained 8 trays, loaded one above the other. The material to be dried was placed in thin layers on the trays and the trays were placed inside the dryer and hot air blown through it. Two heaters heated the air from both sides of the tray loading area. Thermostat was used to control the temperatures in the two heating zones.Dryer was started 2hrs.earlierto the start of experiment to get steady state conditions.

2.1 Preparation of *Sandge*

Standardized*Sandge* recipe of carrot(80%), okra(9%), green chilies(3.5%), coriander leaves(2%) , sesame seeds(3.5%) and salt (2%) was used in the experiments. Carrots were peeled and grated using food processor (Inalsa, India). Coriander leaves were separated from the roots and stems, dried on muslin cloth till surface moisture was soaked/evaporated and finely chopped. Both ends of the okra pods were removed and the pods were crushed in the mixer. Green chilies were separated from the stalks, chopped and ground to a paste. The vegetables were weighed and mixed well with weighed quantities of sesame seeds and salt in a large bowl. Loose balls of around 2 inchdiameter were made manually and kept on the perforated tray in the tray dryer. Each tray of size 24 cm x 33 cm contained around 20 balls weighing around 20-25g each. The trays were weighed and placed in the dryer one above the other. The drying kinetics of *sandge*was studied at three different drying temperatures 45, 50 & 55ºC. The *sandge* samples dried at the three different temperatures were weighed every hour using a digital weighing balance with 0.01g sensitivity. The relative humidity of air varied between 45-50% during the experiments. It was measured at regular intervals with hygrometer. The drying was continued till constant weight was obtained. The position of the tray was changed every 2 hrs. to allow uniform heat transfer and the balls were moved upside down to get uniform surface heating. The experiments were conducted in triplicates at each drying temperature.

2.2 Drying kinetics for *Sandge*

The drying rate curves for the three drying temperatures were obtained by plotting the drying rate against time. Also the drying curves for moisture content (kg/kg db) versus time of drying (hrs.) for the three drying temperatures were plotted to see the influence of temperature on the time required for drying.

2.3 Mathematical modelling of drying curves

The data obtained experimentally for the three different temperatures studied (45ºC, 50ºC and 55ºC) was plotted in theform of the dimensionless variable moisture ratio (MR) versus time (expressed in hours), where

$$MR = \frac{W - We}{Wo - We} \quad \text{.............. (1)}$$

With *W* the moisture content at any time *t*, *We* the equilibrium moisture content and *Wo* the initial moisture content,all expressed in dry basis (g water/g dry solids). The value of *We* was found to be relatively small as compared to *Wo*&*W*, hence the error involved in simplification was negligible[23] and the moisture ratio was calculated as

$$MR = W/Wo \quad \text{................ (2)}$$

For drying model selection, the experimental sets of (MR, *t*) were fitted to the four different empirical models from the literature, shown in Table 1. Statistical analysis of the fitting of data was carried out using XLSTAT, 2016, 0.2.

A non-linear regression procedure was used to fit the thin-layer drying models available in the literature to the experimental moisture loss data and the models were compared based on the coefficient of determination, root mean square error, and the reduced chi-square between the observed and predicted moisture ratios. The higher values for R^2 and lower values of $\chi^2$and RMSE were chosen as the criteria for goodness of fit[24].

$$R^2 = 1 - \left[\frac{\sum_{i=1}^{N} (MR_{pre,i} - MR_{\exp,i})^2}{\sum_{i=1}^{N} (\overline{MR}_{pre} - MR_{\exp,i})^2} \right] \quad \text{................ (3)}$$

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$$RMSE = \left(\frac{1}{N} \sum_{i=1}^{N} \left[MR_{pre,i} - MR_{exp,i} \right]^2 \right)^{\frac{1}{2}}$$

………………(4)

$$\chi^2 = \frac{\sum_{i=1}^{N} \left(MR_{exp,i} - MR_{pre,i} \right)^2}{N - m}$$

or $\chi^2 = (RMSE)^2 * N/N\text{-}m$

………………(5)

Where, RMSE: Root mean square error

N: No. of observations

m: No. of constants used in the thin layer models (Newton, Page, Logarithmic, Henderson and Pabis)

$MR_{pre,i}$ is the i^{th} predicted moisture ratio, $MR_{exp,\ i}$ is the i^{th} experimental value of moisture ratio.

Table.1: Empirical models for drying kinetics

S.NO	MODEL NAME	TYPE	REFERENCE
1	Newton	MR=exp(-kt)	Mujumdar[25]
2	Page	MR=exp(-kt^n)	Diamante and Munro[26]
3	Logarithmic	MR=aexp(-kt+c)	Yagcioglu*et al.*[27]
4	Henderson and Pabis	MR=aexp(-kt)	Zhang and Litchfeld[28]

2.4 Moisture Diffusivity and Activation Energy

According to Fick's second law for unsteady-state diffusion, assuming that the samples used can be approximated to cylinders,the diffusion is expressed as follows:

$$\frac{\partial W}{\partial t} = \frac{1}{r}\left[\frac{\partial}{\partial r}\left[D_e r \frac{\partial W}{\partial r} \right] + \frac{\partial}{\partial z}\left[D_e r \frac{\partial W}{\partial r} \right] \right]$$

………………(6)

whereD_e is the effective moisture diffusivity (m^2/s), *r*is thecylinder radius (m), *z* is the height (m) and *t* is the time,expressed in seconds.

Assuming uniform initial moisture content and constant diffusivity throughout the sample, the solution of eq. (6) becomes

$$\ln(MR) = \ln(4/b_1^2) + \left[-De\,(b_1^2/r^2)\ \ t \right]$$

………………(7)

which is a equation of straight line $y = y_o + ax$, where

$y_o = \ln(4/b_1^2)$

……………… (8)

$a = -De\,(b_1^2/r^2)$

……………… (9)

From the graph plotted between ln (MR) versus time, for each of the temperatures, value of D_e and b_1 was calculated.

The diffusivity varies with temperature according to Arrhenius equation as

$D_e = D_e^o \exp(-E/RT)$

………………(10)

Where D_e^o is the effective diffusivity at infinite temperature (m^2/s), E is the activation energy for molecular diffusion (J/mol), R is the universal gas constant (R= 8.314 J/ (mol) K) and T is the drying temperature expressed in Kelvin[29].

Eq. (10) can be written as

$\ln(D_e) = \ln(D_e^o) + (-E/R)\ 1/T$

………………(11)

Which is a straight line , $y' = y'_o + a'x$,

Thus by plotting $\ln(D_e)$ versus (1/T), y' and a' were calculated as

$y' = \ln(D_e^o)$

………………(12)

$a' = -E/R$

………………(13)

From eq. 12 & 13, values of D_e^o and E were calculated.

III. RESULTS & DISCUSSION

3.1 Drying kinetics

Temperature of drying is the most important factor of drying rate[20]. Hence the drying kinetics of *sandge*was studied at three different air temperatures 45, 50 & 55ºC. The drying rate was plotted against time and the drying rate curves for the three drying temperatures have been shown in Fig.1.The drying rate in the first hour of drying was 0.034, 0.048 and 0.055kg of moisture removed/hr. at 45, 50 and 55ºC respectively, which implied that air temperature has been a very important factor of drying rate for *sandge*. As seen from the graph, although the initial moisture content of the samples was quite high (92.43%), a constant drying rate period was not observed under the experimental conditions and the drying of *sandge* took place in the falling rate period which showed that diffusion phenomenon controlled the drying of *sandge.* Similar results were observed during the air-convective drying of potato, carrot, green pepper, red pepper, yellow pepper, garlic, mushroom, onion, leek, pea, corn, celery, pumpkin and tomato[20].The graph indicated that the loss of moisture was at its highest in the first half of drying; however it slowed down in the subsequent drying period. The drying rate of *sandge*during the first hour was highest at 55ºC, followed by 50ºC and 45ºC drying temperatures. After2 hrs.of drying, the values of drying rate of *sandge* dried at 45, 50 & 55ºC were almost similar. After a period of 4 hrs.,the drying rate slowed down for all the three drying temperatures, but the drying was faster at 55ºC.

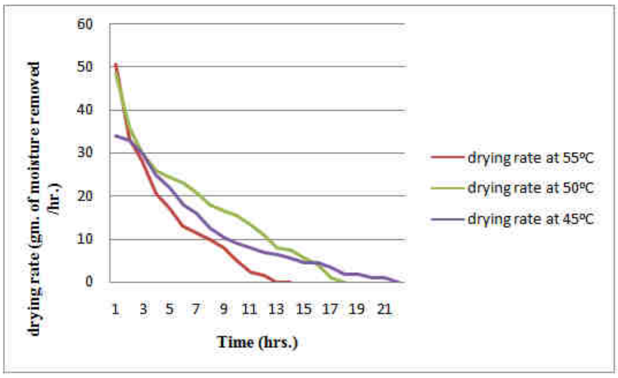

Fig.1: Drying rate curves for Sandge at 45, 50 & 55ºC

Fig.2 explains the drying curves for moisture content (kg/kg db) versus time of drying (hrs.) for the three drying temperatures. The curve was plotted to see the influence of temperature on the time required for drying. The drying time for *sandge* was 13hrs., 17hrs.and 22hrs. at 55, 50 and 45ºC.As expected, there was an acceleration of drying process due to the increase in drying temperatures from 45 to 55ºC.

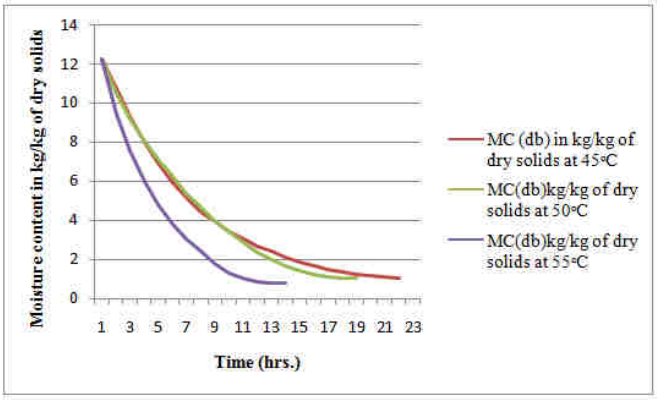

Fig.2: Drying curve of Sandge at 45,50& 55ºC

3.2 Fittings of the experimental data to empirical models

The drying kinetics data obtained for the three different temperatures, 45, 50 & 55ºC, in the form of moisture ratio (MR) versus time (hrs.) has been shown in Table2 . The data was fitted to four different empirical models: Newton, Page, Logarithmic, Henderson& Pabis. The results of such fittings, obtained with the software XLSTAT, 2016.02 for the three temperatures and for each model have been presented in Table 3-5, which show the values of the estimated parameters along with the statistical information, coefficient of determination (R^2), root mean square error (RMSE) and chi-square (χ^2).

Table.2: Moisture ratio and time at three drying temperatures (45, 50 & 55ºC) for Sandge

S.No.	Time (hrs.)	MR (45 ºC)	MR (50 ºC)	MR (55 ºC)
1	0	1	1	1
2	1	0.88	0.86	0.77
3	2	0.76	0.75	0.62
4	3	0.65	0.66	0.49
5	4	0.56	0.58	0.39
6	5	0.48	0.51	0.31
7	6	0.42	0.43	0.25
8	7	0.36	0.38	0.2
9	8	0.32	0.33	0.15
10	9	0.28	0.28	0.11
11	10	0.25	0.23	0.08
12	11	0.22	0.19	0.07
13	12	0.2	0.16	0.07
14	13	0.17	0.14	-

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15	14	0.15	0.11	-
16	15	0.14	0.1	-
17	16	0.12	0.09	-
18	17	0.11	0.08	-
19	18	0.1	0.08	-
20	19	0.09	-	-
21	20	0.08	-	-
22	21	-	-	-

The MR values are an average of triplicates

Table.3: Results of fitting to empirical models for 45ºC drying temperature (n=21)

Parameters/ Models	Newton	Page	Logarithmic	Henderson & Pabis
Estimated parameters	k=0.139	k=0.154 n=0.951	k=0.138 a=0.996 c= -0.004	k=0.138 a=0.992
R^2	0.998	0.999	0.998	0.998
RMSE	0.013	0.010	0.013	0.013
χ^2	0.000177	0.000111	0.000197	0.00018

Table.4: Results of fitting to empirical models for 50ºC drying temperature (n=19)

Parameters/ Models	Newton	Page	Logarithmic	Henderson & Pabis
Estimated parameters	k=0.144	k=0.128 n=1.057	k=0.145 a=1.004 c= 0.005	k=0.145 a=1.009
R^2	0.998	0.999	0.998	0.998
RMSE	0.013	0.011	0.014	0.013
χ^2	0.00017	0.00013	0.00023	0.00018

Table.5: Results of fitting to empirical models for 55ºC drying temperature (n=13)

Parameters/ Models	Newton	Page	Logarithmic	Henderson & Pabis
Estimated parameters	k=0.237	k=0.244 n=0.981	k=0.235 a=0.997 c= -0.005	k=0.235 a=0.992
R^2	0.999	0.999	0.999	0.999
RMSE	0.009	0.009	0.009	0.009
χ^2	0.00008	0.00009	0.0001	0.00009

Table 3-5 revealed that all the fittings were good, with high values of coefficient of determination (R^2) between 0.998 to 0.999, low values of root mean square error (RMSE) between 0.009 to 0.014 and chi-square (χ^2) between 0.00008 to 0.0001. For the drying temperatures of 45 & 50ºC, although goodness of fit was obtained for the Page model, with high values of R^2 of 0.999 each, low values of RMSE 0.010 and 0.011, χ^2 of 0.00011and 0.00013 respectively, the Newton's model was selected to be the perfect fit, since the values of n were nearly equal to 1. For 55ºC, the goodness of fit was obtained for the Newton's model, with high value of R^2 of 0.999, low value of RMSE of 0.009 and value of χ^2 of 0.00008. The very low values of χ^2 and RMSE indicated that the values predicted by the model were very close to the experimental values. Reyes *et al*. (2008) studied the drying kinetics for carrot, dried using different drying methods such as tunnel drying, vacuum-freeze drying, with or without assisted infrared radiation, fluidized bed drying assisted by microwave radiation and a combination of these methods and found that the Page's model fitted adequately to the drying process with specific parameters for each drying zone[30]. Vazquez-Vila *et al*. (2009) studied the drying kinetics of carrots in osmotic and air-convective drying processes. Experimental drying

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kinetics werefitted satisfactorily to a first order (simple model) kinetics and to the Page's model in order to determine the kinetic constants during drying[31].

3.3 Diffusion coefficient and activation energy

Fig. 3-5 and Table6 show the results of the fitting to equation $y = y_o + ax$, where $y = \ln(MR)$, $y_o = \ln(4/b_1^2)$ and $a = -De\,(b_1^2/r^2)$ and x= time. The equation was used to estimate the values of effective diffusivity, De at the three drying temperatures, 45, 50 & 55ºC. The high value of coefficient of determination, R^2 (0.996-0.997) and F value (3264.34 - 4759.38) indicated that the quality of fitting was good. Diffusivity increased from $1.75 \times 10^{-6} m^2/s$ at 45ºC to $17.5 \times 10^{-6} m^2/s$ at 55ºC.

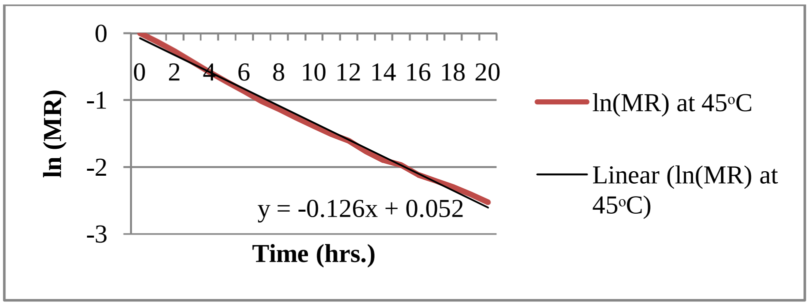

Fig. 3: Plot of ln (MR) vs. Time (hrs.) at 45ºC

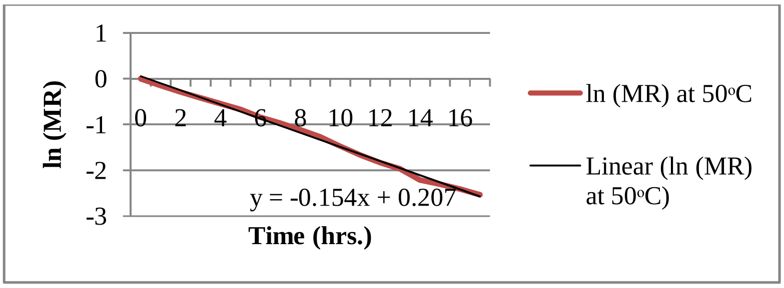

Fig.4: Plot of ln (MR) vs. Time (hrs.) at 50ºC

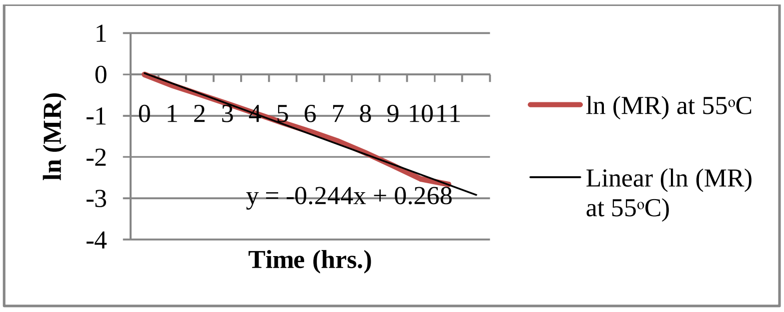

Fig.5 : Plot of ln (MR) Vs. Time (hrs.) at 55ºC

Table.6: Estimation of diffusion coefficients at three drying temperatures (45,50& 55ºC) for Sandge

Parameters/ Drying temperatures	45ºC	50ºC	55ºC
R^2	0.996	0.997	0.997
y_o	0.052	0.2077	0.2688
A	-0.1266	-0.1543	-0.2447
b_1	5.33	2.66	2.34
r(m)	0.0198	0.0198	0.0198
De (m^2/s)	1.75×10^{-6}	8.54×10^{-6}	17.5×10^{-6}
RMSE	0.051	0.049	0.051
F value	4704.67	4759.38	3264.34
Pr>F	<0.0001	<0.0001	<0.0001

The values of the diffusion coefficients were used to fit Eq. y= y'$_o$ + a'x, where y= ln(De), y'$_{o=}$ ln(De°), a= -E/R and x= 1/T. The graph was plotted between ln(De) versus 1/T and has been shown in Fig.6. The results from the graph have been presented in Table 7. The average radius of the samples was found to be 0.0198m. The high value of R^2 (0.976) and F-value (40.12) indicated that the fitting was good. The molecular diffusivity at infinite temperature, De°and the activation energy for moisture diffusion, E were determined from the graph. De° was estimated to be 0.038m^2/s and E to be 9.57kJ/mol. Doymaz (2007) reported the values of effective diffusivity of pumpkin slices to be 3.88×10^{-10} to 9.38×10^{-10} m^2/s for the thin-layer drying carried out under three air temperatures of 50, 55 and 60°C, whereas the activation energy was found to be 78.93 kJ/mol. The values of De for onion slices dried at 30, 50 and 60°C were $3.6540\times10^{-09}m^2$/s at the lowest temperature and $9.5324\times10{-}^{09}m^2$/sat the highest temperature whereas the De°was$1.1679\times10^{-04}m^2$/s, and the activation energy for moisture diffusion,E, was found to be 26.4 kJ/mol[31].

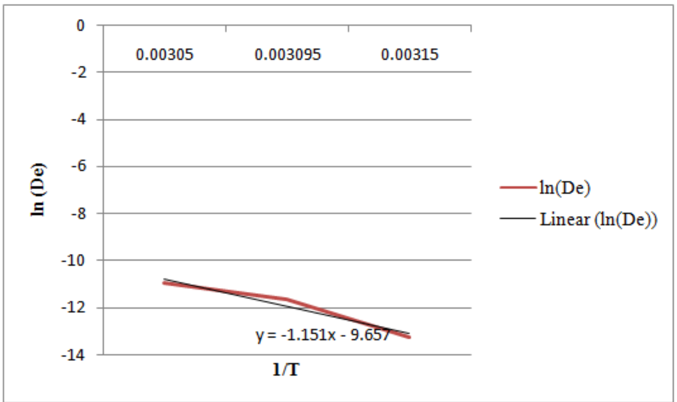

Fig.6: Plot of ln (De) vs. 1/T

Table.7: Estimation of parameters to determine diffusivity at infinite temperature,De^0 and activation energy, E

Parameter	Value
R^2	0.976
y'$_o$	-9.6574
a'	-1.1543
De^0 (m^2/s)	0.038
E (J/mol)	9.57
F value	40.12
P value	~0

IV. CONCLUSION

The drying kinetics of *Sandge,* a traditional food adjunct in India was studied for air convective drying at 45, 50 and 55°C. The drying rate curve and the drying curve were plotted. The drying rate increased with temperature and the drying time lowered. From the drying curve, it was seen that the drying took place in falling rate period and diffusion controlled the drying process. The experimental data was fitted to four different empirical models for thin layer drying, Newton, Page, Logarithmic, Henderson & Pabis. From the results, it could be verified that the models used in this study showed good predicting capacity and performance for all the three temperatures, over the entire duration of the drying process. With the selectioncriteria of high values of coefficient of determination (R^2), low values of root mean square error (RMSE) between and chi-square (χ^2), Newton's model was selected as perfect fit.Applying the model of Fickian unsteady state diffusion, effective moisture diffusion coefficient (De) was calculated.The diffusivity varied from 17.5 x $10^{-7}m^2$/s to 1.75 x $10^{-5}m^2$/s within the temperature range and fitted the Arrhenius equation. The molecular diffusivity at infinite temperature, De° was estimated to be 0.038m^2/s and the activation energy for moisture diffusion, E to be 9.57k J/mol.

REFERENCES

[1] Brennan J.G., In: *Food Dehydration: A Dictionary and Guide,* Oxford: Butterworth-Heinemann Ltd., 1994.
[2] Mujumdar,A. S., New Dehydration Technologies for Dairy and Food Products,*Indian Dairyman*, 60: 3, 2008.
[3] Bartz, J.A., Brecht, J.K., Postharvest physiology and pathology of vegetables, Series: Food Science and Technology (second ed.), CRC Press, 2002.
[4] Kader, A.A. (ed.), In: *Postharvest Technology of Horticultural Crops* (3rd Edition),UC Publication 3311, University of California, Division of Agriculture and Natural Resources, Oakland, California 94608, 535, 2002.
[5] Tindal, H.D. and Proctor, F.J., Loss Prevention of Horticultural Crops in the Tropics,*ProgFd Nat Sci*, 4 (3-4): 25-39, 1980.
[6] Kitinoja, L. and Gorny, J.R., In: *Postharvest Technology for Small-Scale Produce Marketers: Economic Opportunities, Quality and Food Safety*, UC PTRIC Horticultural Series No. 21, 1999.
[7] Grabowski, S., Marcotte, M. and Ramaswamy, H.S., Drying of fruits, vegetables, and spices. In: *Handbook of Postharvest Technology: Cereals, Fruits, Vegetables, Tea, and Spices*, Chakraverty, A., Mujumdar, A.S.,

Raghavan, G.S.V., Rawaswamy, H.S. (ed), Marcel Dekker, New York, 23:653–695, 2003.
[8] Wankhede, P.K., Sapkal, R.S. and Sapkal, V.S., Drying characteristics of okra slices using different drying methods by comparative evaluation, In: Proceedings of the World Congress on Engineering and Computer Science, October 24-26, San Francisco, USA, 2012.
[9] Alibas, I., Microwave, air and combined microwave-air-drying parameters of pumpkin slices, *LWT-Food SciTechnol*, 40: 1445–1451,2007.
[10] Maskan, M., Microwave/air and microwave finish drying of banana, *J Food Eng*, 44(2): 71-78, 2000.
[11] Banga,J.R., Balsa-Canto, E., Moles, C.G., Alonso, A.A., Improving food processing using modern optimization methods,*Trends Food Sci Tech* ,14(4): 131-144, 2003.
[12] Marinos-Kouris, D. andMaroulis, Z. B.,Thermophysical properties of the Drying of Solids. In A. Mujumdar (Ed.),Handbook of Industrial Drying. NY: Marcel Dekker, 1995.
[13] Vazquez- Vila, M.J.,Chenlo-Romero, F., Moreira-Martinez, R. and Pacios-Penelas, B., Dehydration kinetics of carrrots (*Daucuscarota* L.) in osmotic and air convective drying processes, *Span J Agric Res*, 7(4): 869-875, 2009.
[14] Mazza, G., Dehydration of carrots, Effects of pre-drying treatments on moisture transport and product quality, Int*J Food SciTech*, 18:113–123, 1983.
[15] Bakal S.B., Sharma G.P., Sonawane S.P., and Verma R.C., Kinetics of potato drying using fluidized bed dryer, *J Food Sci Tech*,49(5):608-13,2011.
[16] Lee, J.H. and Kim, H.J., Vacuum drying kinetics of Asian white Radish (*Raphanussativus* L.) slices, *LWT-Food SciTechnol*, 42: 180-186, 2009.
[17] Abbasi, S. and Azari S., Novel microwave–freeze drying of onion slices,*Int J Food SciTechnol*, 44: 974–979, 2009.
[18] Doymaz, I., The kinetics of forced convective air-drying of pumpkin slices, *J Food Eng*, 79 (1):243-248, 2007.
[19] Akpinar, E.K., Determination of suitable thin layer drying curve model for some vegetables and fruits, *J Food Eng*,73(1): 75-84, 2006.
[20] Krokida M.K., Karathanos V.T., Marinos-Kuris, D. and Maroulis Z.B., Drying kinetics of some vegetables, *J Food Eng*, 59: 391-403, 2003.
[21] Ahmed, J., Shivaghare, U.S. and Singh, G. , Drying characteristics and product quality of coriander leaves,Transactions of the Institution of Chemical Engineers, Part C, *Food BioProd Process*, 79: 103-106, 2001.
[22] Kayamak-Ertekin, F., Drying and rehydrating kinetics of green and red peppers, *J Food Sci*, 67(1): 168-175, 2002.
[23] Aghbashlo, M., Kianmehr, M. H. and Samimi-Akhljahani, H., Influence of drying conditions on the effective moisture diffusivity, energy of activation and energy consumption during the thin-layer drying of barberries fruit (*Berberidaceae*), *Energ Convers Manage*,49: 2865–2871, 2008.
[24] Demir, V., Gunhan, T., Yagcioglu, A. K. and Degirmencioglu, A., Mathematical modeling and the determination of some quality parameters of air-dried bay leaves, *Bio systems Eng*,88:325–335, 2004.
[25] Mujumdar, A.S., In: *Handbook of industrial drying*, MarckelDekker,New York, 437-562, 1987.
[26] Diamente, L. M. and Munro, P. A., Mathematical modeling of the thin layer solar drying of sweet potato slices,*Solar Energy*,51(4):271–276, 1993.
[27] Yagcioglu A., Degirmencioglu A. and Cagatay F., Drying characteristic of laurel leaves under different conditions. In: A. Bascetincelik (ed.), In: Proceedings of the 7th international congress on Agricultural Mechanization and Energy, Adana, Turkey: Faculty of Agriculture, Cukurova University, 565–569, 1999.
[28] Zhang, Q.andLitchfleld, J. B.,An optimization of intermittent corn drying in a laboratory scale thin layer dryer,*Drying Technol*,9:383–395, 1991.
[29] Akpinar, E. K., Midilli, A. and Bicer, Y.,Single layer drying behavior of potato slices in a convective cyclone and mathematical modeling,*Energ Convers Manage*,44:1689–1705, 2003.
[30] Reyes ,A., Vega ,R., Bustos, R. and Araneda, C., Effect of Processing Conditions on Drying Kinetics and Particle Microstructure of Carrot, *Drying Technol*, 26(10): 1272-1285, 2008.
[31] Guine,R.P.S., Barroca, M.J., Dias, A., Luciano, C. and Mota, C.L.,Convective drying of onion: Kinetics and nutritional evaluation, *Food Bioprod Process*, 88(2-3): 115-123, 2010.