International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319-6734, ISSN (Print): 2319-6726
www.ijesi.org ||Volume 10 Issue 1 Series I || January 2021 || PP 23-30

Evaluation of Some thin-layer Equations in the Prediction of Drying Sliced Okra *(Abelmoschus esculentus)*

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Abstract
Okra (Abelmoschus esculentu) is harvested in sufficient amount during wet season, therefore, postharvest losses increases during off-seasons because of its perishability in nature which leads to expensiveness and lost by deterioration. Drying methods can help in moisture loss (diffusion) in agricultural and biomaterials to avoidance of microbial invasion and deterioration, for elongation in shelf life, minimize packaging operations and for ease transportation. This research is Evaluation of Some thin-layer Equations in the Prediction of Drying Sliced Okra (Abelmoschus esculentus) applying convective oven dryer method at 12 varying temperatures amongst are 60, 65, 70, 75, 80, 85, 90, 95, 100, 105, 110^{0}C, and 115^{0}C and was imputed into Page, Henderson-Parbis, and Lewis models in other to predict the drying kinetics based on linearize Fick's Second law of diffusion. The temperature dependent effective diffusivity and the related activation energy was investigated as their values ranges from 1.369x10^{-7}-7.12x10^{-8}m^2/sec and 0.1235kJ/mol.k respectively which is an indication that moisture reduction from the samples increased rather sharply at the initial stages of drying became exponentially at the later stages. It is therefore, shows that drying of the Okra (Abelmoschus esculentu) took place almost entirely in the falling rate period, characteristic of drying of biomaterials. The Page model closely followed by the Henderson-Parbis' were noticed to be the best models applicable for predicting the drying behaviour of the Okra (Abelmoschus esculentu) by a non-linear regression analysis.

Key words: *Okra , drying kinetics, thin layer, activation energy, and effective moisture diffusivity.*

Date of Submission: 29-12-2020 Date of Acceptance: 10-01-2021

I. INTRODUCTION

Okra (Abelmoschus esculents (L) Monarch is an annually harvested vegetable crop belonging to malvaceae family. Okra is mostly sliced and dried and sometimes grinded into a powder form. Okra is consumed as snack, cooked and fresh vegetable addictive to soup, stew or salace. Okra is consumed in a large quantity in Nigeria (FAO 2014). Okra is a good source of carbohydrate, protein, dietary fibre, calcium, magnesium, potassium and vitamin A and C (Pendre *et al* 2012). Because of its sensitivity and essentiality to storage most fresh okra preserved in some way such as solar drying, hot air dryer, open sun dryer and ovum drying method. Solar dryer is a reciprocal to hot air and open sun drying methods mostly in a place where sunshine is favourable during harvest period (Pangavhane, Sawhney and Sarsavadia, 2002).

Okra freshly harvested have high systematic moisture content and respiratory activities whereas it can be best preserve at moisture level of 10% wet basis (Shivhare *et al* 2000). Due to the high level of moisture content of okra, okra is subjected to easily deterioration causing chemical, physical, and biological damage. Drying helps in reducing postharvest losses of fruits and vegetables, particularly those that have moisture content as high as 70% (Guan *et al* 2013). Drying lengthen the shelf life of agricultural product without addictive of any form of preservative and it assists in size reduction during packaging and reduce cost of transportation (Figiel 2010). Drying does not only reduce moisture content but also affect its organoleptive properties, enzymative activity, rheology properties, hardness and microbial spoilage.

The two most common type of drying are sun drying and hot air drying and they are different types of disadvantages that are not hygienic and not desirable for food industry (Soysal and Oztekin 2001). Oven drying method is a good alternative method. It has a space capacity, hygienic condition, time saving, precise control system, energy saving, easy setup and shutdown. It reduces drying time and stop food from being decomposing (Maskan 2000). It's applied to numbers of agricultural products such as banana (Masken 2000), Spinads (Ozkan *et al* 2007). As shown in Plate 1.

Preservation, drying has been a method to pro-long it shelf life to prevent deterioration but improved and maintained it quality. Severally, several publication has been published on drying of biomaterials, they include egg plant (Ertekin and Yaldiz., 2004), mud snail meat (Burubai and Bratua., 2015), Green pepper and Onion (Yaldiz and Ertekin, 2001), Soyabeans (Gely and Santalla, 2000), apple (Wang *et al*; 2006), palm weevil (zibkere and Egbe 2019) and African nutmeg (Burubai and Etekpe, 2014). This research work is Evaluation of Some thin-layer Equations in the Prediction of Drying Sliced Okra *(Abelmoschus esculentus).*

Plate.1 A Picture of Sliced Okra (Abelmoschus esculents (L) Monarch

II. MATERIALS AND METHOD

Okra *(Abelmoschus esculentus)* was harvested fresh from Ondewari town market Southern Ijaw local government area of Bayelsa state. The sample was taken to the food processing laboratory in Niger Delta University, Bayelsa State Department of Agricultural and Environmental Engineering in other to study their drying kinetics Okra *(Abelmoschus esculentus)* was measured with vanier caliper with equal thickness of $13\times \mathbf{10}^{-3}$m and was weigh with top digital balance which initial weight was taken as 29.85grams and was oven dried using (WTC binder oven Model WTCB 1718). The samples of equal weight and thickness were measured and oven dried at varying temperatures from 60^0C-115^0C with an increment of 5^0C. The initial moisture content of the samples was then determined by the oven method as recommended by ASAE standard (S368 41 2000). The samples were studied and experimental data and predicted data were calculated accordingly from the beginning of the drying experiment at every 5mins to when its equilibrium moisture content took place. The method of drying employed in this research was oven drying method. This method was also applied by Jittanit, (2011) for pumpkin seeds and grape seeds (Robert *et al*, 2008). The drying test was replicated thrice at each temperature levels and averages were recorded.

2.1 Estimating Effective Diffusivity, D_e

Fick's second law of moisture diffusion was used in this technical research in a permeable media and was adapted in the method of drying as reported by (Crank, 1975)

$$\frac{dM}{dt} = De\left[\frac{d^2 M}{dr^2}\right] \quad (1)$$

where

M = moisture content at time t, kg_{H_2O}/kg_{solid}

t = drying time, min.

r = radius of an equivalent sphere (distance from the core to the surface), mm

D_e = effective diffusivity, mm^2/min.

The moisture ratio prevalent in the drying system can be expressed as [Sahey and Singh 2005]

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

where

M_e = equilibrium moisture content (emc), kg_{H_2O}/kg_{solid}

M_o = initial moisture content, kg_{H_2O}/kg_{solid}

M = moisture % (db) at any time, t during dehydration process

In calculating the effective moisture diffusivity (Deff) the application Fick's second law equation of diffusion was used. However, constant moisture diffusivity infinite slab geometry and a uniform initial moisture distribution were taken into consideration in equation (5).

$$\frac{\partial M}{\partial t} = \nabla.\left(D_{eff}\nabla M\right) \quad (3)$$

where

M is the moisture content (kg water/kg dry mater), t is the drying time, and D_{eff} is the effective diffusivity (m^2/s).

In order to resolve the partial differential equation, it's taken that

i. equal thickness and length during drying
ii. heat transfer between the sampled material and drying air is equilibrium
iii. the initial "M" is uniform continuity amidst the material

Equation (3) can be deduced for standard geometric in cylindrical for the specimen equation (4) using boundary condition [Crank, 1975]

$$MR = \frac{M-M_e}{M_o-M_e} = \frac{8}{\pi^2}\int_{n=1}^{\infty}\frac{1}{(2n-1)^2}e^{-(2n-1)^2\frac{\pi^2 D_e t}{l^2}} \qquad (4)$$

Giving n = number of cylindrical surfaces

It can be observed that (2n - 1) = $\varepsilon^2{}_n$ as the root of a related Bessel function.

And for a cylindrical geometry, L = R_c = radius of cylinder,

Then equation 4 will give

$$\mathrm{MR} = \frac{\mathrm{M} - \mathrm{M_e}}{\mathrm{M_o} - \mathrm{M_e}} = \int_{n=1}^{\infty}\frac{1}{\varepsilon^2{}_n}e^{-\varepsilon^2{}_n\left(\frac{\pi^2 D_{eff}\, t}{R_c{}^2}\right)} \qquad (5)$$

Taking only the first term rendering others as negligible, equation 5 can reduce to [Zogzas et al., 1996]

$$\mathrm{MR} = \frac{\mathrm{M} - \mathrm{M_e}}{\mathrm{M_o} - \mathrm{M_e}} = \frac{4}{\varepsilon_{z1}}e^{-\varepsilon_{2n}\left(\frac{D_{eff}\, t}{R_c{}^2}\right)} \qquad (6)$$

where

MR = moisture ratio

Taking natural log on both sides, equation 6 will linearize to

$$\ln(\mathrm{MR}) = \ln\frac{4}{\varepsilon^2{}_n} - \varepsilon^2{}_n D_{eff}\left(\frac{1}{R_c}\right)^2 t \qquad (7)$$

The effective diffusivity, D_e in the drying system can then be deduced from the slope of the plot of ln(MR) versus drying time, t with intercept $\ln\frac{4}{\varepsilon_{2n}}$ [Guine et al., 2011]

$$D_{eff} = \frac{Slope\ of\ plot\ [R_c{}^2]}{\varepsilon^2\, n} \qquad (8)$$

And from equation 2, if values of M_e are small in relation to values of M and M_o (assumed to be zero) in [Roberts et al 2008] then the equation would reduce to

$$\mathrm{MR} = \frac{\mathrm{M}}{\mathrm{M_o}} \qquad (9)$$

2.2 Activation Energy

Arrhenius equation was used to calculate the activation energy as shown in equation (11)

$$D_e = D_o(e^{-E_a/Rt}) \qquad (10)$$

where

E_a = activation energy, kJ/mol
D_e = effective diffusivity at t°K, m^2/s.
D_o = pre-exponential factor of the Arrhenius equation at 0°K, m^2/s.
R = universal gas constant (8.314 x 10^{-3}, kJ/mol.K).
t = air temperature expressed in °K

Simplification of (10) gives

$$\ln D_e = \ln D_o - \frac{E_a}{R}t^{-1} \qquad (11)$$

or

$$-\frac{E_a}{R}t^{-1} = \ln D_e - \ln D_o \qquad (12)$$

or

$$\frac{E_a}{Rt} = \ln\left(\frac{D_o}{D_e}\right) \qquad (14)$$

$$\frac{E_a}{R}t^{-1} = \ln\left(\frac{D_o}{D_e}\right) \qquad (15)$$

Plotting of $\ln D_e$ as a function of t^{-1} will be linear with intercept, $\ln D_o$ and slope, $-\frac{E_a}{R}$; hence the activation energy can be estimated as [Navneet et al., 2012].

$$E_a = \text{-ve slope}(R) \qquad (16)$$

2.3 During Evaluation

Mathematical models in evaluating the characteristic of o agricultural bio-materials during drying in technical literature, different of such are listed in Table I, amongst which page, Henderson and Lewis model are chosen for experimentation in this work on sliced Okra.

Table 1: List of Thin-layer Drying Models with References (Source [24])

S/No.	Title of Model	Model Expression	Reference
1	Lewis	$MR = \exp(-kt)$	[Kingly et al., 2007]
2	Wang & Singh	$MR = 1 + at + bt^2$	[Wang et al., 1978]
3	Page	$MR = \exp(-kt^n)$	[Page, 1948]
4	Logarithmic	$MR = a\exp(-kt) + c$	[Togrul and Pehlivan, 2003.]
5	Henderson & Pabis	$MR = a\exp(-kt)$	[Henderson and Pabis 1961]
6	Two Term	$MR = a\exp(-k_0t) + b\exp(-k_1t)$	[Hodge and Taylor 1999]
7	Verma	$MR = a\exp(-kt) + (1-a)\exp(-gt)$	[Hii 2009]
8	Hii, Law & Cloke	$MR = a\exp(-kt^n) + c\exp(-gt^n)$	[Yaldiz 2001]
9	Approximation of diffusion	$MR = a\exp(-kt) + (1-a)\exp(-k\,a\,t)$	[Verma 1978]
10	Simplified Fick's	$MR = a\exp(-c(t/L^2))$	[Diamente and Munro 1993]
11	Midilli–Kucuk	$MR = a\exp(-kt^n) + bt$	[Midilli 2020]
12	Modified Page -II	$MR = \exp(-c(t/L^2)^n)$	[Diamente and Munro 1993]

2.4 Statistical Analysis

Non- linear regression equation was used to determine each constant of selected statistical model in other to obtain the best model for experimental data that described the drying curves. The best suitable and most appropriate of the selected model was examined from reduced chi-square (X^2), root mean square error (RMSE), coefficient of determination (R^2) and mean bias error (MBE). The higher the values of R^2 (proximity to one), the lower the values of (X^2) and the RMSE (proximity to zero) ascertained the goodness of fit (McMinn, 2006). These evaluation criteria methods can be determined as

$$X^2 = \sum_{i=1}^{n} \frac{(MR_{pre} - MR_{exp})^2}{N-K} \quad (17)$$

$$MBE = \frac{1}{N}\sum_{i=0}^{n}(MR_{Pred} - MR_{exp}) \quad (18)$$

$$RMSE = \frac{1}{N}\sum_{i=0}^{n}(MR_{Pred} - MR_{exp})^{1/2} \quad (19)$$

III. RESULTS AND DISCUSSIONS

3.1 characterizing Drying Kinetics

The moisture ratio of the sample was determined from the drying data (moisture ratio) collected plotted against time as shown in figure1

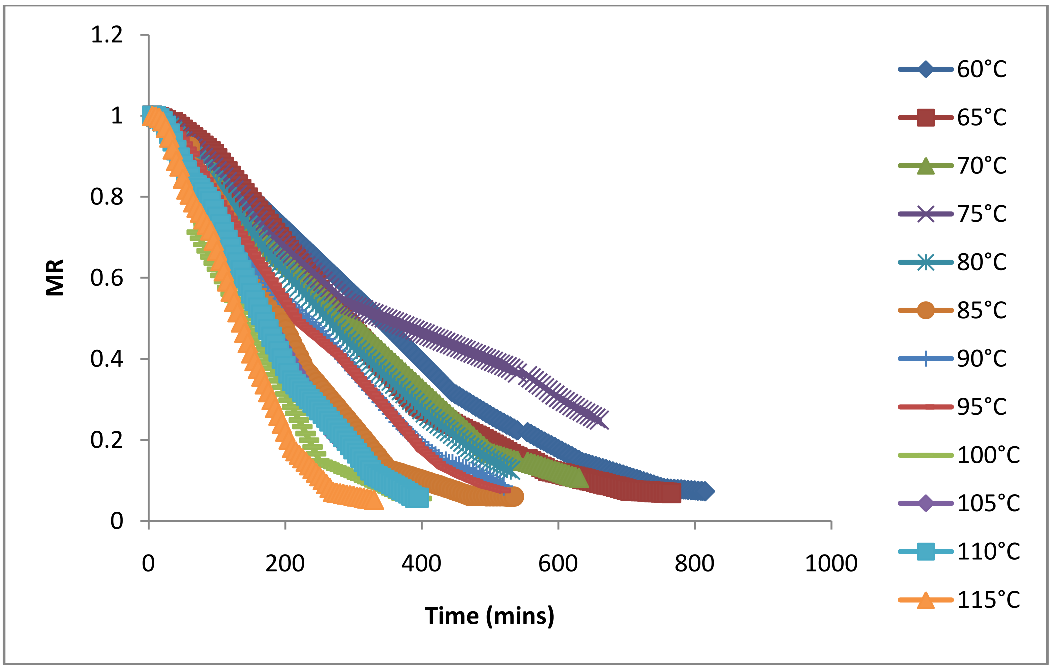

Figure 1: Moisture ratio for Okra *(Abelmoschus esculentus)* at different temperature

Experimentally, from figure 1 shows that the higher the temperature, the shorter the time of drying. It has proof clearly like other Agricultural biomaterials, the drying of Okra *(Abelmoschus esculentus)* falls mainly under the falling rate period. This indicated that, the drying rate of Okra *(Abelmoschus esculentus)* was basically controlled by internal diffusion. Similar results had been published by other scientists on different biomaterials and food products (Doymaz, 2004, Kilic, 2009, Burubai and Etekpe, 2014, Davies et al., 2020).

3.2 Statistics for Goodness of Fit

The statistical parameters are useful in analysing experimental results. The statistical parameters considered in this work are coefficient of determination (R^2), mean square error (MSE) reduced chi-square (X^2) mean bias error (MBE) as shown in Table 1 below. The R^2 values according to the models were recorded in the range of 0.9775-0.999 for page model, 0.9632-0.9908 for Henderson model and 0.9568-0.9908 for Lewis model. The MSE values ranging from 0.00158-0.0661 for page, 0.1366-1.7011 for Henderson, and 0.2771-1.0499 for Lewis model. It shows that page has the lowest MSE value and the reduced Chi-square value (X^2) closer to 0 which ranging from 0.000158-0.00109 while Henderson model ranging from 0.018954-2.984027, 0.0175-1.1193 for Lewis model. Therefore page model been the lowest MSE and (X^2)-value closest to zero is considered to be the best model predicting the drying behaviour of Okra *(Abelmoschus esculentus)*. Thus a relationship between measured and predicted moisture ratios is as shown in Fig 2 and since the moisture ratio values are banded or clustered along the straight line of the graph, it is an indication of good fitness of the page model in describing the drying characteristics of Okra *(Abelmoschus esculentus)*

Table 1 Statistical results of the model for Okra *(Abelmoschus esculentus)*

MODEL	Temp (0°C)	a	n	k	R^2	MBE	X^2	RMSE
	60		0.000116	0.6522	0.9984	0.00324	0.0017115	0.041113
	65		0.000098	1.5646	0.9999	0.00107	0.000158	0.000497
	70		0.00015	1.5813	0.9928	0.004041	0.001617	0.001584
	75		0.000466	1.2411	0.9866	0.00127157	0.0002135	0.0144982
Page	80		0.000391	1.3564	0.9986	0.00318957	0.0010991	0.0328386
	85		0.000264	1.5096	0.9969	0.00380728	0.0015805	0.03938278
	90		0.000294	1.4488	0.9831	0.00370566	0.0014561	0.03779004
	95		0.000196	1.5252	0.9932	0.00367881	0.0014216	0.03733583
	100		0.000146	1.7055	0.9773	0.007029	0.004054	0.06287
	105		0.000219	1.5859	0.9926	0.006028	0.002909	0.053242
	110		0.000224	1.5828	0.9924	0.00602343	0.0029407	0.00286625
	115		0.000141	1.7567	0.9845	0.008138	0.0045076	0.066114
	60	1.3867		0.0035	0.9785	0.046852	0.357864	0.59449
	65	1.3668		0.004	0.9980	0.057671	0.508961	0.708675
	70	1.4718		0.0057	0.9568	0.077861	0.600422	0.766839
	75	1.0251		0.002	0.9908	0.011982	0.018954	0.13661
Henderson	80	1.2535		0.0039	0.9733	0.034978	0.132178	0.360117
	85	1.4262		0.0063	0.9821	0.109182	1.29915	1.129389
	90	1.2807		0.0047	0.971	0.049164	0.2563031	0.501372
	95	1.3795		0.0052	0.9632	0.064182	0.432696	0.651379
	100	1.384		0.0083	0.9867	0.136963	1.539193	1.225036
	105	1.4799		0.0074	0.9644	0.107364	0.922776	0.948217
	110	1.4736		0.0074	0.9639	0.108609	0.956089	0.965342
	115	1.5909		0.0104	0.97	0.209386	2.984027	1.701059
	60			0.0035	0.9785	0.418864	0.176543	0.418864
	65			0.004	0.9980	0.509274	0.261089	0.509274

	70	0.0057	0.9568	0.505459	0.25815	0.505459
	75	0.002	0.9908	0.132048	0.01757	0.132048
	80	0.0039	0.9733	0.277107	0.07752	0.277107
Lewis	85	0.0063	0.9821	0.780531	0.614976	0.780531
	90	0.0047	0.971	0.381507	0.146961	0.381507
	95	0.0052	0.9632	0.459624	0.213325	0.4596624
	100	0.0083	0.9867	0.873075	0.771909	0.873075
	105	0.0074	0.9644	0.623686	0.394036	0.623686
	110	0.0074	0.9639	0.63859	0.413026	0.63859
	115	0.0104	0.97	1.04993	1.1193126	1.04993

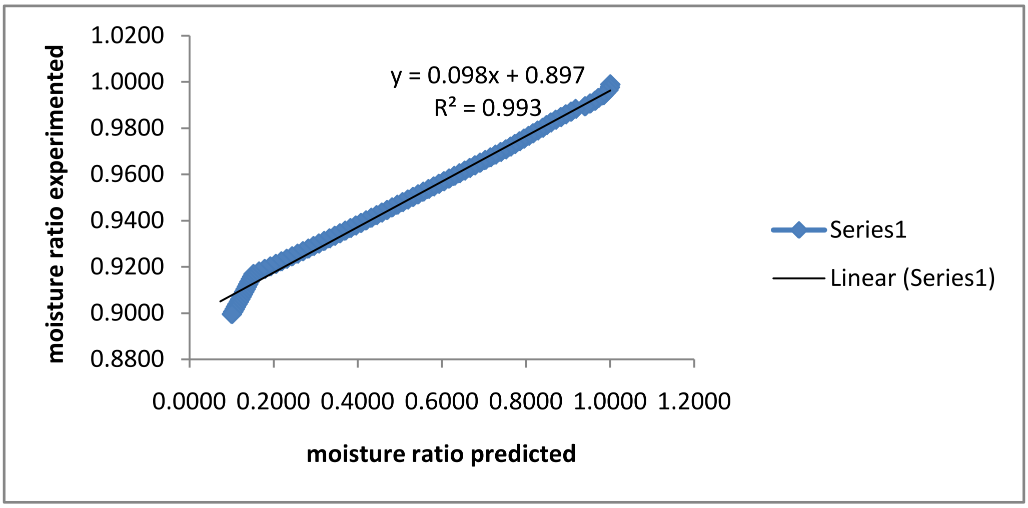

Figure.2. Relationship between experimental and Predicted moisture ratio

3.3 Effective Moisture Diffusivity

This was evident that moisture diffusivity increased when the drying temperature was increased and the kinetics could be as a result of higher temperatures affecting the activity of water molecules, causing higher moisture diffusivity. Similar results were reported by Sacilik (2007), Jittanik (2011), Doymaz (2004), Robert *et al* (2008). For Okra *(Abelmoschus esculentus)*, the same approach was used in determining the effective moisture diffusivity using figure 2 below and the effective moisture diffusivity varied from $1.369x10^{-7}$ -$7.12x10^{-7}m^2$/sec for respective temperature ranges from 60^0C, 65^0C, 70^0C, 75^0C, 80^0C, 85^0C, 90^0C, 95^0C, 100^0C, 105^0C, 110^0C and 115^0C. According to table 3 of the Okra *(Abelmoschus esculentus)* shows that the effective moisture diffusivity increases with an increase in temperature. This reports obtained in this work agree with the report of Burubai and Bratua (2015) and Sacilik (2017)

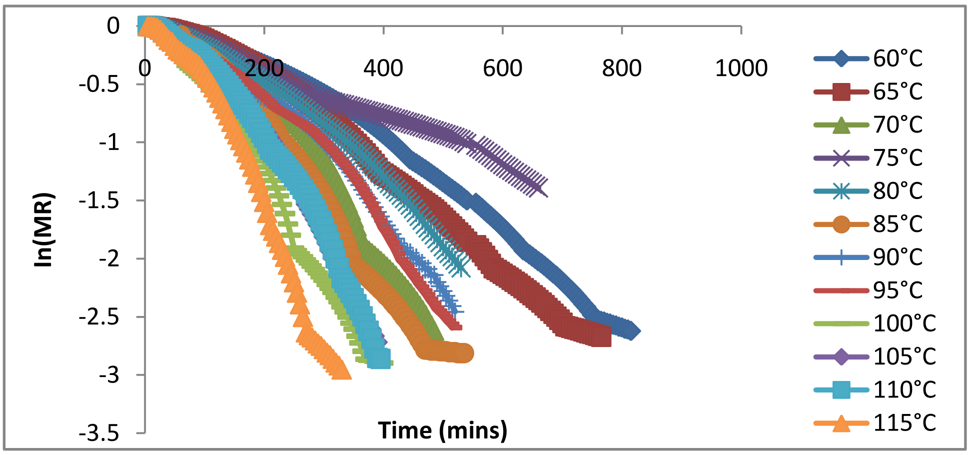

Figure 2: Estimation of Moisture Diffusivity Coefficient of Okra *(Abelmoschus esculentus)*

Table 3 Moisture diffusivity values of Okra *(Abelmoschus esculentus)*

Temp (0°C)	Effective moisture Diffusivity m^2/sec
60	0.0000002396
65	0.0000002739
70	0.0000003902
75	0.0000001369
80	0.0000002670
85	0.0000002191
90	0.0000003218
95	0.0000003560
100	0.0000005682
105	0.0000005066
115	0.000000712

3.4 Activation Energy

Activation energy is the energy that is responsible for the initiation of mass transfer from a wet biomaterial during drying. The temperature dependence of moisture diffusivity is reported to obey Arrhenius Law, and the activation energy was calculated from the In Deff Versus temperature curve as shown in Figure 3. The energy of activation for Okra *(Abelmoschus esculentus)* was recorded as 0.1235kJ/mol.k.

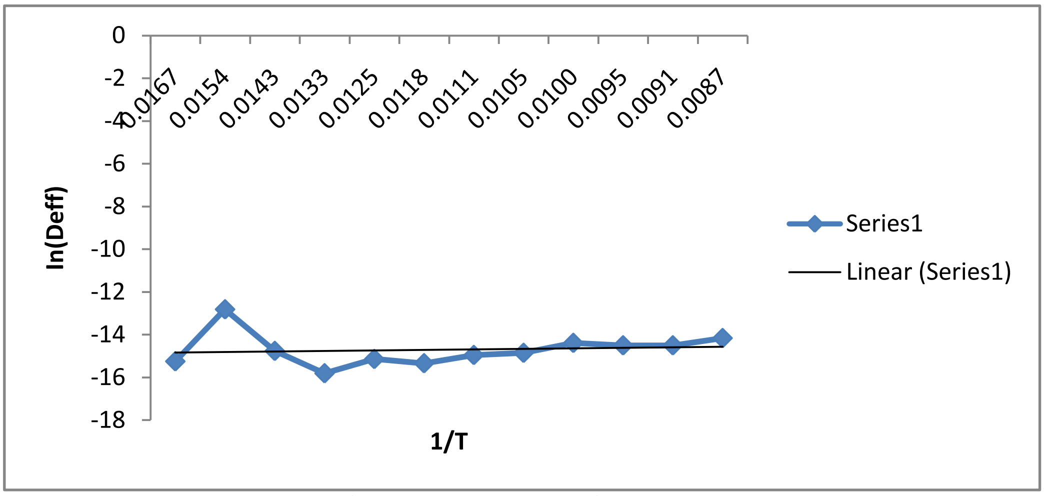

Figure 3 Estimation of Activation Energy of Okra *(Abelmoschus esculentus*

IV. CONCLUSION

In conclusion, Evaluation of some thin layer equations in the prediction of drying sliced Okra *(Abelmoschus esculentus)* was investigated and it was observed that the drying process have followed the falling rate model, in accordance with related literature. Experimental values were fitted into three experimental models (page, Henderson-pabis and Lewis) to evaluate the best predicting the drying kinetics of the sample. Page model was considered adequate and selected to be good predictor of the drying characteristic of Okra at the drying temperatures investigated having undergone statistical analysis. Arrhenius relationship reduces to the slope method, the activation energy was reduced to 0.1245kj/mol.

ACKNOWLEDGEMENT

The authors extensively used the laboratory facilities of the Department of Agricultural and Environmental Engineering, Faculty of Engineering, Niger Delta University, Bayelsa State, Nigeria for all the experimental works. To this we remain indebted and grateful.

REFERENCES

[1]. Burubai, W. and Etekpe, G. W., 2001. Microwave-Drying Behaviour of African Nutmeg (*Monodora myristica*) and Ogbono (*Irvinga gabonensis*) Kernels. Advanced Journal of Agricultural Research. Vol. 2(12), pp. 189-196
[2]. Burubai .W and I. Bratua 2015. Drying Kineics of Preosmosed Acute Mud Snail Meat (*vivipararous Contectus*). Journal of Science and Sustainable Technology pp100-113.
[3]. Crank J. 1975. The mathematics of diffusion 2nd ed, Oxford University Press. London, UK.414 pp.
[4]. Doymaz I. 2004. Convective air drying characteristics of thin layer carrots. *J. Food Eng*., 61:359-364.
[5]. Midilli A; Kucuk, H; and Taper, Z.A. 2020. New model for single-layer Drying technology 20: 1502-1513.
[6]. Diamente L. M and Munro P. A. 1993. Math matical modeling of the thin layer solar drying of sweet potato slices" Solar Energy, Vol. 51, Number 4, pp 271-276.

[7]. Ertekin C, and Yaldiz 2004. Drying of egg plant and selection of a suitable thin layer drying model. *Journal of Food Engineering, 63, 349-359.* In: Jacas J, Caballero P,Avilla J (eds) El control biolo´gico de plagas y enfer -medades. Publicacions de la Universitat Jaume I,Castello´n de la Plana, pp 87–112.
[8]. Figiel A.2010. Drying kinetics and quality of beetroots dehydrated by combination of convective and vacuum-microwave method J. Food Eng;98:461-470.
[9]. FOA 2014. Faostate Database http://faostat.fao.org accessed 20 june, 2016.
[10]. Gely MC, and Santalla M. 2000. Effect of some physical and chemical properties of oil seeds on kinetics parameters. Drying technology, 18(9), 2155-2166.
[11]. Giblin-Davis R. 2001. Borers of palms. Insects on palms. CABI Publishing, Wallingford Great Britain: 297-300.
[12]. Guan Z, Wang X, Li M, Jiang X. 2013. Mathematical modelling in hot air drying of thin layer fresh tilapia fillets. Pol. J Food Nutr. Sci 25: 1524-1532.
[13]. Guine, R. P. F; Pinho, S and Barroca, M. J. 2011.Study of the convective drying of pumpkin (Cucurbita maxima). Food Bio-production Process 89(4): 422 – 428.
[14]. Henderson, S.M and Pabis S. 1961.Grain Drying Theory I. Temperature Effects on Drying Coefficient. Journal of Agricultural Engineering Research, 6; 169-174.
[15]. Hii, J.O., Coates, D,B; Withbreed, A.M; Clem R.L; Robertson, M.J; Pengelly B. C. 2009. Seasonal Changes in pasture quality and diet Selection and their relationship with live weight gain of steers grazing tropical grass and grass-legume Pastures in Northern Australia. Annin. Prod. Sci.; 49(11): 983-993,
[16]. Hodge, B.K and Taylor, R. P. 1999. Analysis and Design of Energy System, 3rd Ed., Prentice Hall Inc. New Jersey.
[17]. Jittanit W 2011. Kinetics and temperatures dependent moisture diffusivity of pumpkin seeds during drying. Kasetsart J. (Nat. Sci.) 45:147-158.
[18]. Kilic, A. 2009. Low temperature and high velocity (LTHN) application in drying: Characteristic and Effects on the Fish Quality. *Journal Food Engineering,* 91, 173-182.
[19]. Kingly, R.P., Goyal, R.K., Manikantan, M.R. and Ilyas, S.M. 2007. Effect of pre-treatment and drying air temperature on drying behaviour of peach slice. International Journal of Food Science and Technology, 4:65-69.
[20]. Maskan M. 2000. Microwave/air and microwave finish drying of banana J. Food Eng.; 44:71-78.
[21]. Navneet, K; Sarkar, B. C and Sharma H. K. 2012. Mathematical modelling of thin layer hot air drying of carrot pomace. Journal of Food Science and Technology 49(1): 33 – 41,
[22]. Ozkan IA, Akbudak B, Akbudak N. 2007. Microwave drying characteristic of Spinach. J. Food Eng.; 85: 303-308
[23]. Page G. E. 1949. Factors influencing the maximum rates of air drying Shelled Corn in the layers. Msc. Thesis purdue University, Indiana. USA.
[24]. Pendre NK, Nema P, Sharma H, Rathore SS, Kushwah SS. 2012. Effect of drying temperature and slice size on quality of dried Okra (abelmoschus esculentus (L) moench) J Food Sci. Tech.; 49:378-381.
[25]. Robert JS, David RK, Olga P 2008. Drying kinetics of grape seeds. *J. Food Eng., 89:460-465.*
[26]. Sacilik, K. 2007. Effect of drying methods on thin-layer drying characteristics of hull-less seed pumpkin. *J. Food Eng., 79:23-30.*
[27]. Shivhare U, Gupta A, Bawa A, Gupta P. 2000. Drying characteristic and product quality of Okra. Drying tech. 18:409-419.
[28]. Sahey, K. M and Singh, K. K. 2005. Unit Operations in Agricultural Processing. 2nd Ed. VIKAS Publishing PVT Ltd, New Delhi, pp 125 – 130.
[29]. Soysal, Oztekin S. 2001. pH-postharvest technology: comparison of seven equilibruim moisture content equation for some medicinal and aromatic plants. J Agric Res.; 78:57-63.
[30]. Togrul, I.T., Pehlivan, D. 2003. Modelling of thin layer drying of some fruits under open-air sun drying process. Journal of Food Engineering 65, 413–425.
[31]. Verma, S.V; and Singh, R.P. 1978. Nutritional value of fermented guar meal for boilers. World Rev. Anim. Prod., 21:47-50.
[32]. Wang. C.Y., and Singh, R.P. 1978.Use of Variables equilibrium moisture content in modelling rice drying. ASAE meeting paper, St. Joseph No.78-6505.
[33]. Yaldiz O. and Ertekin C, 2001. Thin layer solar drying of some different vegetables. Drying technology, 19(3), 583-596.
[34]. Zibokere, D. S and Egbe, E. W. 2019.Thin-layer Drying Kinetics of Palm Weevil (Rhynchophorus ferruguneus) Larvae. Annals of Applied Science 5(2): 40 – 46,.
[35]. Zogzas, N. P; Maroulis, Z. B and Marinos-Kouris, D. 1996.Effective moisture diffusivity estimation from drying data. A ccomparison between various methods of analysis. *Drying Technology* 14(7-8): 1543 – 1573.

Egbe E.W, et. al. "Evaluation of Some thin-layer Equations in the Prediction of Drying Sliced Okra (Abelmoschus esculentus)." *International Journal of Engineering Science Invention (IJESI),* Vol. 10(01),