International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 12 Issue 3 ǁ March 2024 ǁ PP. 319-328

Drying Kinetics of Smoked Catfish Using an Improved Smoking Kiln

Eke, Mike Ojotu[1], Okedokun, Olukayode Williams[2*], Yusufu Muhammed Ikagu[3], Kamaldeen Oladimeji Salaudeen[3], Adarabierin Imoleayo[3].

[1]Department of Food Science and Technology, University of Agriculture, Makurdi, Nigeria
*[*2]Federal College of Animal Health and Production Technology, Ibadan, Nigeria.*
[3]Nigerian Stored Products Research Institute (NSPRI), Kano Station,
*Email address: sirkay0889@gmail.com *Corresponding author.*

ABSTRACT
Smoking is a long period of preservation of fresh fish from deteriorating and preventing the loss of its nutritional value. This present work was aimed at investigating the mathematical modeling of smoked catfish folded in horseshoe shape using an improved smoking kiln with indirect sources of heat. Modeling drying kinetics of the improved smoking kiln was carried out using data obtained from the drying process of catfish samples dried on the four trays of the kiln. Data were fitted into seven empirical models after simplifying them into linear regression analysis using SPSS version 20 and Sigma-Plot 14 statistical software. Lewis model was best fitted and selected based on the highest coefficient of determination (R^2) tending to 1.0000, the least Root Mean Square Error (RMSE), and the least Chi-square ($\chi 2$) values tending to 0.0000. Drying on the four trays of the kiln without exchanging the positions of the trays during the drying process was archived after 12 h at 9.73 % moisture content, mean drying rate of 2.31 kg/h, and total output capacity of 2.79 kg/h. Effective moisture diffusivity (D_{eff}), and Activation Energy (E_a) were determined for the smoked catfish using a linearized Arrhenius equation. Four Lewis model equations were developed that describe the drying kinetics for the four drying trays in the smoking kiln. Samples in Tray D closest to the charcoal box had the highest value of D_{eff} and the lowest value of E_a. The result showed that the higher the temperature, the higher the effective diffusivity; and the higher the drying temperature the lower the activation energy of thin-layer drying of catfish with an improved smoking kiln.

Keywords: *Modelling, Drying kinetics, Effective diffusivity. Activation energy, Drying.*

Date of Submission: 10-03-2024 Date of acceptance: 23-03-2024

I. INTRODUCTION

Fish production in Nigeria and the world over forms an important source of food, nutrition, income generation, and recreation (Ozigbo, *et al*., 2014). It is a very good source of animal protein, omega-3 fatty acids, and other vitamins and minerals necessary for body development. But it's an highly perishable food material and will begin to deteriorate a few minutes after post-mortem. Several methods of preservation that have been adopted to increase the shelf-life of fish include salt curing, sun drying, smoking, cold storage, freezing, and canning (Sameer, 2020). These methods of preservation have been able to increase the shelf-life of fish from a few hours to months depending on the type adopted. In Nigeria, and other developing countries of the world the most common method of preservation and increasing the shelf-life of caught fish is smoking and drying (Akande and Adeyemi 2016; Adeyeye *et al*., 2015). Emmanuel *et al*. (2015), gave the advantages of smoked fish as increasing the product shelf-life, giving better flavor, and making protein available to the generality of people all year round. In addition to these, the heat treatment processing technology of the smoking kiln is simple and cheap. Smoking is a long period of preservation lasting from a few hours to some months depending on the type and system of smoking. The natural chemicals in the smoke of smoldering charcoal from hardwood have the added benefit of both killing and inhibiting the future growth of mold, yeasts, and bacteria. These chemicals are the basic reason for the preservation power of the smoking process (Akande and Adeyemi; 2016).

Drying kinetics according to Agarry et al. (2013) and Tenyang et al. (2013), is an intensive energy post-harvest unit operation. Thin-layer method of drying is a general way of drying most food and agricultural materials to extend their shelf-life by reducing considerably their moisture stress (Nwakuba *et al*., 2018 Taheri-Garavand *et al.* 2011). It is a theory that throws light into the process of heat and removal of moisture from food materials and is very important in the development of drying models (Adeyeye *et. al*., 2019; Gupta and Patil, 2014). According to Mehmet, et al. (2015), a deep understanding of mass transfer is required to make use of mathematical models in designing and optimizing the drying process of agricultural food materials.

Different models such as Lewis, Henderson, and Pabis, Logarithmic, Page, etc, have been developed to estimate the drying processes of agricultural materials by researchers. The drying kinetics of fresh catfish folded in horseshoe shape and smoked with an indirect smoking kiln has not been adequately studied in the literature. This present work aims to investigate the drying kinetics of African mudfish (*Clarias garipenus*) with the objectives of developing mathematical expressions of estimating the thin-layer drying kinetics, determining their activation energy E_a and the effective moisture diffusivity D_{eff}.

II. Materials and Methods

Preparation of Samples

Fish samples for the experiment were prepared according to the method described by Omodara, et al. (2016). Upon receiving, the catfish were tranquilized with salt, butchered, completely degutted, and washed to remove mucilage and blood stains. The fish was then cured (soaked in a solution of 350g of salt in 50 liters of water for 30 min). This treatment was to reduce moisture from fish tissue before smoking and also to add taste. Thereafter samples were folded into a horseshoe shape and arranged on the four (4) drying trays under room temperature to remove surface water for 1h before loading inside a preheated kiln dryer. The improved smoking kiln used was purposely designed and fabricated for this experiment. Data for analysis were collected during the smoking process.

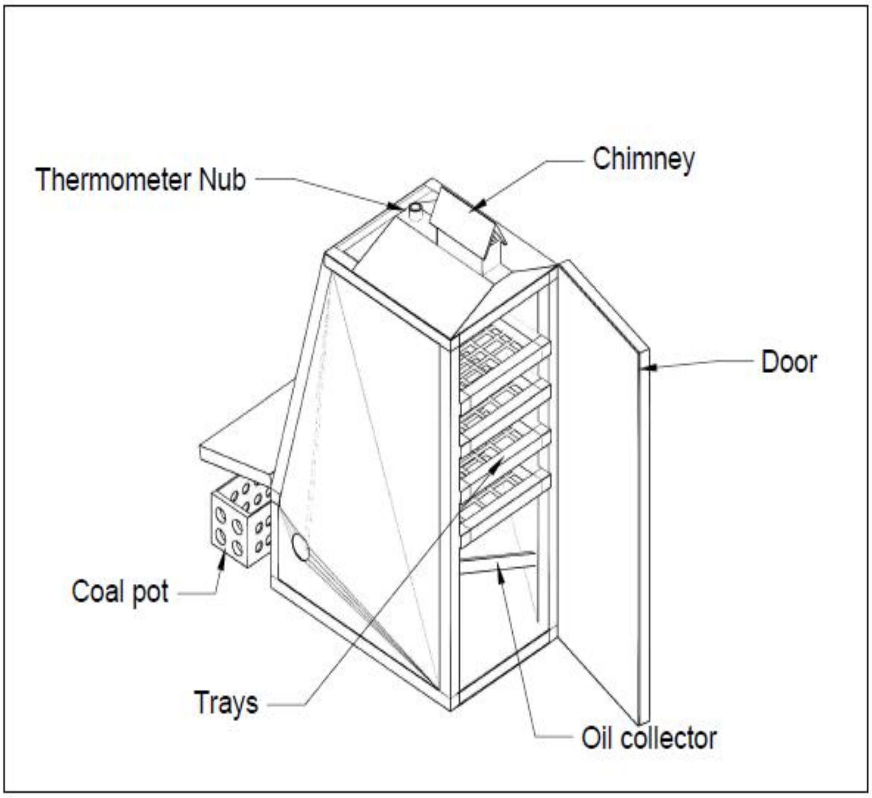

Figure 1: Component parts of the Developed Smoking Kiln.

Drying Rate
Three batches of fish were dried inside the smoking kiln. Each set of fresh fish was weighed on a digital scale with the initial weight recorded as M_1 (g) at pre-loading inside the smoking chamber. The initial time T_1 when drying commences was also recorded. As drying progressed, at a regular interval of 1h the drying fish trays were brought out to measure the weight on a digital scale and recorded. This continued until the weight became constant at safe moisture content on a dry basis (Ikenweiwe *et al.*,2010). The final weight was recorded as M_2 and the final time as T_2. The mean smoking rate for the three batches was then determined. The drying rate of the fish was calculated from equation 18 as given by Omodara et al. (2016).

$$R = \frac{dm}{dt} = \frac{M_1 - M_2}{T_2 - T_1} \quad (1)$$

$$\text{Mean drying rate } R_{mean} = \frac{R_1 + R_2 + R_3}{3} \quad (2)$$

Where R = Drying rate, dm = change in mass, dt= change in time (h), M_1= initial weight of fresh fish, and M_2= Final weight of dried fish.

Moisture Content (MC)
Moisture content (MC) of the dried sample was calculated from equation (3) below as given by Agarry et al. (2013).

$$MC = \frac{M_w - M_d}{M_w} \% \quad (3)$$

Where: MC= Moisture Content;
M_w = Wet mass of the sample, M_d= Dried mass of the sample

Output Capacity
The output capacity of the newly developed smoking kiln was calculated by the following expression:

$$\text{Output Capacity} = \frac{\text{Total weight of fresh catfish smoked (Kg)}}{\text{Total Time Taken to Smoke (hr)}} \quad (4)$$

Modelling the Obtained Data from the Experiments
Moisture Ratio (MR)
The method of calculating MR as described by Mehmet et al. (2015) was adopted. Moisture ratio for thin layer drying of sample was expressed as:

$$MR = \frac{M_t - M_e}{M_o - M_e} \quad (5)$$

Where MR is the dimensionless moisture rate, M_t is moisture content dried bases (kg water/kg dry matter) at any time t during drying process, M_o is the initial moisture content (kg water/kg dry matter) of the fish and M_e is the equilibrium moisture content which was taken to be zero (M_e = 0) because it was relatively small compared to M_t or M_o for a thin layer drying of food material such as fish (Mehmet et al. 2015; Agarry et al. 2013). The Moisture Rate formula now arrived at equation (6)

$$MR = \frac{M_t}{M_o} \quad (6)$$

Drying Kinetics of Smoked Catfish
Drying kinetics is a method of predicting the drying curve pattern of agricultural material. This is done by fitting the experimental data obtained into mathematical models. The measured drying properties such as moisture ratio, temperature, drying rate, smoking time, diffusivity etc are fitted into empirical model equations to predict the drying pattern of materials (Aggary *et al.*, 2013). Some empirical equations are available for predicting drying patterns. Seven common types were chosen to be fitted for this current work. These are Lewis, Page, Handerson, Logarithmic, Two Term, Wang and Pabis, and Thompson Models.

Table 1: Model Equations for Drying Kinetics

S/N	Model Names	Equations
1	Lewis	$MR = \exp^{-kt}$
2	Page	$MR = \exp(-kt^n)$
3	Henderson and Pabis	$MR = a\exp(-kt)$
4	Logarithmic	$MR = ae^{(-kt)} + C$
5	Two Terms	$MR = a\exp(-k_1t) + b\exp(-k_2t)$
6	Wang and sigh	$MR = 1 + a.t + b.t^2$
7	Thompson	$t = a. \ln MR + b.(\ln MR)^2$

Adapted from Mehmet. et al. (2015).

For the selected models, the equations were simplified into linear regression using the statistical analysis software SPSS 17 (For Lewis and Page Models) and Sigma Plot 14 (For Handerson, Logarithmic, Two Term, Wang and Pabis, and Thompson Models). The Statistical values for the various model parameters generated from the two software packages used were then recorded.

Goodness of Fitting of Data into Model Equations

The goodness of fit of the dehydration parameters is the selection of the best empirical models out of the chosen models to describe the drying curve of moisture rate (MR) against drying time (T) using statistical software SPSS 17 version and Sigma Plot 14. The criteria considered included the closeness of the coefficient of determination (R^2) to 1.0000, the least values (closeness to 0.0000) of both chi-square ($\chi 2$) and the Root Mean Square Error (RMSE) given by the following equations:

$$R^2 = \frac{\sum_{i=1}^{N} (MR_{prei} - MR_{\exp ave})^2}{\sum_{i=1}^{N} (MR_{\exp i} - MR_{\exp ave})^2} \quad (7)$$

$$RMSE = [\frac{1}{N} \sum_i^N (MR_{predi} - MR_{\exp i})^2]^{1/2} \quad (8)$$

$$\chi 2 = \sum_{i=1}^{N} \frac{(MR_{\exp i} - MR_{pre,i})^2}{N - Z} \quad (9)$$

Where: $MR_{pre\ i}$ is the ith experimental predicted moisture ratio.
$MR_{exp\ i}$ is the ith experimental observations moisture ratio.
$MR_{pre,\ avg}$ is the average experimental moisture ratio,
N is the number of experimental observations.
Z is the number of constants.

Determination of Effective Diffusivity (D_{eff})

During the drying process, mass transfer occurs from one layer to the other from the product's inner core to the outside layer by diffusion before it evaporates from the surface (Rayaguru, and Routray 2012). The factors that determine the rate of diffusivity of mass transfer in drying food materials include - size, thickness, arrangement/orientation, configuration, and type/species among others (Nwakuba *et al.*, 2018, Tenyang *et al.*, 2013).

The effective diffusivity (D_{eff}) of drying kinetics of smoked catfish was determined by calculation based on the mathematical model of Fick's second law of diffusion (equation 10) that expresses a relationship between moisture ratio (MR) and effective moisture diffusivity (D_{eff}) (Mehmet *et al.*, 2015, Agarry *et al.*, 2013). Experimental data were fitted into equation (10) after performing linear regression analysis on the equation to obtain an expression for $D_{eff.}$

$$MR = \frac{8}{\pi^2} \exp(-\frac{\pi^2 D_{eff} t}{4L^2}) \quad (10)$$

Linearizing equation (10) gave (11)

ln ($\frac{(MR\pi^2)}{8} = \frac{\pi^2 D_{eff}}{4L^2}(t)$ (11)

Slope of the linear graph = $\frac{\pi^2 D_{eff}}{4L^2}(t)$ (12)

$D_{eff} = \frac{4L^2 t}{\pi^2}$ (13)

Where:
Π= 3.142, MR = Moisture Ratio, D_{eff} = Effective Diffusivity (m^2/s), L = Thickness of the samples (m). In the case of catfish formed into a horseshoe shape, it was assumed that the thickness L is constant for all samples since their average sizes were not significantly different. L was then assumed as a unit. t = Drying temperature measured in Kelvin(K).

Determination of Activation Energy (E_a)

The activation energy for diffusivity is the energy required for diffusion to take place between layers of the product during the drying process. It was estimated from the Arrhenius equation as given below:

K = $Ae - {}^{Ea}\!/_{RT}$ (14)

Linearizing equation (14) gives:

lnK= lnA - $\frac{Ea}{RT}$ (15)

lnK = - $(\frac{Ea}{R})\frac{1}{T}$ (16)

Ea was estimated by plotting the graph of lnK against $\frac{1}{T}$

Ea = -lnK. (RT) (17)

Where: Ea = Activation energy, K = Rate constant, R = Gas constant given as 8.314 J/mol, T = Absolute temperature (K).

III. RESULTS AND DISCUSSION

Effect of Drying on Catfish (*Clarias garipenius*)

The drying rate of any material is determined by the following factors: the thickness/size of the material, the amount/steadiness of heat energy available, orientation/arrangement of materials to be dried in the drying chamber, and rate of moisture removal from the drying zone. The heat energy supplied from charcoal attained a maximum temperature of 130 ^oC before trays of fresh catfish were loaded in the kiln and steadily reduced to 80-85^oC which was high enough to achieve drying of the fish samples within twelve hours. This result was similar to that of Olayemi et al. (2013) who obtained an average drying temperature of 85 ^oC at full loading. The Drying Rate and Output Capacity results were 2.31kg/h and 2.79 kg/h respectively. This was an improvement to NSPRI (Olayemi *et al.*,2013) Charcoal, Gas, and Electric smoking kilns having Drying rates of 1.15kg/h, 1.78kg/h and 2.14kg/h respectively. Their drying time was Charcoal 24 h, Gas 18 h, and Electric 17 h compared with the drying time of 12 h for this new design. This can be attributed to good hot air circulation by natural convection currents within the system. It shows that the kiln can be successfully operated without a blower. The short height of the kiln could account for this advantage which has further reduced the cost of production of the kiln. The double-walled body also made this design operator friendly and heat that could have been dissipated to the surroundings was made good use of in smoking the fish.

The result of moisture ratio (MR) of the smoked catfish from figure 1 indicates a steady loss of moisture from the layers of fish tissues to the surrounding atmosphere following a falling rate drying pattern. The drying pattern of the fish on the four drying trays shows a similar pattern. This can be adduced to even distribution of heat throughout the burning chamber of the improved smoking kiln. This is similar to the findings of Mehmet et al. (2015) in drying salmon and trout fillets using ultrasonic vacuum dryer; Rayaguru and Routray, (2012) in oven dried stone apple slices; Najla and Bawatharan, (2019) in solar drying of red chillies.

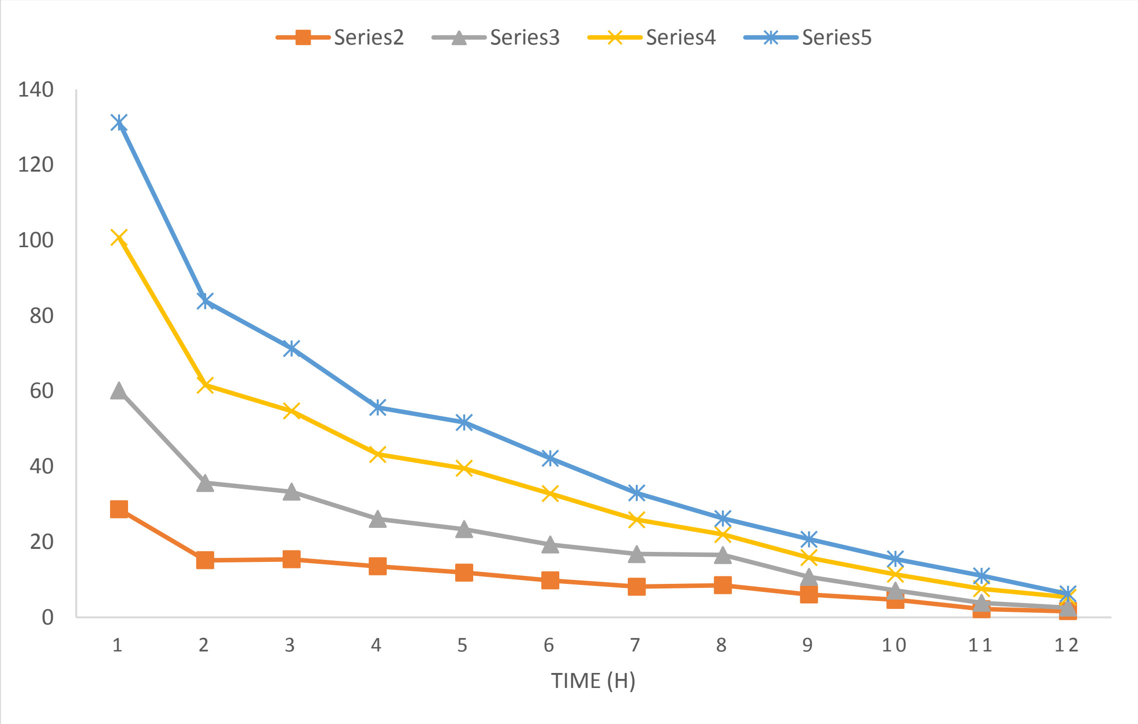

Figure 1: Percentage Moisture Ratio (MR) against Time (h) Graph for the Drying Trays

Drying Kinetics of the Smoked Catfish

The data obtained from the drying behaviour were fitted into seven empirical models such as Henderson and Pabis, Logarithmic, Two-Term, Wang and Singh, Page, Lewis, and Thompson models to determine which of them was most suitable for predicting the drying curve for catfish on each tray. The results of various model parameters are presented in Table 2. Out of the seven fitted, the Lewis model was found to be the most fitted. The results were as follows: RMSE ranges from 0.104 - 0.2743, Chi-square result ranges from 0.013-0.0883, coefficient of proportionality R ranges from 0.947-0.990, R^2 ranges from 0.896-0.980 and rate constant k ranged from -0.263 to -0.203 for tray A to D respectively. From the result, the values of drying rate constant K for tray A to D shows no significant ($p<0.05$) difference. The result of this smoking kiln confirmed an improved version with the shortening of time of operation, positioning of a charcoal box that discourages impartation of polycyclic aromatic hydrocarbon (PAHs) on smoked fish that are carcinogenic in nature when compared with the earlier work of Olayemi et al. (2013), Ikenwiewa et al. (2010), Magawata and Musa (2015).

In this work, the rate of moisture removal from the fish per unit time on all the trays was almost the same regardless of the position of the trays to the heat source. It is an improvement on previous work whereby drying trays had to be rearranged in the course of drying as a result of poor circulation of hot air. This improvement can be attributed to good hot air circulation through natural convection, conduction, and radiation. The heat loss to the surroundings through any of these three means of heat transfer was negligible and this can be a result of the lagging between the double-layer walls of the smoking kiln. Also, the health of the operator was guaranteed throughout the processing period since they were not exposed to excessive heat from the kiln

Table 2 ModellingDrying Kinetics of the kiln

Models	Parameters	Tray A	Tray B	Tray C	Tray D
Henderson and Pabis	RMSE	1.529	1.168	1.134	0.780
	$\chi 2$	2.8056	1.6356	1.5421	1.678
	R^2	0.9421	0.9685	0.9788	0.9854
	a	14.74	28.22	33.90	28.34
	b	0.105	0.208	0.2045	0.214
Logarithmic	RMSE	1.512	1.106	1.125	0.779
	$\chi 2$	3.048	1.632	1.518	1.842
	R^2	0.9222	0.9717	0.9791	0.9854
	a	23.47	29.40	34.21	28.38

	b	0.1714	0.1637	0.191	0.211
	c	-2.367	-2.58	-0.82	0.126
Two Term	RMSE	1.1265	1.1675	1.1336	0.7448
	$\chi 2$	1.9036	2.045	1.928	1.886
	R^2	0.9577	0.9685	0.9788	0.9867
	a	27.18	14.24	17.1	9.63
	K_1	10.89	0.208	0.204	1.88
	b	19.83	13.98	16.80	26.89
	K_2	0.1445	0.208	0.2045	0.204
Wang and Singh	RMSE	1.58	1.253	1.2178	0.9966
	$\chi 2$	2.9955	1.883	1.78	2.182
	R^2	0.9170	0.9637	0.9755	0.9762
	a	-2.48	-3.43	-4.64	-3926
	b	0.075	0.123	0.1921	0.165
Thompson	RMSE	0.6451	0.5519	0.4788	0.6308
	$\chi 2$	0.4995	0.335	0.2751	0.478
	R^2	0.9651	0.9744	0.9808	0.9666
	a	-1.10	-0.578	-3.923	-0.876
	b	0.075	-0.941	-0159	-0.912
Lewis	RMSE	0.239	0.269	0.104	0.274
	$\chi 2$	0.069	0.072	0.013	0.088
	R^2	0.985	0.973	0.980	0.984
	k	-0.203	-0.263	-0.213	-0.238
Page	RMSE	1.329	0.963	1.042	0.722
	$\chi 2$	2.120	1.113	1.304	1.138
	R^2	0.941	0.979	0.982	0.013
	N	-7.345	-8.992	-10.65	-8.873
	k	1.83E9	3.67E9	4.34E12	2.47E10

Where a, b. c, n, k, $k_{1,}$ and k_2 are the model fit parameters.

Table 3. D_{eff}., Ea, R^2 and Model equations of the improved kiln

Trays	D_{eff} x10^{-5} (m^2/s)	Ea J/mole	R^2	Lewis Model Equations
A	2.27	4680.30	0.978	MR = $e^{0.203t}$
B	2.36	4580.53	0.981	MR = $e^{0.263t}$
C	2.39	4538.90	0.980	MR = $e^{0.213t}$
D	2.69	4213.17	0.991	MR = $e^{0.238t}$

Note: MR =Moisture Ratio, t = Drying time e = exponential.

Goodness of Fit and Kinetic Model Prediction of Smoked Fish

In this present work, the experimental data obtained in drying catfish on four wire gauze drying trays hanging at different distances to the source of heat inside the drying chamber of an improved smoking kiln were fitted into seven common empirical models: This is to determine which of the models best described the drying curve of fish on each tray. The experimental data from the four trays were successfully modeled. How well the model fits were determined by the highest R^2 which tends toward 1.0000 and the least RMSE and $\chi 2$ values which tend toward 0.0000 (Taheri-Garavand *et al.*, 2011; Nwakuba *et.al.*, 2018).

Based on the higher R^2, least RMSE, and Chi-square the best model to describe the thin-layer drying kinetics of the smoked catfish was Lewis using the designed smoking kiln.

The linear regression model equations for the four drying trays based on the Lewis equation can be applied to obtain a drying curve pattern under similar drying conditions without necessarily going through experimental procedures. With these equations knowing the moisture ratio (MR) the drying time (t) can easily be predicted.

Equations 18, 19, 20. and 21 can be used to predict the drying behaviour of the studied catfish using the Lewis model for each of the drying trays:

MR = $e^{0.203t}$ – Tray A (18)

MR = $e^{0.263t}$ - Tray B (19)

MR = $e^{0.213t}$ - Tray C (20)

MR = $e^{0.238t}$ -Tray D (21)

Key: MR is the moisture ratio, t is the drying time,

Effective Moisture Diffusivity (D_{eff})

The result of this present work was as presented in Table 3 according to the drying trays positions. It was observed from the result that D_{eff} for trays A, B, C, and D were 2.27 x 10^{-5} m^2/s, 2.36 x 10^{-5} m^2/s, 2.39 x 10^{-5} m^2/s and 2.69 x $10^{-5}$$m^2$/s respectively. Effective moisture diffusivity is the ease of movement of moisture from one layer to the other during the fallen rate period of drying within a food material with the aid of heat energy from a source. (Adeyeye, 2019; Rayaguru and Routray, 2012; Nwakuba *et al.*, 2018) It is quite different from the drying rate which is the vapourization of the released moisture from the material into the surrounding atmosphere per unit time. (Adeyeye, 2019, Aghbashlo *et. al*., 2008), though the two are related as the higher the drying rate, the higher the effective diffusivity and the shorter the time of drying. Tray D which was the closest to the heat source had a higher value of diffusivity followed by C and B up to A in that order. The implication was that the higher the temperature of the drying fish the faster the mass transfer movement; the higher the effective diffusivity rate of the fish sample. Rayaguru and Routray, (2012); Nwakuba et. al (2018); Mehmet et al. (2015); and Aggary et al. (2013), who dried stone apple slices, titus and sardine fish fillets, salmon and trout fillets, and pineapple slices respectively got similar results as this. The D_{eff} result of dried pineapple of Agarry et al. (2013) was smaller compared with the result of this work because it was easier to break the moisture bond in pineapple flesh compared with smoked fish as the tissue of smoked fish was more closely packed than that of pineapple flesh, so it was more difficult for mass transfer to move through. The bigger size and thickness of catfish samples was also a factor.

The result of Activation energy (Ea) value for each tray was A - 4680.03J/mol, B – 4580.53J/mol, C – 4538.90J/mol and D – 4213.17J/mol. It was observed from Figure 1 that the drying pattern of the four trays followed the same trend despite their different positions away from the heat source without swerving their positions during drying. It was observed that the closer the fish tray was to the heat source the lower the E_a of diffusivity. Adeyeye, (2019); and Aghbashlo et al. (2008) defined activation energy E_a as "the energy required to break the moisture particles bonding for moisture movement in fish drying" The E_a of diffusivity for this work shows that the higher the temperature the lower the activation energy. The heat from the charcoal box was high enough to supply the energy required to break the bonds and free the moisture molecules to cause it to move from within the fish to the outside layer where it vaporized and escaped into the atmosphere. The lower the value of Ea, the greater the D_{eff} and the faster the drying of fish samples. Conversely, the farther away from the heat source the fish tray was, the higher the E_a required to free the moisture particles. As observed from the result table, the E_a for trays A to D showed a small difference in values but not significant enough ($p<0.05$). This can be adduced to good circulation of hot air from the bottom to the top of the kiln despite the absence of a fan to aid air circulation. The short height of the kiln might have also contributed to this advantage.

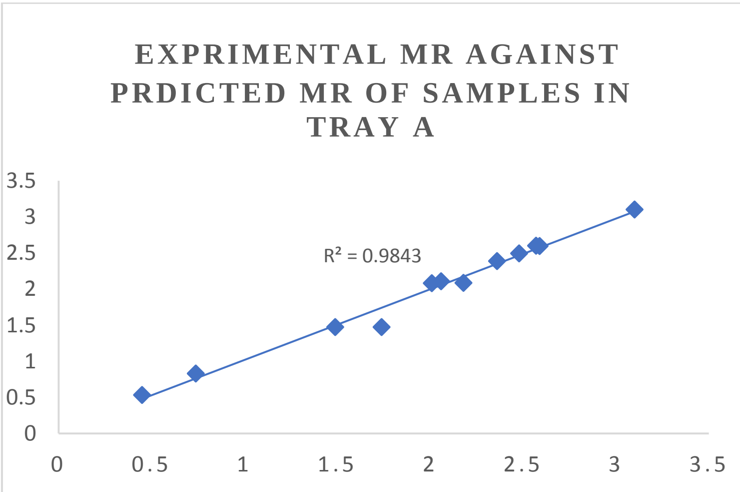

Figure 2. Comparison of Experimental and Predicted Moisture Ratios for Tray A

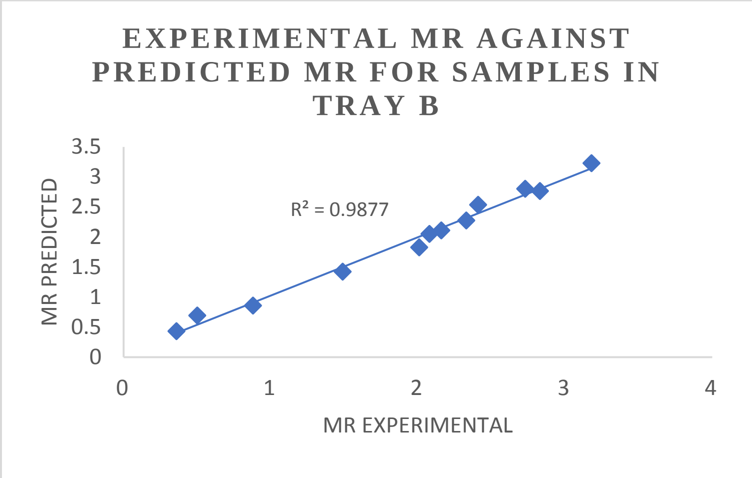

Figure 3. Comparison of Experimental and Predicted Moisture Ratios for Tray B

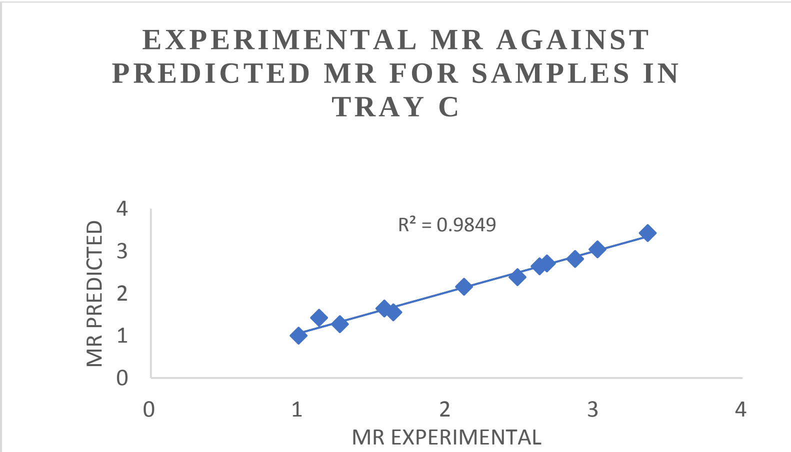

Figure 4. Comparison of Experimental and Predicted Moisture Ratios for Tray C

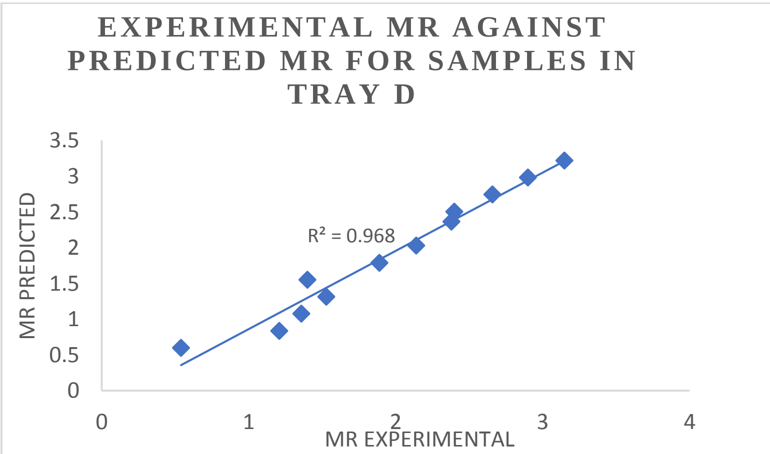

Figure 5. Comparison of Experimental and Predicted Moisture Ratios for Tray D

The Lewis drying model equations (18) to (21) for catfish samples on trays A to D of the improved smoking kiln was validated by plotting the graph of experimental moisture ratio (MR_{exp}) against predicted moisture ratio (MR_{pre}) for each drying trays as shown in Figures 2 to 5. The graphs produced a linear function. The closeness of coefficient of determination (R^2) to unity indicates a goodness of fit of Lewis model to describe the drying kinetics of catfish using the improved smoking kiln.

IV. CONCLUSION

An improved smoking kiln has been developed and evaluated. The temperature profile, smoking rate, output capacity and moisture ratio were all determined. The data obtained from the smoking process of catfish were successfully fitted into seven model equations. Out of the seven, Lewis model best described the drying curve pattern during the fallen rate period of drying. This was based on statistical analysis results of highest value of coefficient of determination (R^2) tending to unity, the least values of root mean square error (RMSE) and chi-square ($\chi 2$) tending towards zero. The drying time to achieve safe moisture content of 9.73 % was 12 h. The mathematical model equations that predicted the drying pattern for catfish on each of the four trays were successfully developed using the parameters obtained from Lewis model. The effective diffusivity and the activation (E_a) of the smoked catfish was determined for the four drying trays and the result indicated that the closer the trays to the heat source the lower the activation energy and the higher the rate of effective diffusivity. The drying curve of catfish on the four trays followed the same pattern. There was no need exchanging tray positions during drying process as hot air from smoldering charcoal was well circulated by natural convection current.

REFERENCES

[1]. Adeyeye S. A., Oyewole O.B., Obadina A.O., Omemu A. M., Adeniran O. E., Oyedele H. A., and Abayomi S. O. (2015). Quality and Safety Assessment of Traditional Smoked Fish from Lagos State, Nigeria. International Journal of Aquaculture, 2015, Vol.5, No.15, 1-9.

[2]. Adeyeye S. and Ayofemi O. (2019). An overview of fish Advances of Science and Technology for Society AIP Conference Procedings. 1755, 050006-1 050006-8; 978-0-7354-1413-6

[3]. Agarry, S.E. Ajani A.O and. Aremu M.O. (2013). Thin Layer Drying Kinetics of Pineapple: Effect of Blanching Temperature – Time Combination Available online at Nigerian Journal of Basic and Applied Science, 21(1): 1-10.

[4]. Akande, G. R., and Adeyemi. R. S. (2016). Performance of a bio-fueled detachable fish smoking kiln. Agricultural Engineering International: CIGR Journal, 18(3):233-244.

[5]. Emmanuel M. A., Abiodun O. A., Awosusi D. (2015). Design, Fabrication and Operation of a Smoking kiln. International Journal of Engineering and Technical Research (IJETR) ISSN: 2321-0869, Volume-3, Issue-3.

[6]. Ikenweiwe, N.B., Bolaji, B.O. and Bolaji, G. A (2010). Fabrication and Performance Assessment of a Locally Developed Fish Smoking Kiln**.** Ozean Journal of Applied Sciences 3(4), 2010 ISSN 1943-2429.

[7]. Magawata I. and Musa T. (2015). Quality characteristics of three Hot-Smoked fish species using locally fabricated Smoking kiln. International Journal of Fisheries and Aquatic Studies 2015; 2(5): 88-92.

[8]. Mehmet B., Mahmut K., Barıs Y. (2015) Dehydration kinetics of salmon and trout fillets using ultrasonic vacuum drying as a novel technique.Journal ofUltrasonics Sonochemistry 27: 495–502.

[9]. Najla M.M.M, And Bawatharani R., (2019) Evaluation of Page Model on Drying Kinetics of Red Chillies. © APR 2019 | IRE Journals | Volume 2 Issue 10 | ISSN: 2456-8880 Nigerian Agricultural Journal. Volume 49 Number 1, Pp.46-56

[10]. Nwakuba, N.R., Okafor, V.C., Abba, E.C. and Nwandikom, G.I (2018). Thin-Layer Drying Kinetics of Fish in a Hybrid Solar-Charcoal Dryer

[11]. Olayemi F. F., Ra.ji A. O., Oyelese, O. A., Oyewole S.N., Omodara Michael A. (2013). Effective Fish Smoking Kiln for Developing Country International Journal of Scientific and Engineering Research Volume 4, Issue 1, 2229-5518.

[12]. Ozigbo E., Anyadike C, and Adegbite O. (2014). Review of Aquaculture Production and Management in Nigeria American Journal of Experimental Agriculture.

[13]. Rayaguru, K. and Routray, W. (2012). Mathematical modeling of thin layer drying kinetics of stone apple slices. International Food Research Journal 19(4): 1503-1510.

[14]. Sameer G. Chebbi (2020). Principles of Fish Preservation and Processing. Pp 1-2 file:///C:/Users/HP/Desktop/Fish%20Production%20%20&%20Preservation/Principles%20of%20fish%20preservation%20and%20processing.htm.

[15]. Taheri-Garavand, A., Rafieea, S. and Keyhania, A. (2011). Mathematical modeling of thin layer drying kinetics of tomato influence of air dryer conditions. International Transaction Journal of Engineering, Management andApplied Sciences and Technologies, 2(2), 147-160.

[16]. Tenyang, N., Macaire W. H., Tiencheu, B. N. and Takugan F. H., Tchouanguep M. F., Villeneuve, P. and Linder, M. (2013). Lipid Oxidation of Catfish (Arius maculatus) after Cooking and Smoking by Different Methods Applied in Cameroon. Food and Nutrition Sciences, 4, 176-187