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Research Article

Studying the Thin Layer Drying Kinetics of African Giant Snail (*Achatina achatina*)

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ABSTRACT

African Giant Snail (*Achatina achatina*) is eaten after eviscerating the flesh from the shell and separating the edible part from the other viscera in a dried or semi-dried state, in the coastal area where they are predominately available. Drying is a veritable technology for its storage beyond immediate consumption. This study thus, studied the Thin Layer Drying Kinetics of African Giant Snail (*Achatina achatina*). A laboratory convective oven dryer was used as the heating source, on temperature range of 60°C-100℃ applied in a varying manner on multiples of 10℃. The layer thickness was about 0.013-m. The drying profile showed a typical falling rate period with no distinct constant rate period for all the temperature levels used in this work. Moisture loss (diffusion) data obtained from the experiments were fitted to four popular empirical thin-layer models of ANN, Page, Lewis, and Henderson-Pabis, respectively, and their suitability was validated using statistical parameters (of R_2, RMSE and χ^2). This was done to select thin-layer model that would suitably describe the drying kinetics of the samples over the range of temperature levels chosen in this work. Consequently, the ANN and that of Henderson-Pabis respectively were taken to have reliably predicted the drying behaviour of the samples at the chosen temperature levels. The effective diffusivity and the temperature-related activation energy values ranged from 2.191 $m^2/min \times 10^{-10}$ m^2/min-8.219 $m^2/min \times 10^{-11}$ m^2/min and 22.5 kJ/mol, respectively. Drying rates along with characterizing drying constants and curves also showed an exponential increase with temperature.

Keywords: African giant snail; Thin-layer drying kinetics; Drying curves; Effective diffusivity; Activation energy

INTRODUCTION

African Giant Snail (*Achatina achatina*) serves as delicacies in tropical areas. In Africa, snails serve relatively cheaper and highly portentous see plate 1. Snail meat is highly proteineous with about 80.9%-89.92% of dry with low fat and cholesterol [1,2] and very good to those with health consciousness. The snail meat is characteristically tender and having a pliable or springy texture when chewed, with a sui generis, nice floral-like, mushroom-like flavour when cooked. Snails has it limitation because of it perishability and seasonality [3,4]. Snails are easily prone to rapid damage due to unprotection to several kids of microbes and contaminants as they creep or crawl on the soil. In order to reduce this limitation, they are traditionally smoked-dried and sale by table-top traders. Nevertheless, the smoke-dried snails though have good market value locally but does not meet international standard to earn foreign exchange. Snails population are high during the wet season where they are harvested in large amount by the rural communities and they are very cheap, but become scarce [5] and very expensive during the dry season reasons because they are difficult to find. Many researchers have worked in Gian Africa snail and has focused on the proximate composition of the various species [5-9].

Snail meat is eaten and preserved by eviscerating the flesh from the shell and separating the edible part from the other viscera for further processing; the edible portion is then parboiled incubated with seasonings to individual taste of organleptic properties which is then sold in the market by table-top trader.

Drying does not deplete but would retain required flavour, colour and nutritive value, and also influence physicochemical and quality characteristic of products. The report of [10] shows that drying as an industrial preservation technique in which moisture content

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and water activity of bio-materials are reduced by motive heated air. This definition thus, excludes drying methods such as sun-drying and freeze-drying where drying is achieved without a significant presence of convective air. Appropriate technologies designed for such mechanized drying are rife in technical literature [10].

Many mathematical models have however, been used to describe the thin-layer drying process of several of such food products, and these also serves as tools for process control and in drying simulation studies, and for predicting the suitable drying conditions. Therefore, in this work, the drying behaviour of the African Giant Snail (*Achachatina achatina*) was investigated on thin-layers and the emanating experimental data was fitted to the selected thin-layer drying models to characterize the drying kinetics of the African Giant Snail (*Achachatina achatina*). This would also create a good data base for improved equipment design of the drying processes [10-12].

Figure 1: A African Giant Snail (*Achachatina achatina*).

Theoretical framework

Thin-layer drying as applied to high systemic moisture biomaterials is a complicated process with simultaneous heat and mass transfer. Thin layer as a concept refers to a layer of a product that can be described as sufficiently small in thickness whereon air characteristics everywhere in the layer could be considered identically uniform with no observable variations. Then in thin-layer drying it is expected that all individual particles of the material are fully exposed to the drying air. The conditions of thin layer drying are often divided into two periods of drying which are the constant rates and the falling rate periods. In this work, thin-layer drying was done in batches of single beds or layers split to different small but uniform thickness each. It is usual to place or arrange the different splits in vertical series such that hot air in a forced convective stream could be made to pass over them. The hot air stream can then be seen to absorb moisture from the first split through the others, such that the exhaust from one split becoming input air to the subsequent split, and on through the final or terminal split. Passing through a number of thin splits in this manner, it is evident that the moisture pick-up ability of the air stream declines one over the next layer. For the success of such simulation work therefore, the splits (now to be referred to as thin-layers), be made infinitesimally thin and arranged in such a manner that the inlet hot air stream simply exhausts through the layers undiminished in its moisture carrying capacity. Drying would then become achieved in all the splits, each batch characterized by different drying rates at the different temperature levels applied [13]. Literature reports show that most drying activities of biomaterials generally omit the constant rate period but do so largely in the falling rate period [14,15]. The entire rate period of the drying process is known to be a diffusion (molecular transport) phenomenon through a continuum of interface slits and generally governed by Fick's second law (moisture flux proportional to the moisture gradient) given as [16].

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

Where,

$M = moisture\ content\ at\ time\ t,\ \mathrm{kg}_{H_2O}/kg_{Solid}$

$t = drying\ time,\ min.$

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

$De = effective\ diffusivity,\ mm^2/\mathrm{m}in.$

The Moisture Ratio (MR) prevalent in the drying system can be expressed in:

$$MR = \frac{M - M_e}{M_0 - M_e} \quad (2)$$

$M_e = equilibrium\ moisture\ content\ (emc),\mathrm{kg}_{H_2O}/kg_{H_2O}$

$M\ is\ as\ previously\ defined$

$M\ is\ as\ previously\ defined$

Estimating effective diffusivity, De

Effective diffusivity (De) is a temperature and moisture content dependent diffusion parameter that describes and drives the moisture transport process in the condition of any diffusion mechanism during drying of any visco-elastic material. Of the three stages in the drying profile namely, the free stage, the constant rate period and the falling rate period, the effectiveness of moisture transport is observable more in the third - the falling rate period during drying [17,18]. The mathematical expression for effective diffusivity, De as derived for a material of cylindrical geometry at the falling rate period during drying is [19,20].

$$MR = \frac{M - M_e}{M - M_e} = \frac{6}{\pi^2}\int_{n=1}^{\infty}\frac{1}{(2n-1)^2}e^{-(2n-1)^2\frac{\pi^2 D_e t}{L^2}} \quad (3)$$

$for\ n = number\ of\ cylindrical\ surfaces\ placed\ in\ slits\ (thin-layers)$

$Taking\,(2n-1)^2 = \epsilon_n\ recognized\ as\ the\ root\ of\ a\ related\ Bessel\ function,\ and\ for\ a\ material\ of\ cylindrical\ geometry,$

$L = R_c = radius\ of\ cylinder$

$Then\ equation\ 3\ will\ reduce\ to$

$$MR = \frac{M - M_e}{M_o - M_e} = \frac{6}{\pi^2}\int_{n=1}^{\infty}\varepsilon_n^{-2}e^{-\varepsilon_n}\left(\frac{\pi^2 D_e t}{R_c^2}\right) \quad (4)$$

Taking only the first term (n=1) rendering others as negligible, equation 4 would become [21].

$$MR = \frac{M - M_e}{M_o - M_e} = \frac{6}{\varepsilon_1}\int_{n=1}^{\infty}e_n^{-\varepsilon_1}\left(\frac{D_e t}{R_c^2}\right) \quad (5)$$

Where, MR=Moisture Ratio

Taking natural log on both sides, equation 5 will linearize to

$$\ln MR = \ln\frac{6}{\varepsilon_1} - \varepsilon_1 D_e (\frac{1}{R_c})^2 t \quad (6)$$

The effective diffusivity, De in the drying system can then be obtained from the slope of the plot of $\ln(MR)$ versus drying time, t with intercept $\ln\frac{6}{\varepsilon_1}$

$$De = Slope\ of\ plot \frac{R_c^2}{\varepsilon_1} \quad (7)$$

And from equation 2, if values of Me are small in relation to values of M and M_o (assumed to be zero) in [22,23] then the equation would reduce to

$$MR = \frac{M}{M_o} \quad (8)$$

Thin-layer drying models

The use of mathematical models in estimating the behavior of agricultural and other bio-materials during drying is common in technical literature. Several of such thin-layer drying models are listed in Table 1 (the Lewis, the Page and the Henderson-Pabis models respectively) are selected for validation in this work on African Giant Snail (*Achatina achatina*). From equation 5, taking n=1 and further simplifying would bring about the thin layer drying equation of the Lewis model (Table 1).

$$MR = e^{-kt} \quad (9)$$

The Henderson-Pabis model (Table 1)

$$MR = A\, e^{-kt} \quad (10)$$

and when n>1, the Page model (Table 1)

$$MR = e^{-kt^n} \quad (11)$$

Equation 9 can further simplify as

$$ln(MR) = ln(k) - kt \quad (12)$$

Or,

$$ln\left(\frac{M}{M_o}\right) = ln(k) - kt \quad (13)$$

Where ln(k) is seen as kinetic (drying) rate constant and a, b, n are model constants.

Then the plot of moisture ratio on natural logarithm axis against drying time of equation 11, the intercept, ln(k) on the moisture ratio axis and slope, -kt, the effective diffusivity, De can now be deduced.

Table 1: List of Thin-layer Drying Models with References.

S/No.	Title of Model	Model Expression	Reference
1	Lewis	MR = exp(-kt)	(Kingly et al., 2007)
2	Page	MR = exp(-kt^n)	(Page, 1946)
3	Henderson & Pabis	MR = a exp(-kt)	(Togrul, 2003)

Activation energy, Ea

This is energy required to initiate the diffusion (the phenomenon of moisture transport) during drying of biological materials. Activation energy, Ea can be estimated from the relationship between Effective diffusivity, De and temperature, t which is assumed to be an Arrhenius type function given as [24].

$$D_e = D_o (e^{-\frac{E_a}{Rt}}) \quad (14)$$

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 (12) gives

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

Or,

$$-\frac{E_a}{R} t^{-1} = \ln nD_e - \ln nD_o \quad (16)$$

$$\frac{E_a}{Rt} = \ln\left(\frac{D_0}{D_e}\right) \quad (17)$$

$$\frac{E_a}{R} t^{-1} = \ln\left(\frac{D_0}{D_e}\right) \quad (18)$$

Plotting of lnDe as a function of t-1 (Figure 3) will be linear with intercept, lnDo and slope, -Ea/R; then the activation energy can be estimated [25].

$$E_a = -ve\ slope(R) \quad (19)$$

Obtaining drying curves

Drying rates and their control are essential in describing thin-layer drying. Higher drying rates at the different drying temperatures can reduce drying time [26]. However, drying at high temperatures (say above 80°C) in several drying conditions, could adversely affect the final quality of high body moisture materials [27,28]. The reduction of moisture in the drying process can possibly to relate in say (y) direction in a given split for a given drying temperature to the drying time (t) in a cubic polynomial form as follows [29].

$$y = c_0 + c_1 t + c_2 t^2 + c_3 t^3 + c_4 t^4 \ldots. \quad (20)$$

Where the c's are constants caring for the intrinsic factors in the drying process. Differentiating equation 20 with respect to time will yield drying rate as follows.

$$\frac{dy}{dt} = -\left(c_1 + 2c_2 t + 3c_3 t^2 + 4c_4 t^3 \ldots\right) \quad (21)$$

The negative sign indicates decay in drying rate with passage of drying time. Considering higher powers of t as negligible, equation 19 can reduce to:

$$Drying\ rate \left(\frac{dy}{dt}\right) = -\left(c_1 + 2c_2 t + 3c_3 t^2\right) \quad (22)$$

Equation 22 is semi-parabolic on a drying rate *vs* drying time plot, yielding drying curves for the different drying temperatures chosen in this work.

MATERIALS AND METHOD

Sample preparation

A large quantity of freshly harvested African Giant Snail (*Achachatina achatina*) (some 25 kg) was obtained from a local but general market at Ondewari town in Southern Ijaw Local Government Area of Bayelsa state, Nigeria. They were thoroughly washed in fresh water and meat was carefully removed from the shell using sterilize needle and allowed to stabilize in the ambience of the Laboratory. Using a 0.001 cm precision veneer caliper each of the African Giant Snail (*Achachatina achatina*) meat to be used in the drying tests was measured of the basic dimensions, stratified into groups of different but equal thickness and length, re-stabilized and stored without any further treatment in refrigerated cabinets in the Food Processing Laboratory, Department of Agricultural and Environmental Engineering of Niger Delta University, Bayelsa State. Identical samples were then drawn from the stratified lot for the drying tests. The samples were then oven dried in a thin-layered form, to a constant final weight using WTC binder oven Model WTCB 1718 at varying temperatures from 60°C-100°C with increments of 10°C. All weight measurements were done using a laboratory-type top digital balance with 0.01 g precision. The initial and all other moisture content values were taken using the oven method of ASAE standard (ASAE, 2000). The moisture reduction process (i.e. weight loss) for each sample was monitored at specific time intervals (of about 10 min) to point of equilibrium and in a manner as described in the works of [19] on Spiced Okpokuru (*Oryctes rhinoceros*), and on catfish. All the drying tests were replicated thrice at each temperature level and average values were recorded. The weight differences before and after drying were used to determine the final moisture content for each replicate, all measured on dry-basis [31].

$$M = \frac{w_i - w_f}{w_f} \quad (23)$$

Where,

M=dry basis moisture content, %-db

Wi=initial weight of the specimen, g

Wf=initial weight of the specimen, g.

Statistics for goodness of fit

Thin-layer drying models can normally be evaluated and the quality of fit compared using certain statistical indicators such as coefficient of determination, R_2; the non-parametric reduced chi-square, χ^2, the root mean square error, RMSE and mean bias error MBE. The usual criteria are that an acceptable goodness of fit is said to have occurred in describing the drying curve of a given model if R_2 value is high and the values of other indicators, χ^2, RMSE and MBE are low. In this work, the experimental drying data of the samples obtained at different temperatures were used to fit into the three commonly used thin-layer drying models. The goodness of fit of the selected mathematical models to the experimental data was evaluated using the given criteria. The statistical parameters used as the indicators were calculated as follows [32-34].

$$R^2 = 1 - [\sum_{i=1}^{n} (MR_{pre,i} - MR_{\exp,i})^2] \quad (24)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (MR_{pre,i} - MR_{\exp,i})^2}{n}} \quad (25)$$

$$\chi^2 = \frac{\sum_{i=1}^{n} (MR_{pre,i} - MR_{\exp,i})^2}{n-k} \quad (26)$$

$$MBE = [\sum_{i=1}^{n} (MR_{pre,i} - MR_{\exp,i})^2] \quad (27)$$

Where,

$MR_{pre.}$=predicted moisture ratio

$MR_{exp.}$=experimental moisture ratio

n=number of observations

k is as previously defined.

RESULTS AND DISCUSSION

Characterizing drying kinetics

It was necessary to transform the drying data obtained from the experiments into dimensionless Moisture Ratios (MR). These MR values were then plotted as a function of drying time for the African Giant Snail (*Achachatina achatina*) respectively at the selected temperatures (Figure 2), while Figure 4 presents the variations of the moisture ratios given in logarithmic form [ln(MR)] plotted as a function of drying time. This is drawn to enable the estimation of activation energy in the drying system. It is known that activation energy promotes the molecular transport phenomenon (diffusion) that drives the drying process. The moisture ratios are all given in dry basis (db). The plots in the Figures are observed to have followed the general trend of drying curves as reported for many bio-materials. The curves exhibited initial steeper slope, an indication of an initial increased and accelerated moisture loss in drying. This could be due to increased water activity within the samples resulting from a quicker migration of moisture to the surface for evaporation and evacuation, helping to shorten the drying time. The drying process however, became slower (the curves became flattened) at the later stages, even with increasing temperatures (Figure 2) as lesser and lesser water become available for evaporation at the surface of the samples.

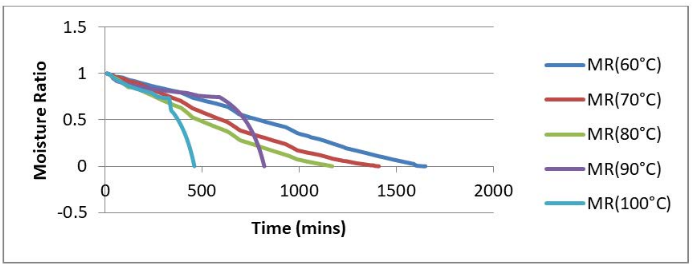

Figure 2: Moisture ratio versus drying time of African Giant Snail (*Achachatina achatina*) at different temperatures.

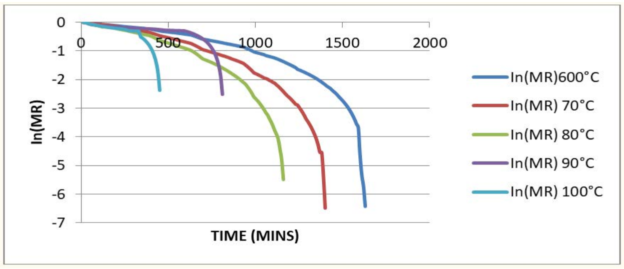

Figure 3: Drying curves of (Logarithmic moisture ratio vs drying time).

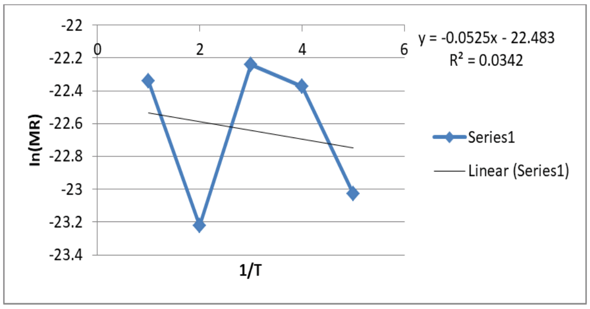

Figure 4: Estimation of Activation Energy for specimens of African Giant Snail (*Achachatina achatina*).

This is rather characteristic of such bio-materials with high constituent moisture mixed with fats/oils and protein which greatly reduce water activity even with increase in drying temperature. The situation is also typical of a falling rate drying period without the feature of case-hardening even on the high temperatures ranges, generally agreeing with reports on thin layer drying works on fresh water clam, salted catfish fillets [13,35-37].

Fitting experimental data into thin-layer drying models

The transformed dimensionless moisture ratios were used to fit to the empirical models of ANN, Lewis, Page, and Henderson and Pabis, respectively, and for all the different drying temperatures chosen in this work. The fitted parameters were subjected to statistical analysis for all the drying conditions (Table 2 and Table 3). The fitting results in concurrence with the statistical analysis showed that the coefficient of determination, R_2 values were consistently high in the range of 0.8389-1.000 for all the models. The indication here is that all the used empirical models could satisfactorily describe the drying behavior of the samples. When tuned further with the other statistical parameters, the model expression of ANN and Henderson-Pabis model followed by that of the Page model had the highest R_2 values and the lowest χ^2 and RMSE values in the temperature range of the work. This showed the suitability of these models in describing the drying kinetics of the samples. It was therefore, satisfactory to selected ANN and Henderson-Pabis model to predict the drying kinetics of the African Giant Snail (*Achachatina achatina*) on the drying temperatures applied in this work Figure 5 and Figure 6.

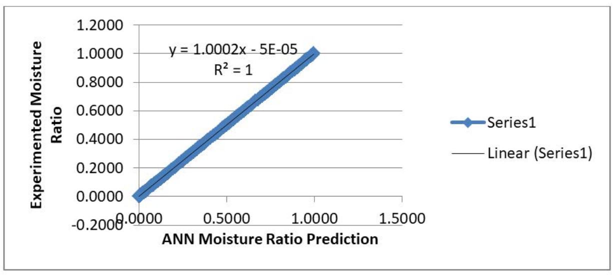

Figure 5: Relationship between Experimented Moisture ratio and ANN Moisture Ratio Prediction at 70°C.

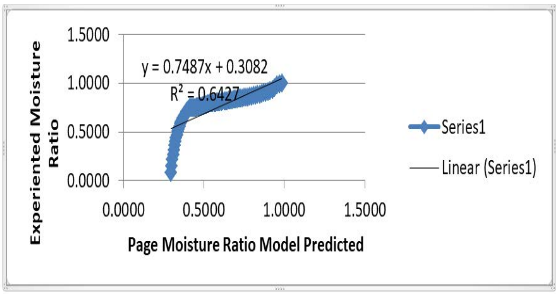

Figure 6: Relationship between Experimented Moisture ratio and Page Model Moisture Ratio Prediction at 70°C.

Estimation of effective moisture diffusivity and activation energy

Using data obtained from the drying experiments, the logarithmic moisture ratio values, ln(MR) were plotted as a function of drying time, t at the various drying temperatures (Figure 2). Estimation of the effective moisture diffusivity was then done using the method of slopes, derived from the regression line relating the ln(MR) values and the varying drying times, validated with the corresponding coefficients of determination, R_2 (at 1.000). It is clear from Figure 2 that effective moisture diffusivity, De increased fairly greatly as drying temperatures increased. This is expected because, though, the temperature dependency of moisture retention capacity of a visco-elastic material is a function of the body structure and the presence of void fractions and is known to significantly affect moisture diffusivity, it is shown that less energy was required to remove moisture at the higher drying temperatures as the water molecules obviously become more loosely bound to the body matrix of the samples than at lower drying temperatures. In fact, the De values ranged from 22.19110 $m^2/min \times 10\ m^2$-10 m^2/min-8.219 × 10 m^2/min-11 m^2/min. This observation is similar to that indicated for palm weevil larvae for shrimps [13,38,39].

Table 2: Statistical Parameters of African Giant Snail (*Achatina achatina*) on Three Selected Thin-layer Drying Models.

PAGE MODEL				
TEMP	MBE	X²	RMSE	R²
60°C	0.03145	0.000192	0.013764	0.9686
70°C	0.0081	5.76E-05	0.00759	0.9919
80°C	0.2665	0.001645	0.040389	0.8389
90°C	0.0239	0.00023	0.017004	0.976
100°C	0.02742	0.000609	0.024416	0.9726
LEWIS MODEL				
TEMP	MBE	X²	RMSE	R²
60°C	0.0432	0.000264	0.001261	0.9567
70°C	0.03689	0.000262	0.016118	0.9631
80°C	0.03128	0.000267	0.016282	0.9687
90°C	0.00929	0.000113	0.010584	0.9907
100°C	0.02629	0.00056	0.0237	0.937
HENDERSON MODEL				
TEMP	MBE	X²	RMSE	R²
60°C	0.00092	5.58E-06	0.002355	0.999
70°C	0.002556	1.83E-05	0.004242	0.9974
80°C	0.001811	1.56E-05	0.003918	0.9982
90°C	8.63E-07	1.07E-07	0.000322	1
100°C	5.14E-07	1.15E-09	3.31E-05	1

Table 3: Artificial Neural Network Prediction (ANN) on African Giant Snail (*Achatina achatina*).

S/N	Temperature	RMSE	X^2	MBE	R^2
1	60°C	1.3907E-06	1.934E-12	3.191E-10	1
2	70°C	0.00000291	1.6668E-12	2.35E-10	1
3	80°C	6.3034E-06	3.973E-11	4.649E-09	1
4	90°C	3.68E-08	1.355E-11	1.112E-09	1
5	100°C	0.000111	1.234E-08	5.67805E-07	0.9999

mud snail meat Figure 3 was drawn to linearize Figure 2 to enable the estimation of the process activation energy, Ea using the slope method. It can be observed in the figure 3 that the plot is only slightly negative meeting with the required orientation for the slope method. The evaluated value of the process activation energy, Ea gave 22.5 kJ/mol which is seen to be within the literature range of 12.7 kJ/mol-110 kJ/mol for high moisture biomaterials and 21.6 kJ/mol-39.03 kJ/mol for fruits and vegetables [30,40-53].

CONCLUSION

African Giant Snail (*Achachatina achatina*) was investigated to estimate its drying kinetics on thin layers. In line with other biological materials as reported in several technical literatures drying was observed to follow the falling rate period. In the work, experimental data were fitted to four selected thin-layer models to explore the best for predicting the drying kinetics of the samples. ANN and Henderson-Pabis model followed closely by Page model were observed to present good estimators of the drying behaviour of the Page model the drying temperature so applied. The activation energy value was deduced to be 22.5 KJ/mol and falls within the range as in technical literature over the same temperature range in this work. The effective moisture diffusivity values increased with increase of drying temperature.

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