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DRYING KINETICS OF FISH (*Clarias gariepinus*) SMOKED WITH BIOGAS

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ABSTRACT

This is aimed at studying the aeration kinetics of catfish (Clarias gariepinus) smoked directly with biogas. Five live fresh fishes (Clarias gariepinus) were obtained from Fishery and Aquaculture Technology Department in FUTA, Ondo State, Nigeria at the age of 4 months with average weight of 900 g each. The fishes were killed, de-gutted, thoroughly washed with water, cut into pieces of 3 cm length. The chunks were laid in a single layer on a mesh directly exposed to biogas flame obtained from bio-decomposition of poultry waste and the weight was being monitored at 15 minutes interval until constant weight was observed. The study showed that the time taken for drying of Clarias gariepinus to reach the humidity point of around 12.43% (db.) was two and a half hours. The drying data was subjected to 10 thin-layer drying models. The compared the performances of the models using the determination of coefficient (R^2), reduced chi-square ($\chi 2$) and root mean square error (RMSE) between the calculated and predicted moisture ratios. The results showed that Henderson and Pabis modified model (highest R^2 and lowest $\chi 2$ and RMSE of 0.998, 0.00021 and 0.01386 respectively) *was found to satisfactorily describe the biogas drying curves of Clarias gariepinus.*

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1.0 INTRODUCTION

Fish is one of the main products consumed in terms of animal protein Fish, smoking, biogas, equilibrium moisture content and it is largely consumed in Nigeria. It is preferred over pork or beef in that it is cheap and acceptable without religious bias (Eyo, 2001). According to the Nigeria fishery statistics – 2016 Summary report, the total fish demand for Nigeria calculated on the basis of the current population structure is 3.32m Mt while domestic production from Aquaculture, Artisanal and Industrial fisheries stood at 1.123 m Mt.

This local supply can currently meet 50% of the demand for fish (Udo and Umanah, 2017).

The cheapest means of animal protein is fish which accounts for about 37% of Nigeria's total protein intake. It accounts for 22% of the protein intake in Sub-Sahara Africa (FAO, 2003). Fish is a highly perishable product and there is a need for immediate processing if unrefrigerated to prevent wastages. According to Orengoh and Kisumo, (2007) due to poor treatment, management and

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storage 50% of total annual fish harvest goes to waste. In addition, large amount of fish normally spoils because the landing sites are usually far from markets and consumption points. It is necessary to adopt appropriate as well as affordable processing and preservation techniques for fish especially in the artisanal fishermen's environment in order to reduce the wastage and spoilage of fish during periods of oversupply and to enhance long storage.

Microbial spoilage of fish may be prevented by different methods such as drying, freezing, smoking, salting and use of modified atmospheric storage, (Gupta and Gupta, 2006). The simplest method among the several methods of long term preservation of fish is smoking as it does not require sophisticated equipment or highly skilled workers .One of the major ways of adding values to fish in the Tropics is by smoking and drying.

In developed countries where refrigeration and integrated infrastructures for efficient transportation of perishables are in place, smoking is not a means of fish preservation but used to enhance the flavour of the fish. But in developing countries, hot smoking is still a very important method of fish preservation. In this process, drying is of pricipal importance for preservation because level of moisture in the flesh of fish contributes to bacterial activity and spoilage (Abba *et al*., 2009; Abidemi-Iromini *et al.,* 2011).

In order to smoke and dry fish, several methods have been developed. However, most electricity-driven technologies are not applicable at the artisanal fishermen level due to inadequate supply and high cost of electricity. Some equipment developed for drying of fish includes dryers (mechanical, solar, hybrid etc.), ovens and kilns. . Different models of improved ovens and kilns were developed in various parts of Africa in an effort to develop an effective method of fish smoking (Davies *et al*., 2008; Davies *et* al., 2009)

The study of the experimental kinetics and modeling of the mass transfer phenomenon in fish during air drying therefore continues to be of great interest (Bellagha *et al*., 2002; Bellagha *et al*., 2006; Jain and Pathare, 2007; Chavan *et al*., 2008; Kituu *et al.,* 2010; Boeri *et al*., 2011). Several authors have developed, and analysed models for thin layer drying of biological products, using conventional or solar tunnel dryers (Joshi *et al.,* 2005; Mujaffar and Sankat, 2005; Odote *et al*., 2015). Table 1 shows some thin layer drying models commonly used by different researchers.

Biogas specifically refers to a gas produced by the anaerobic digestion or fermentation of organic matter including manure, sewage sludge, municipal solid waste, biodegradable waste, energy crops or any other biodegradable feedstock. Biogas is composed mainly of methane and carbon dioxide. Therefore, it is very pertinent to study the aeration kinetics of cat fish smoked with biogas.

2.0 MATERIALS AND METHODS

Smoking Procedure

Five live fresh fishes of *Clarias gariepinus* specie were obtained from Fishery and Aquaculture Technology Department of the Federal University of Technology, Akure, Ondo State, Nigeria at the age of 4 months

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Table 1: Thin-layer drying models

S/N	Model Name	Model	References
1.	Newton	MR = exp(-kt)	Ayensu, (1997); Togrul & Pehlivan, (2004); Upadhyay *et al.,* 2008
2.	Page	MR = exp(-kt^n)	Senadeera *et al.*, (2003); Kaleemullah & Kailappan,(2006); Saeed *et al.*, (2006)
3.	Modified Page	MR = exp((kt)^n)	Sogi *et al.*, (2003); Goyal *et al.*, (2007)
4	Modified Page II	MR = exp(-k(t/L^2)^n)	Midilli *et al.* (2002)
5	Henderson & Pabis	MR = a.exp(-kt)	Ozdemir & Devres, (1999); Saeed *et al.* (2006); Kashaninejad *et al.* (2007)
6	Modified Hend. & Pabis	MR = a.exp(-kt)+b.exp(-gt) +c.exp(-ht)	Karathanos, (1999); Yaldiz & Ertekin, (2001); Kaya *et al.*, (2007b)
7	Simplified Fick's (SFFD) diffusion	MR = a.exp(-kt)+c	Lahsasni *et al.*, (2004b); Babalis *et al.*, (2006); Celma *et al.*, 2007
8	Logarithmic	MR = a.exp(-c(t/L2))	Togrul & Pehlivan, (2002; 2003); Wang *et al.*, (2007)
9	Two-term	MR = a.exp(-kt)+ b.exp(k1t)	Rahman *et al.*, (1998); Lahsasni *et al.*, (2004b); Wang *et al.*, (2007)
10	Two-term Exponential	MR = a.exp(-kt)+(1-a)exp(-kat)	Midilli & Kucuk, (2003); Sacilik *et al.*, (2006); Tarigan *et al.*, (2007)
11	Verma *et al*	MR = a.exp(-kt)+(1-a)exp(-gt)	Karathanos, (1999); Yaldiz & Ertekin, (2001); Doymaz, (2005b)
12	Diffusion approach	MR = a.exp(-kt)+(1-a)exp(-kbt)	Yaldiz & Ertekin, (2001); Togrul & Pehlivan, (2002); Wang *et al.*, (2007);
13	Lewis	MR = exp(_kt)	Callaghan JR *et al.*, 1971; Lui Q *et., al* 1997
14	Yagcioglu et al.	MR = aexp(_kt) + c	Yagcioglu A *et al.*, 1999
15	Wang and Singh	MR = 1 + at + bt2	Wang and Singh, 1978
16	Thomson	t = a.ln(MR) + b[ln(MR)]^2	Paulsen andThomson, 1973, Thomson *et al.,*1968
17	Midilli and Kucuk	MR = aexp(_ktn) + bt	(Midilli *et al.,* 2002)
18	Hii et al.	$MR = a \exp(-kt\,n) + c \exp(-gt\,n)$	Hii *et al.,* 2009

with average weight of 900 g each . The fishes were killed, gutted, washed thoroughly with water, cut into pieces of 3 cm length each and placed on the wire gauze of the smoking kiln heated by biogas. The fish chunks were turned at intervals of 30 mins and smoked to an average moisture content of 12.43% wet basis. The products were allowed to cool after smoking, packed in polythene bags to reduce infestation by microorganisms and transferred to the laboratory for analysis.2.0

Determination of Moisture Ratio (MR)

Moisture ratio is the ratio of the moisture content at any given time to the initial moisture content (both relative to the equilibrium moisture content). It was calculated using equation predicted by Thakor *et al.* (1999) and Shivhare *et al.* (2000):

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Plate 1: Fully filled biogas system setup

Plate 2: Freshly sliced clarias set for smoking

$$M_R = \frac{M - M_e}{M_0 - M_e}$$

where; M, M_0 and Me are present, initial and dynamic equilibrium moisture contents respectively. This was later simplified by Togrul and Pehlivan, 2004 and Akpner *et al.* (2006) as

$$M_R = \frac{M_t}{M_0}$$

where M_R is Moisture ratio

M_t is Moisture content at any time t

M_o is Initial Moisture content

Determination of Drying Rate (DR)

The drying rate as expressed by Ceylan *et al.* (2007); Doymaz, (2007) and O¨zbek & Dadali, (2007):

$$D_R = \frac{Mt + dt - Mt}{dt}$$

where D_R is drying rate

M_t is instantaneous moisture content

d_t is change in time

Goodness-of fit statistics

Thin-layer drying models were estimated and related by using statistical measures. Consequently, the quality of the fitted models was evaluated. These measures were used:

a. ***Root mean square error (RMSE)***

It's signifying the noise in the data (Demir *et al.*, 2004; Doymaz, 2005b; Wang *et al.*, 2007):

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{N} \left(\text{MR}_{\text{exp, i}} - \text{MR}_{\text{cal, i}}\right)^2}{N}}$$

b Correlation coefficient (R^2)

The correlation coefficient, R^2 can be used to test the linear relation between measured and estimated values, which can be calculated from the equation

$$R^2 = \frac{\sum_{i=1}^{N}(M_{Ri,} - M_{Rpre,i}) * (M_{Ri,} - M_{Rexp,i})}{\sqrt{\left[\sum_{i=1}^{N}(M_{Ri,} - M_{Rpre,i})^2\right] * \left[\sum_{i=1}^{N}(M_{Ri,} - M_{Rexp,i})^2\right]}}$$

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Where R^2 is called the coefficient of determination, $M_{Rexp,i}$ stands for the experimental moisture ratio found in any measurement, $M_{Rpre,i}$ is the predicted moisture ratio for this measurement and N is the total number of observations.

c. Reduced chi-square (χ^2)

$$\chi^2 = \frac{\sum_{i=1}^{N}(M_{Rexp,i} - M_{Rpre,i})^2}{N - n}$$

The reduced v-square may be calculated as:

Where, n is the number of constants. The goodness becomes better the lower the values of the reduced chi-square..

Drying models

A lot of heat and mass transfer phenomena is involved in drying process which are difficult, mathematically, to be described in microscopic scale. Simple semi-empirical expressions is often used for design and analysis which can adequately, describe the drying kinetics, when the external resistance to heat and mass transfer, is eliminated or minimized (Midilli *et al.*, 2002). Carrying out experiment using a thin-layer of the material being dried is a common way to do this. Numerous modeling and experimental efforts on single layer drying have been proposed by different authors.

Statistical Analysis

All analyses were conducted in triplicates. Mean scores of the results and their standard deviation were reported. Analysis of Variance (ANOVA) was carried out on all the physical parameters measured to test for variability at 5% level of significance. Duncan Multiple Range Test, (Duncan, 1955) was used to separate means. Statistical Package for Social Science (Version 19.00) was used.

3.0 RESULTS AND DISCUSSIONS

The results obtained from the drying experiment carried out in accordance with the standard methodologies are hereby stated.

Initial Moisture Content of Fresh *Clarias gariepinus*

The initial moisture content of fresh *Clarias gariepinus*was observed to be 51.13% wet basis.

Drying Characteristics of *Clarias gariepinus*

Figures 1- 3, below show the disparity of moisture content with time, variation of drying rate with time and the variation of drying rate with moisture content respectively for *Clarias gariepinus* smoked with biogas. The final moisture content was observed to be 12.43% dry basis. The time required to reach the final moisture content was about 2 hours 30 minutes. It is observed that there was no constant rate drying period in the drying of *Clarias gariepinus*. Majority of the drying took place in the falling rate period. This means that from the beginning of the drying process the internal water movement was controlled (Yusheng and Poulsen, 1988). It is shown that moisture is removed from the cat fish during the falling rate period during which the rate is ruled by the transfer of water by diffusion. (Jason, 1958; Wheaton and Lawson, 1985; Ismail and Wooton, 1992). Fick's second law of diffusion has been widely used to estimate the average drying time during the first falling rate period (Chirife, 1983).From

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the start of the drying, the rate at which moisture is being removed decreased sharply and continued until after the first 30 minutes where there was a short constant rate period for about 15 minutes after which it continued to decrease till it reached the equilibrium moisture content. Hence, drying during the falling rate period is governed by water diffusion in the material.

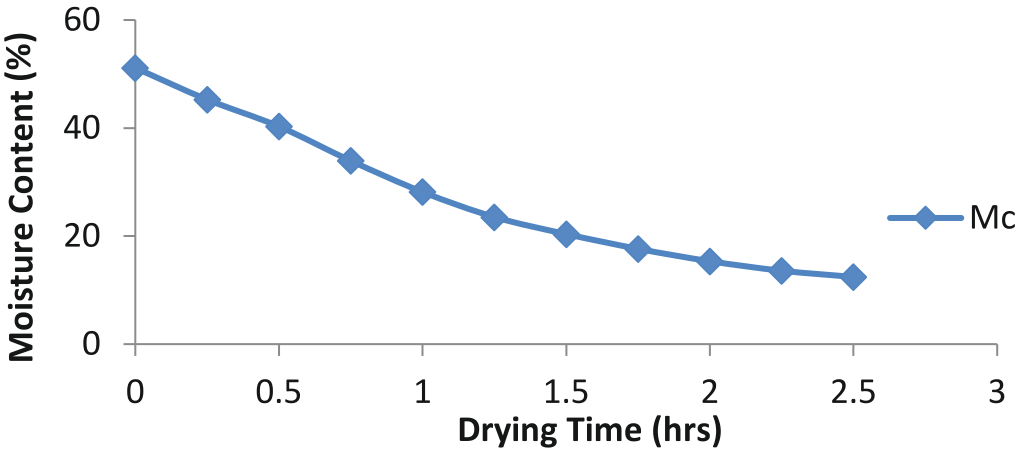

Figure 1: Variation of moisture content with drying time for Clarias gariepinus smoked with biogas

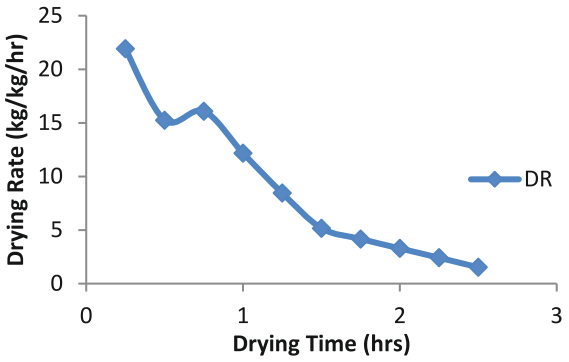

Figure 2: Variation of drying rate with drying time for Clarias gariepinus smoked with biogas

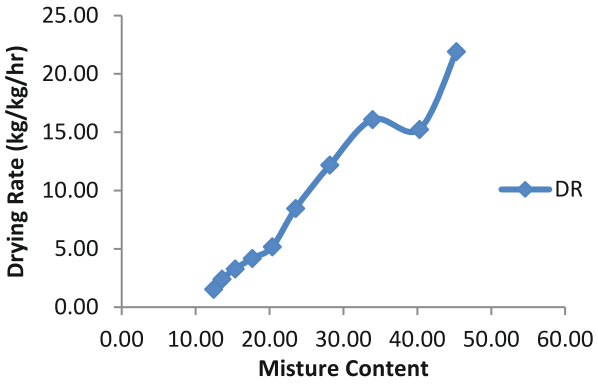

Figure 3: Variation of drying rate with moisture content for Clarias gariepinus smoked with biogas

Evaluation of the Mathematical Models

The statistical results from models are summarized in Table 2. The drying data were fitted to 10 thin- layer drying models. Comparison of performances of these models using the determination of coefficient (R^2), reduced chi-square ($\chi 2$) and root mean square error (RMSE) between the calculated and predicted moisture ratios were done. The statistical parameter estimations showed that R^2, $\chi 2$ and RMSE values varied from 0.9614, 0.00499, and 0.06703 for Wang and Singh model to 0.998, 0.00021and0.01386 for Modified Henderson and Pabis model respectively (Table 2). The best model describing the drying features of *Clarias gariepinus* smoked with biogas was chosen as

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Plate 3: Biogas-smoked catfish

Plate 4: Used up stored biogas

the one with the highest R^2 values and the lowest χ^2 and RMSE values. Of all the models tested, the Modified Henderson and Pabis model gave the highest value of R^2 and the lowest values of χ^2 and RMSE.

Figure 4 compares experimental data with those predicted for the Modified Henderson and Pabis Model for *Clarias gariepinus* smoked with biogas. The estimation using the model disclosed MR values hooped along the straight line with a very high value of R^2 (0.998), which showed the correctness of this model in describing drying kinetics of *Clarias gariepinus* smoked with biogas.

4.0 CONCLUSION

Nonlinear regression analysis was carried out to determine and select the thin layer model that best describe the drying kinetics of *Clarias gariepinus* chunks in a smoking kiln

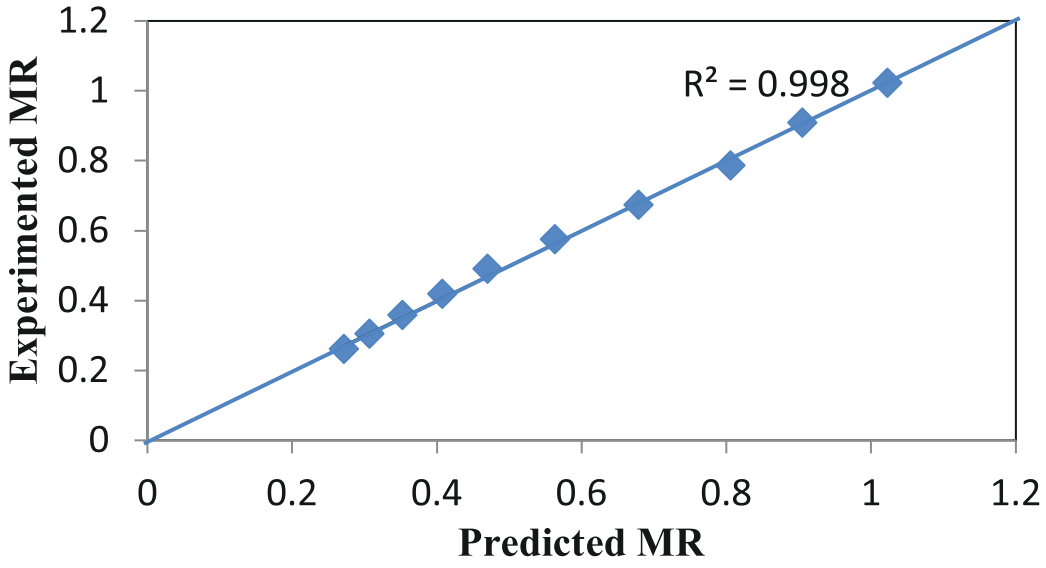

Figure 4: Comparism of Experimented MR against Predicted MR for the Modified Henderson and Pabis Model of Clarias gariepinus smoked with biogas

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Table 2: Summary of Values of the drying constants and coefficients of mathematical models through non-linear regression analysis method for *Clarias gariepinus* smoked with biogas.

S/N	MODEL NAME	MODEL CONSTANTS	R^2	$\chi 2$	RMSE
1	Modified Hend. and Pabis	a=1.081520343, b=-0.269622004, c=0.210499253, g=0.151588459, h=0.182395781, k=0.010524502	**0.998**	**0.00021**	**0.01386**
2	Two-term	a=1.069092546, c=--0.046490676, k= 0.010389653, g=-0.695596904	0.9976	0.00022	0.01422
3	Hii *et al*	a=1.06909692, k=0.03493492, c=--0.04653, g=1.402980261, n=0.29734706	0.9976	0.00022	0.01422
4	Verma *et al*	a=-1.069098852, k=0.01038971, g=2.614103477	0.9968	0.00028	0.01591
5	NEWTON	K= 0.00953259071307583	0.9961	0.00074	0.02595
6	Henderson and Pabis	a= 1.044387063 , k= 0.010073862	0.9956	0.00033	0.01741
7	Diffusion approach	a=-1.875447347, k=0.012952224, b=1.459125466	0.9947	0.00049	0.02119
8	Two-term Exponential	a=0.001616651, k=5.862441105	0.9908	0.00078	0.02650
9	Midilli and Kucuk	a=1.022593827, b= -0.00493046, k= 0.118971419, n=1.12	0.9633	0.00291	0.05122
10	Wang and Singh	a= -0.005807695, b= 0.008	0.9614	0.00499	0.06703

powered with biogas. Results showed that the Modified Henderson and Pabis model was able to describe the drying kinetics of the fish fillets with R^2, $\chi 2$, and RMSE values ranging from 0.998, 0.00021 and 0.01386 respectively.

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