Greener Journal of Science, Engineering and Technological Research
Vol. 8(3), pp. 022-032, July, 2018
ISSN:2276-7835; ICV: 5.62

DOI Link: http://doi.org/10.15580/GJSETR.2018.3.062818070
http://gjournals.org/GJSETR

The Mathematical Modelling of the Effects of Thin Layer Drying of Groundnut (*Kerstigiella geocarpa harms*)

[1]OBUMSELI Pacifine Chioma,
[2]CHINWEUBA Dennis Chukwunonye,
[3]NWANDIKOM Godfrey Ifeanyichukwu,
[4]MADUBUIKE Chimaobi Nnaemeka

[1,2,3,4]Department of Agricultural and Bioresource Engineering, School of Engineering and Engineering Technology, Federal University of Technology, Owerri Imo state Nigeria.

ARTICLE INFO

Article No.: *062818070*
Type: *Research*
DOI: *10.15580/GJSETR.2018.3.062818070*

Submitted: *17/06/2018*
Accepted: *22/06/2018*
Published: *27/07/2018*

****Corresponding Author***
Chinweuba Dennis Chukwunonye
E-mail: *dennischukwunonye @gmail.com*

Keywords:
Kerstigiella geocarpa harms, groundnut, thin-layer drying, moisture diffusivity, activation energy

ABSTRACT

A research was done on the effects of mathematical modelling of the thin layer drying of groundnuts *(Kerstigiella geocarpa harms)* at 67% Moisture Content (% dry basis) and varying air temperatures of 45, 55 and 65ºC, at air velocities of 0.6, 1.0 and 1.5 m/s. In order to select the most suitable form of the drying curve, 5 different thin layer semi-theoretical drying models were fitted to experimental data and the moisture diffusivity was calculated from Fick's second law as the major equation. The highest value of coefficient of determination (R^2), the low values of errors from the Sum of Square Error (*SSE*) and Root Mean Square Error (*RMSE)* indicates that the Two-Term model can satisfactorily describe the drying curve of groundnuts (*Kerstigiella geocarpa harms*) for drying air velocity of 1.5 m/s and temperature of 55ºC. According to the results, the calculated value of effective moisture diffusivity varied from 1.33 to 4.11×10^{-9}m^2/s and the value of activation energy varied from 26.29 to 30.57 kJ/mol.

1. INTRODUCTION

Groundnut is regarded as one of the most important protein-rich crops and it occupies the fifth position as oilseed crop globally after soybean, cottonseed, rape seed, and sunflower seed (El- Sayed *et al.,* 2001; Davies, 2009). It is grown as annual crop on about 19 million hectares of land in tropical regions and the warmer areas of temperate regions of the world (Adejumo *et al.,* 2005). Table 1 depicts the nutrient composition of groundnuts in various processed states.

Table 1: Nutrient Composition of the groundnut subjected to different processing methods

(Groundnut) seeds on % dry weight basis Compositions	Raw groundnut % dry weight	Sun-dried groundnut % dry weight	Roasted groundnut % dry weight
Moisture content	7.48	3.40	1.07
Ash content	1.48	1.38	1.41
Crude fibre	2.83	2.43	2.41
Crude fat/oil	46.10	43.80	40.60
Protein	24.70	21.80	18.40
Carbohydrate	17.41	27.19	36.11

Source (Adekanye *et al.*, 2009).

Drying is the process of removing the moisture in a product up to certain threshold value by evaporation (Darvishi et al., 2012), in this way, the product can be stored for a very long period, since it decreases the water content of the product, reduces microbiological activities and minimizes physical and chemical changes during storage of the product (Darvishi *et al.,* 2012). Drying is one of the most widely used methods for food preservation (Molina Filho *et al.,* 2011). The main objective of drying is to remove water until the level of microbiological contamination and deterioration reactions are greatly minimized (Doymaz, 2007; Akpinar and Bicer, 2004). It also provides longer shelf-life, smaller space for storage and lighter weight for transportation (Ismail and Nagy, 2012; Ertekin and Yaldiz, 2004). Drying products under the sun is the most common method used to preserve agricultural products in tropical and subtropical countries (Papu *et al.,* 2014).

However, being unprotected under the rain, wind-borne dirt and dust, microbial attacks, infestation by insects, rodents and other animals, products may be seriously degrade to the extent that sometimes become inedible and the resulted loss of food quality in the dried products may have adverse economic effects on domestic and international markets (Akoy *et al.,* n.d.). Hence, the drying process of agricultural products should be undertaken in a closed equipment (solar or industrial dryer) to improve the quality of the final product (Akoy *et al.,* 2008).

The drying process takes place in two stages, according to Megha and Sanjay, 2015. The first stage happens at the surface of the drying material at a constant drying rate and is similar to the vaporization of water into the ambient and the second stage drying process takes place with decreasing of drying rate, when the drying process is controlled by the internal mass transfer, mainly in the falling rate period; modeling of drying is carried out through diffusion equations based on Fick's second law (Midilli and Kucuk, 2003).

Drying is a complex thermal process in which unsteady heat and moisture transfer occur simultaneously (Akoy, 2014; Sahin and Dincer, 2005).

It is important to develop a better understanding of the controlling parameters in this complex process according to the engineering point of view (Doymaz, 2007).

There are mathematical models of drying processes which are used for designing new or improving existing drying systems (equipment) or even for the control of the drying process (Doymaz, 2014).

Many of these mathematical models have been proposed to describe the drying process of which thin-layer drying models have been widely in use (Kara and Doymaz, 2015).

When choosing the appropriate drying systems, numerous factors are put into consideration which includes time, energy and product properties (Barbosa *et al.,* 2007).

The time used in the process is related to the energy and mass exchange between the product and the drying air, which can be analyzed by the effective diffusivity (Park *et al.,* 2002).

There are several thin layer drying models available in the literature and used by researchers to explain drying characteristics of agricultural products (Doymaz, 2007). These models are categorized as theoretical, semi-empirical and empirical (Akoy, 2014). Moreover, the drying kinetics of food is a complex phenomenon and requires simple representations to predict the drying behaviour, and for optimizing the drying parameters.

Many researchers have carried out mathematical modeling and experimental studies on the thin layer drying of various vegetables and fruits, for example, white mulberry (Doymaz, 2004), mango slices (Goyal *et al.,* 2006), sweet cherry potato slices (Aghbashlo *et al.,* 2009), onion slices (Arslan and Özcan, 2010), sweet cherries (Doymaz and Ismail, 2011), banana (da Silva *et al.,* 2013) and mango slices (Akoy, 2014).

However, there is limited information and research on drying kinetics of groundnut seeds in literature. Therefore, the objectives of this study were:

(a) To investigate the thin-layer drying characteristics of groundnuts *(Kerstigiella geocarpa harms)*
(b) Modeling of the thin-layer drying of groundnut seeds by testing three drying semi theoretical models
(c) To estimate the effective diffusivity coefficient and energy of activation for groundnuts *(Kerstigiella geocarpa harms)*

2. MATERIALS AND METHODS

Raw Material Used

Groundnuts (*Kerstigiella geocarpa harms*) for this experiment were harvested from a farm in Anam Anambra West Local Government Area of Anambra State Nigeria. The groundnuts were removed from the pods and left to dry in open air; it was turned every hour to ensure uniformity during drying (Chinweuba *et al.,* 2016).

Drying Procedure

In order to simulate the actual practices of artificial drying, the groundnut was dried using an oven at air temperature of 45℃, 55℃ and 65℃. The dryer consists of heating unit, temperature control unit, drying chamber and centrifugal fan that has a regulator for air velocities of 0.6m/s, 1.0m/s and 1.5m/s. Drying, commenced from 8 a.m. till 7 p.m. daily and terminates when the groundnut's moisture content has little or no change. The average initial moisture content of the groundnut was 67 ± 0.85% (dry basis), as determined using a precision air-oven method, at a temperature of 103℃ for 24 hours until constant weight was reached, according to the standard method of AOAC (2000) and moisture content on wet basis (%w.b.) was calculated by the following equation:

$$MC_{wb} = \frac{W_w}{(W_w + W_d)} \times 100\% \quad (1)$$

Where:
MC_{wb} = moisture content, % (wet basis)
W_w = weight of water, g
W_d = weight of dry matter, g

Moisture content on wet basis was converted to moisture content on dry basis by the following equation:

$$MC_{db} = \frac{MC_{wb}}{(100 - MC_{wb})} \quad (2)$$

Where: MC_{db} = moisture content, decimal, dry basis

Prior to starting the experiments, the experimental dryer was adjusted to the selected temperature and air velocity for about half an hour to reach thermal stabilization. Then the samples were uniformly spread in a single layer of 8mm thickness on a tray. Representative samples of the groundnuts for moisture content determination were dried in the experimental dryer.

At the interval of 15 mins during the experimentation, the tray with sample was taken out of the drying chamber and weighed on a digital balance and placed back into the drying chamber.

For measuring the mass of the sample at the digital top pan balance (Ohaus, Pine Brook, NJ USA) of ±0.001 g accuracy, was kept near to the drying unit and weight measurement process took less than 10 seconds time. The drying process stopped when there is little or no change in the seeds moisture content.

All the experiments were repeated three times at each drying temperature and air velocity; the average values were used to determine the drying characteristics of the groundnuts.

Mathematical Modelling of Drying Curves

The moisture ratio and drying rate of groundnuts during drying experiments were calculated using the following equations:

$$MR = \frac{M - M_e}{M_o - M_e} \quad (3)$$

Where: *MR* is the dimensionless moisture ratio; *M*, M_0 and M_e are the moisture content at any time, initial moisture content and equilibrium moisture content, respectively. However, *MR* was simplified to equation 4 (Pala et al, 1996; Akoy, 2014):

$$MR = \frac{M}{M_o} \quad (4)$$

$$Drying\ Rate = \frac{M_{t+dt} - M_t}{dt} \quad (5)$$

Where, M_t and M_{t+dt} are the moisture content at *t* and moisture content at *t+dt* (kg water /kg dry matter), respectively, *t* is drying time (hr).

The drying curves were fitted to five selected thin layer drying models (Table 2) that are widely used in most food and biological materials; namely, Newton , Page, Henderson and Pabis, Logarithmic and Two-Term models.

Table 2: Selected thin layer drying models

MODEL NAME	MODEL EQUATION	EQUATION NO.	REFERENCES
Newton	$MR = exp^{(-kt)}$	6	(Soysal et al, 2006)
Page	$MR = exp^{(-kt)n}$	7	(Zarein et al, 2013)
Logarithmic	$MR = A\ exp^{(-kt)} + C$	8	(Akpinar et al, 2006)
Henderson and Pabis	$MR = A\ exp^{(-kt)}$	9	(Zarein et al, 2013)
Two- Term	$MR = Aexp(-k_1 t) + Bexp(-k_2 t)$	10	(Sarimeseli, 2011)

These models shown in Table 2 were generally derived by simplifying the general solution of Fick's second law (Motavali, 2013).

Statistical *Analysis*

The goodness of fit of the five selected drying models to the experimental data was determined using three statistical parameters, namely; coefficient of determination (R^2), sum square error (*SSE*) and root mean square error (*RMSE*).

These parameters can be calculated by using the following equations:

$$SSE = \frac{1}{N}\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pred,i}\right)^2 \quad (11)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pred,i}\right)^2} \quad (12)$$

Where:
MR_{exp} = Experimental moisture ratio
MR_{pred} = Predicted moisture ratio
N = Number of observations
n = Number of constants

The higher R^2 values and the lower *SSE* and *RMSE* values are goodness of fit (Sacilik *et al.,* 2006; Akoy, 2014).

Determination of Effective Moisture Diffusivity and Activation Energy

Effective moisture diffusivity describes all possible mechanisms of moisture movement within the food, such as liquid diffusion, vapour diffusion, surface diffusion, capillary flow and hydrodynamic flow. A knowledge of effective moisture diffusivity is necessary for designing and modelling mass-transfer processes such as dehydration, adsorption and desorption of moisture during storage. The drying data in the falling rate period are usually analysed by Fick's diffusion equation (Akoy, 2014).

Fick's second equation of diffusion was used to calculate effective moisture diffusivity of parboiled breadfruit seeds, considering a constant moisture diffusivity, infinite cylindrical geometry and uniform initial moisture distribution as follows:

$$MR = \frac{M - M_e}{M_o - M_e} = \frac{4}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left(\frac{-(2n+1)^2\pi^2 D_{eff} t}{4l^2}\right)$$
(13)

Where: $\frac{4}{\pi^2}$ = the shape factor and depends on the geometry of the drying material ($\frac{8}{\pi^2}$ for a slab and $\frac{6}{\pi^2}$ for the sphere).

D_{eff} = the effective diffusivity, (m^2s^{-1})
L = characteristic length, thickness (m)
n = positive integer

For long drying times, the Eq. (13) can be simplified as Eq. (14) by taking the first term of the series solution and expressed in a logarithmic form as follows (Doymaz, 2012):

$$InMR = In\frac{4}{\pi^2} - \frac{\pi^2 D_{eff}\, t}{4l^2} \quad (14)$$

The effective moisture diffusivity was obtained by plotting the experimental data in terms of *In(MR)* versus drying time (hr). From equation (13), a plot of *In(MR*) versus time gives a straight line with a slope of (*k*) in which:

$$k = \frac{\pi^2 D_{eff} t}{4l^2} \quad (15)$$

The dependence of the effective moisture diffusivity on temperature is generally described by the Arrhenius equation (Simal *et al.,* 2005):

$$D_{eff} = D_o \exp\left(\frac{-E_a}{RT}\right) \quad (16)$$

Where:
D_o = the pre-exponential factor of the Arrhenius equation, m^2/s
E_a = activation energy, $kJmol^{-1}$
R = universal gas constant, $kJmol^{-1}K^{-1}$
T = absolute temperature, K
Eq. (16) can be rearranged into the form of Eq. (17) as follows:

$$InD_{eff} = In\,(D_o) - \left(\frac{E_a}{RT}\right) \quad (17)$$

A plot of InD_{eff} as a function of the reciprocal of absolute temperature *1/T* will produce a straight line with slope equal to $(-E_a/R)$, from which the parameter E_a can be estimated.

The activation energy (E_a) was calculated by plotting the natural logarithm of D_{eff} versus the reciprocal of the absolute temperature (T_{abs}). Activation energy is a measure of the temperature sensitivity of D_{eff} and it is the energy needed to initiate the moisture diffusion within the parboiled breadfruit seeds.

3. RESULTS AND DISCUSSION

The Drying Characteristics of Groundnuts (*Kerstigiella geocarpa harms).*

The drying characteristics of the groundnuts are shown in Figures 1, 2 and 3. The initial moisture content of groundnuts before drying was about 67 ± 0.85% dry basis. As expected, the drying temperature had a significant effect on drying characteristics of the groundnut seeds. The moisture content decreased continuously with time and an increase in temperature gave a decrease in drying time. The longest and shortest drying times were recorded at 45℃ (270min at 0.5m/s air velocity) and 65℃ (165min at 1.5m/s air velocity) respectively as seen in figures 1-3.

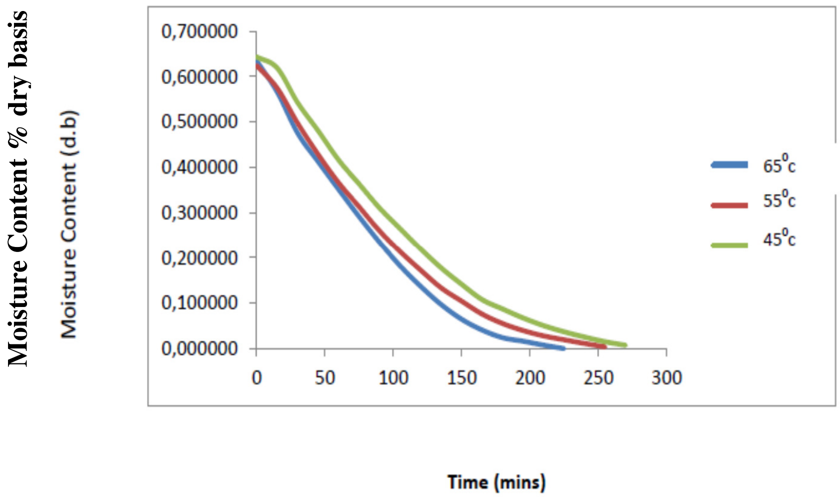

Fig 1: Effect of drying temperature on the moisture content of groundnuts at air velocity of 0.6m/s

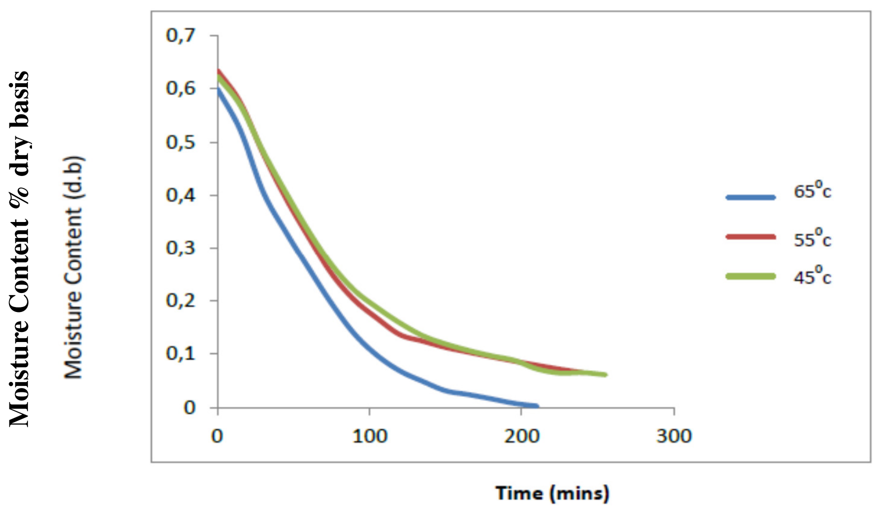

Fig 2: Effect of drying temperature on the moisture ratio of groundnuts at air velocity of 1.0m/s

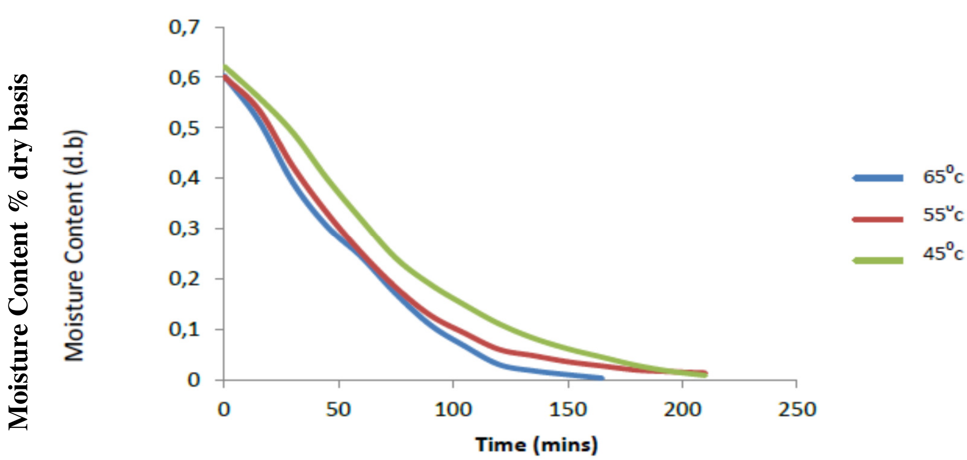

Fig 3: Effect of drying temperature on the drying rate of groundnuts at air velocity of 1.5m/s

Figure 2 shows moisture ratio of the groundnuts plotted against drying time, it is clear from figure 2 that moisture ratio decreased considerably with increasing drying time. The time required to reduce the moisture ratio to any given level was dependent on the drying temperature, being highest at 45℃ drying air temperature and lowest at 65℃ drying air temperature.

Researchers have observed that the main factor influencing drying kinetics of food materials was the drying temperature, as noted in other studies (Belghit *et al.,* 2000; Koulia *et al.,* 2002; Akoy 2014). Therefore, a higher drying temperature gives a higher drying rate and consequently decreases the moisture content faster. This is due to increase of air enthalpy to the groundnuts and subsequent acceleration of water migration within the nuts.

Figure 3 shows the effect of the three temperatures on the drying rate of groundnuts at air velocity of 1.5m/s. As you can see in figure 3 it is clear that there is no constant rate drying period in the drying process of groundnuts, and all the drying process occurs in the falling rate period. This indicates that diffusion is the dominant physical mechanism governing moisture movement within the groundnuts. Similar results were reported for the drying studies on raw mango slices (Akoy, 2014; Goyal *et al.,* 2006), and apricots (Doymaz, 2004).

Effective Moisture Diffusivity

From the table 6, it is clear that drying constant (k) is a function of temperature as it increases with an increase in drying temperature. The determined values of the effective moisture diffusivity (D_{eff}) for the different temperatures are shown in table 6. The diffusivity values were found to be 1.33 x 10^{-9} to 4.11 x 10^{-9} m^2/s at 45ºC to 65ºC. It is clear that effective diffusivity values for groundnuts increase greatly with increasing drying air temperature. When samples were dried at higher temperature, increasing heating energy increased the activity of water molecules leading to higher moisture diffusivities, similar result was reported by Akoy (2014).

The values of effective moisture diffusivity obtained from this study lies within the general range from 10^{-11} to 10^{-9} m^2/s for food materials (Madamba *et al.,* 1996). The values of the effective moisture diffusivity (D_{eff}) are consistent with the reported; the lowest effective moisture diffusivity was 1.33 x 10^{-9} m^2/s at air velocity of 1.0 m/s at temperature of 45°C. The highest effective diffusivity was to 4.11 x 10^{-9} m^2/s at air velocity of 1.5 m/s at temperature of 65°C.

Fitting of the Drying Various Models

Tables 3, 4 and 5 shows values of the drying constants and drying coefficients of the selected models (Table 2) at various selected temperatures and velocities. The fitting of five thin-layer drying models to the experimental data were compared in terms of the three statistical parameters, which are *R^2, SSE and RMSE*. The statistical analysis values are summarized also in table 3, 4 and 5. In most cases, the R^2 values for the models were greater than 0.95, indicating a good fit (Doymaz and Ismail, 2011) except some with high errors.

The R^2 values varied between 0.8178 and 0.9996, except for the Newton and page model that gave high error with negative R^2. These values show that four out of five tested drying models predicted thin layer drying process of parboiled breadfruit adequately. Generally, the Two - term model gave a higher R^2 and lower *SSE*, and *RMSE* (Table 3, 4 and 5), Akoy (2014) reported the same model for mango slices. Thus, this model could be selected to represent the thin-layer drying characteristics of parboiled breadfruit seeds. Hence, the Model equation is

$$MR = 1.721 * \exp(-0.02257 * t) - 0.72 * \exp(0.05025 * t) \quad (18)$$

Table 6: Values of Drying Rate constants (k), Moisture Diffusivity (D_{eff}) and Activation Energy (Ea) at various Drying Temperatures and Air Velocity

	Air Velocity (m/s)					
	0.6		1.0		1.5	
T(⁰C)	**k**	**Deff (m^2/s)**	**K**	**Deff(m^2/s)**	**k**	**Deff(m^2/s)**
45	-0,0152	2,09E-09	-0,00972	1,33037E-09	-0,02268	3,10421E-09
55	-0,0177	2,42396E-09	-0,01016	1,3906E-09	-0,01948	2,66622E-09
65	-0,02	2,73739E-09	-0,02371	3,24518E-09	-0,03003	4,1102E-09
Ea(kJ/mol)	26,29078223		30,57012178		26,35264679	

Table 3: Model parameters for the groundnut seeds at air flow rate of 0.6 m/s

Temp. (°C)	Mod No.	Model Expression	MODEL PARAMETERS							GOODNESS OF FIT		
			A	K	K_1	K_2	B	n	C	R^2	SSE	RMSE
45	1	$MR = \exp(-k * t)$	-	0.00934	-	-	-	-	-	0.9649	0.06941	0.0621
	2	$MR = \exp(-k * t)^n$	-	0.00119	-	-	-	1.43	-	0.999	0.00204	0.01095
	3	$MR = A * \exp(-k * t)$	1.107	-0.0103	-	-	-	-	-	0.9782	0.04317	0.05039
	4	$MR = A * \exp(-k * t) + c$	1.282	0.006747	-	-	-	-	-0.2244	0.9953	0.009274	0.02408
	5	$MR = A * \exp(-k_1 * t) + B * \exp(-k_2 * t)$	-1172	-	-1.581	-1.581	1172	-	-	0.9981	0.003765	0.01584
55	1	$MR = \exp(-k * t)$	-	0.01077	-	-	-	-	-	0.9741	0.04728	0.05274
	2	$MR = \exp(-k * t)^n$	-	0.002031	-	-	-	1.356	-	0.9987	0.002373	0.01218
	3	$MR = A * \exp(-k * t)$	1.084	-0.01163	-	-	-	-	-	0.9823	0.03228	0.04492
	4	$MR = A * \exp(-k * t) + c$	1.213	0.008152	-	-	-	-	-0.1721	0.9967	0.006053	0.02009
	5	$MR = A * \exp(-k_1 * t) + B * \exp(-k_2 * t)$	-198.5	-	-1.639	-1.638	198.7	-	-	0.9981	0.003497	0.0158
65	1	$MR = \exp(-k * t)$	-	0.2017	-	-	-	-	-	-3.274	6.545	0.6837
	2	$MR = \exp(-k * t)^n$	-	0.002271	-	-	-	1.368	-	0.996	0.006168	0.02178
	3	$MR = A * \exp(-k * t)$	1.073	-0.01297	-	-	-	-	-	0.977	0.03519	0.05203
	4	$MR = A * \exp(-k * t) + c$	0.5496	0.5404	-	-	-	-	-0.2567	0.997	0.004657	0.0197
	5	$MR = A * \exp(-k_1 * t) + B * \exp(-k_2 * t)$	0.8454	-	-0.007695	-0.007695	0	-	-	0.845	0.2373	0.1469

Table 4: Model parameters for the groundnut seeds at air flow rate of 1.0 m/s

Temp. (ºC)	Mod No.	Model Expression		MODEL PARAMETERS						GOODNESS OF FIT		
			A	K	K_1	K_2	B	n	C	R^2	SSE	RMSE
45	1	$MR = \exp(-k * t)$	-	0.01062	-	-	-	-	-	0.9915	0.01231	0.02691
	2	$MR = \exp(-k * t)^n$	-	0.008579	-	-	-	1.046	-	0.9922	0.01135	0.02663
	3	$MR = A * \exp(-k * t)$	1.034	-0.011	-	-	-	-	-	0.9931	0.01002	0.02502
	4	$MR = A * \exp(-k * t) + c$	0.2119	0.9807	-	-	-	-	0.03913	0.9947	0.007664	0.0226
	5	$MR = A * \exp(-k_1 * t) + B * \exp(-k_2 * t)$	1.045	-	-0.01146	0.01818	0.0004511	-	-	0.9956	0.006399	0.02138
55	1	$MR = \exp(-k * t)$	-	0.1702	-	-	-	-	-	-4.56	7.568	0.6878
	2	$MR = \exp(-k * t)^n$	-	0.01025	-	-	-	1.023	-	0.9873	0.01731	0.03397
	3	$MR = A * \exp(-k * t)$	1.03	-0.01174	-	-	-	-	-	0.9884	0.01583	0.03248
	4	$MR = A * \exp(-k * t) + c$	0.1901	1.045	-	-	-	-	0.05736	0.9923	0.01047	0.02735
	5	$MR = A * \exp(-k_1 * t) + B * \exp(-k_2 * t)$	1.046	-	-0.01262	0.01442	0.002022	-	-	0.9937	0.008623	0.02575
65	1	$MR = \exp(-k * t)$	-	0.1895	-	-	-	-	-	-4.22	7.932	0.7527
	2	$MR = \exp(-k * t)^n$	-		-	-	-		-	-	-	-
	3	$MR = A * \exp(-k * t)$	1.065	-0.01652	-	-	-	-	-	0.988	0.0182	0.03741
	4	$MR = A * \exp(-k * t) + c$	0.2739	0.9022	-	-	-	-	-0.08488	0.9954	0.006963	0.02409
	5	$MR = A * \exp(-k_1 * t) + B * \exp(-k_2 * t)$	1.249	-	-0.02975	-0.02975	0	-	-	0.8178	0.2769	0.1587

Table 5: Model parameters for the groundnut seeds at air flow rate of 1.5m/s

Temp. (°C)	Mod No.	Model Expression		MODEL PARAMETERS						GOODNESS OF FIT		
			A	K	K_1	K_2	B	n	C	R^2	SSE	RMSE
45	1	$MR = \exp(-k*t)$	-	0.1969	-	-	-	-	-	-3.667	7.843	0.7231
	2	$MR = \exp(-k*t)^n$	-		-	-	-		-			
	3	$MR = A*\exp(-k*t)$	1.087	-0.01409	-	-	-	-	-	0.9817	0.03067	0.04681
	4	$MR = A*\exp(-k*t)+c$	0.3597	0.7558	-	-	-	-	-0.1308	0.9933	0.01134	0.02953
	5	$MR = A*\exp(-k_1*t)+B*\exp(-k_2*t)$	0	-	-0.01258	-0.01258	1.037	-	-	0.9749	0.04225	0.05934
55	1	$MR = \exp(-k*t)$	-	0.1888	-	-	-	-	-	-4.142	7.93	0.7526
	2	$MR = \exp(-k*t)^n$	-		-	-	-		-			
	3	$MR = A*\exp(-k*t)$	1.079	-0.01681	-	-	-	-	-	0.9866	0.02069	0.0399
	4	$MR = A*\exp(-k*t)+c$	1.121	0.01445	-	-	-	-	-0.06155	0.991	0.01381	0.03392
	5	$MR = A*\exp(-k_1*t)+B*\exp(-k_2*t)$	1.721	-	-0.02257	-0.05025	-0.72	-	-	0.9996	0.000561	0.007142
65	1	$MR = \exp(-k*t)$	-	0.2049	-	-	-	-	-	-3.426	5.769	0.7242
	2	$MR = \exp(-k*t)^n$	-	0.003777	-	-	-	1.362	-	0.9968	0.004207	0.02051
	3	$MR = A*\exp(-k*t)$	1.067	-0.01852	-	-	-	-	-	0.9795	0.02673	0.05171
	4	$MR = A*\exp(-k*t)+c$	0.4094	0.7049	-	-	-	-	-0.1684	0.9949	0.006594	0.02707
	5	$MR = A*\exp(-k_1*t)+B*\exp(-k_2*t)$	1.185	-	-0.02611	-0.02611	0	-	-	0.9146	0.1113	0.118

Activation Energy

The activation energy (E_a) was found to be 26.29 kJ/mol - 30.57 kJ/mol. The activation energy value obtained from this study lies within the general range of 12.7 to 110 kJ/mol for various food materials (Akoy, 2014; Zogzas *et al.,* 1996). It is falls within the activation energies of 27.0 kJ/mol for kiwifruit drying in the temperature range 30-90ºC (Simal *et al.,* 2005) and lower than the activation energies of 40.95 kJ/mol for fig drying (Xanthopoulos *et al.,* 2009) and 43.05-49.17 kJ/mol for sweet cherry drying (Doymaz and Ismail, 2011).

4. CONCLUSIONS

The drying curves of groundnuts (*Kerstigiella geocarpa harms)* were greatly affected by the drying temperature, as the drying temperature increase causes a decrease in the drying time. Drying of groundnuts occurred in the falling rate period, which indicates that moisture removal from the product was governed by internal diffusion phenomenon. According to statistical analysis applied to the five drying models used, Two Term models were found to be the most suitable model for describing the effect of thin-layer drying characteristics of the groundnuts. The effective diffusivity coefficients increased with increasing drying temperature, which ranged from 1.33×10^{-9} to 4.11×10^{-9} m^2/s over the temperature range (45 to 65ºC). The activation energy for the parboiled breadfruit seeds was estimated to be 26.29 to 30.57 kJ/mol at temperatures 45 to 65 ºC.

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Cite this Article: Obumseli PC, Chinweuba DC, Nwandikom GI, Madubuike CN (2018). The Mathematical Modelling of the Effects of Thin Layer Drying of Groundnut (*Kerstigiella geocarpa harms*). Greener Journal of Science, Engineering and Technological Research, 8(3): 022-032, http://doi.org/10.15580/GJSETR.2018.3.062818070.