IOSR Journal Of Environmental Science, Toxicology And Food Technology (IOSR-JESTFT)
e-ISSN: 2319-2402,p- ISSN: 2319-2399. Volume 8, Issue 1 Ver. IV (Feb. 2014), PP 16-24
www.iosrjournals.org

Modeling of Thin Layer Drying Kinetics of Salted Fish Fillets (*Tilapia Zilli*) in a Direct Passive Solar Dryer.

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Abstract : *An empirical thin layer drying model for modeling the salted fish filets in a direct passive solar dryer was developed. The experiment was conducted in a factorial form arranged in a completely randomized design (CRD) with three treatments replicated five times. The model got evolved from Wang and Singh model. The statistical analysis was done with a non linear regression analysis program (NLRP). From the result it is evident that the new model was found best to describe the drying process of salted fish filets over the conditions tested (temperature 20 to35.1^{0}C, Relative Humidity54 to100%). Results also showed that the new model in this work was the best in terms of explaining the drying kinetics of the fish fillets with χ^2 , SE R^2, and P values ranging from, 2.22x10^{-6} to 0.001176 ,0.008171 to 0.010844 ,0.9978 to 0.9981 and 0.0226 to 0.2151 respectively.*
Key words: *descale fish, fish filets,, modeling, moisture ratio,natural drying.*

I. INTRODUCTION

Information, from FAO statistical record of the world's fish production from capture fisheries and aquaculture reached 121million tonnes in 1996 [1]. A further breakdown of this figure shows that 72 percent of the total fish production comes from marine catches, 9 percent from marine aquaculture 6 percent from inland catches and 13 percent from inland aquaculture. In Nigeria, sources of fish include coastal and brackish waters, lakes, rivers and lagoons. The coastal artisanal fishery sector of Nigeria is scattered along numerous large and small fishing settlements located within 960 km coastline of Nigeria with its extensive coastal lagoons. Approximately 95% of the catches of the coastal fishermen are normally smoked and limited quantities are sold fresh. From good estimation the post harvests losses of fish is put at 35%. This implies that nearly 25 million tonnes of the world's fishing catch are lost due to poor handling. Also the losses are highest in the country whose populations have the lowest protein intake [2] . Here in Nigeria fish contribute about 40 percent of animal protein intake [3].The implication of this fact is that, any shortfall in fish availability will affect the animal protein intake of people in tropical countries. Fish also generate employment opportunities to many rural dwellers. Similarly a well processed fish and shrimps from the tropics have a ready market in developed countries and are thus good foreign exchange earners. Though some fishes harvested in the tropics are for direct consumption, a great deal of others is processed into fish meal for livestock production. Drying or dehydration is a term used to describe the removal of water from fish or fish product by evaporation. This is the oldest method of fish preservation known to man. Fish drying in the open sun is usually accomplished by exposing the fish to the open sun and atmospheric air to evaporate the moisture [4] . These are some of the characteristics of open sun drying. Considerable losses can occur during open sun drying due to contamination by insects and microorganisms. Also the quality of the fish is lowered significantly, due to over drying, insufficient drying, pecking on the produce by animals and birds and contamination by foreign materials, insects and microorganism as well as discolouration by ultraviolet radiation. Weather changes can drastically affect the quality of the dried produce to such an extent that fungal and bacterial growth can cause decay producing unwanted odour. Moreover, open sun dried fish products do not satisfy the nutritional quality standards [5]. Recently solar and mechanical dryers have been introduced to speed up the drying process considerably to give a product of acceptable quality and extended shelf life. The author [5] worked on experimental study of greenhouse prawn drying under natural convection and concluded that the convective heat transfer coefficient was a function of moisture removal, physical properties of moist air, operating temperature and surface area. Also the values of convective heat transfer coefficient varied significantly with the type and size of substances being dried. In addition the mathematical model developed successfully predicted the convective heat transfer coefficient as a function of moisture content of the prawn.

The author [6] reported in her work on drying of some marine fishes that brining or salting is very important. She pointed out that products not brined or salted may become ideal for the growth of pathogenic organisms and the products may decay within a short period. She further stated that brining helps to prevent insects and mites from reaching the products which can carry most of the microorganisms which can cause fish spoilage. Mathematical modeling of the fish drying process has been reported in literatures mostly in hot air drying under artificial drying systems. However, there is no report at all on modeling of the thin layer drying kinetics of salted fish fillets using natural drying processes. A variant of an existing experimental model was also proposed to better suit the drying kinetics. Therefore, the present study was carried out to model the thin layer solar drying kinetics of salted Tilapia Fish fillets in natural drying and select the best model for these processes.

II. MATERIALS And METHOD

The experiment was conducted at Nsukka in Enugu State of Nigeria. Nsukka is located on latitude $6^0$56 N and longitude $7^0$25 E and 397 m above sea level. The fish sample (Tilapia species) from Domita Farms Nig. Ltd., Uyo, Akwa Ibom State,Nigeria were used for the study. A total weight of 7.5 kg drawn from refrigerated storage were cleaned, eviscerated, heads removed, washed and filleted longitudinally to expose the backbone in preparation for solar drying. The work was conducted as factorial experiment arranged in completely randomised design (CRD) with three treatments having five replicates each. The treatments were descaled fish fillets with no salt (NO), descaled fish fillet with 10 % salt (N10) and descaled fish fillets with 20% salt (N20). The duration of drying per batch in the entire work varied between 1500 minutes (25hrs) of 3 days to 2,040 minutes (34hrs) of 4 days per replicate. The clean samples were of two types, treated with three (3) levels of salt (NaCl) concentration (brine) each. The salt solutions were prepared by dissolving the desired amount in 100ml of distilled water. Samples were soaked for about one hour after which they were removed and excess water was allowed to drain off. The essence of soaking in salt solution is to help prevent spoilage by micro organism and to enhance quick drying. From each salt concentration of the fish soaked, samples of about 1.2kg with five replicates were drawn for further test. For thin layer solar drying test the samples were shaped approximately into a rectangular slab of thickness ranging from 5 to 6 mm, length 5 mm and width 3 mm. Moisture content was determined for each set of treatment combination prior to the commencement of solar drying . The experiment were all set up with appropriate positioning of the dryer in North –South direction along side with other instruments to measure the relative humidity ,temperature, moisture content ,wind speed and solar intensity for accurate recording. The drying experiment was carried out from 8.00am to 4.00pm everyday .At the end of each day a black polythene wrapper was then used to wrap around the entire dryer with the fish product remaining inside for safe storage in favour of the next day's operation. This is to help prevent moisture migration into the semi dried product.

2.1 Instrumentation

The measurement of temperature inside the solar dryer was carried out with a digital pocket thermometer (Checktemp model HI98501 by Hanna instruments USA). Temperature was measured at three positions inside the solar dryer in addition to inlet and exit temperatures .The atmospheric temperature was also similarly measured. The relative humidity was estimated through the measurement of both wet and dry bulb temperatures within and outside the dryer through the use of hygrometer The solar insolation on a horizontal surface for Nsukka and wind speed data for the period of drying were obtained from Centre for Basic Space Research ,University of Nigeria Nsukka. The relative humidity, temperature and wind speed data were also obtained from the same source for comparison. Weight was measured through the use of digital weighing balance (Ohaus instrument model: Scout Pro SPU 402, precision ± 0.01,)

2.2 Mathematical modelling

The lists of thin layer drying models in Table 1 were used for the work. These are semi theoretical and empirical models used in literatures. Semi-theoretical models are derived based on theoretical model (Fick's second law) but are simplified and added with empirical constants in most cases to improve curve fitting. In the empirical models a direct relationship is obtained between moisture content and drying time and the parameters associated with them have no physical interpretation at all. A new model was obtained from Wang and Singh model after series of non linear regression analysis of the data. In these models, the moisture ratio (MR) is defined as shown:

$$MR = (M_i - M_e)/(M_o - M_e) \qquad (1)$$

where the subscripts i e and o denote at time i, equilibrium and initial, respectively. Non-linear regression was performed using the non linear regression program software. Statistical parameters such as the coefficient of determination (R^2), reduced chi-square (χ^2), standard error (SE) and mean relative percent deviation modulus (P) were used as the criteria for selecting the best model.

Table 1 Mathematical models applied to drying curves of various agricultural products.

S/n	Model Name	Model/Equations	Reference
1.	Logarithmic	$MR = a\exp(-kt) + c$	[7]
2	Wang and Singh	$MR = M_0 + at + bt^2$	[8]
3	Thompson	$t = a\ln(MR) + b[\ln(MR)]^2$	[9]
4	Geometric	$MR=at^{-n}$	[10]
5	New model	$MR= Mo+AT^b +CT^n$	This work

Reduced chi square is given as :

$$\chi^2 = \frac{\sum_{i=1}^{N}[M_{EX} - M_P]}{N - z} \qquad (2)$$

Model efficiency or coefficient of multiple determinations (R^2) is given as:

$$EF = \frac{\sum_{i=1}^{N}\left(M_{EX} - \bar{M}_{EX}\right)^2 - \sum_{i=1}^{N}\left(M_p - M_{EX}\right)^2}{\sum_{i=1}^{N}\left(M_{EX} - \bar{M}_{EX}\right)^2} \qquad (3)$$

where M_{EX} and M_p are two sets of variables. M_{EX} = observed data or experimental data, M_p = predicted data, N = number of the observations and z= number of constants in the equations:

$$P = 100/N \sum (M_{EX} - M_P)/M_{EX} \qquad (4)$$

where
P=Mean Relative Deviation Modulus
M_{ex}= observed or experimental data
M_p= predicted data
N=number of observations
Standard error of the sample for the analysis Is given by equation (5) as shown

$$SE = \sqrt{S^2/r} \qquad (5)$$

where SE=standard error, S^2 = sample variance, r=number of replications

III. Results And Discussion

3.1 Drying curves, Relative humidity and Temperature curves

During the process of drying, the environmental parameters were noted as follows; the atmospheric dry bulb temperature (ADB) varied between 20-35.1^{0}C whereas atmospheric relative humidity (ARH) was between 54-100%. The dryer dry bulb temperature (DDB) varied between 35-52^{0}C, the dryer relative humidity (DRH) varied between 28-71%. Fig 1 shows a plot of these physical parameters against drying duration.

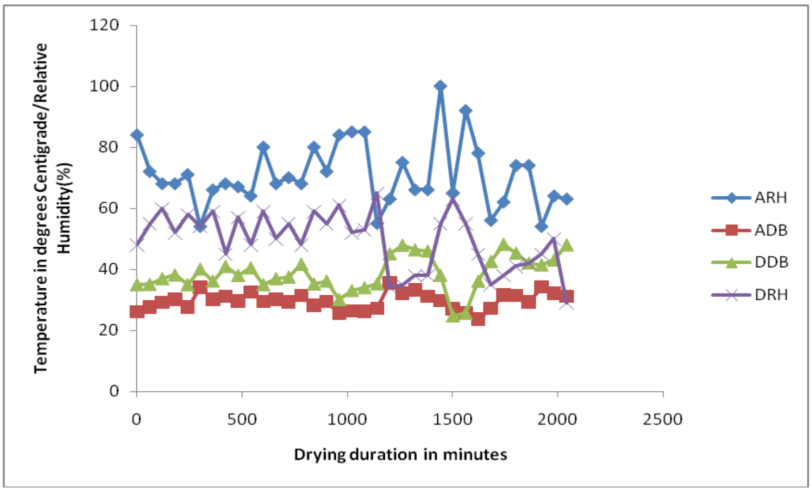

Fig 1 Graph of relative humidity and temperature against drying duration on a typical drying day

A close look at this graph shows that the atmospheric temperature is always lower than the dryer temperature. This is due to the fact that the dryer is able to convert the incident solar energy and store them as heat through its absorber [11],[12],[13]. Moreover the dryer relative humidity was conspicuously lower than the atmospheric relative humidity. This resulted from increase temperature of the dryer which subsequently reduced the relative humidity inside the dryer with consequent increase in moisture transport capability of the humid air. The drying kinetics of the tilapia fish fillets can best be explained through plotted graph of Fig. 2

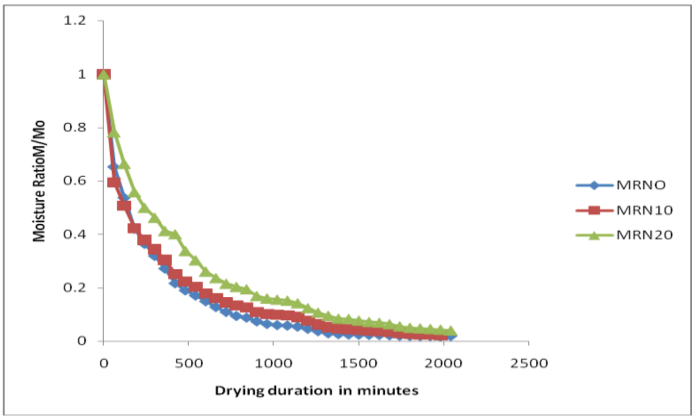

Fig.2 Graph of Moisture Ratio against drying duration for replicate one

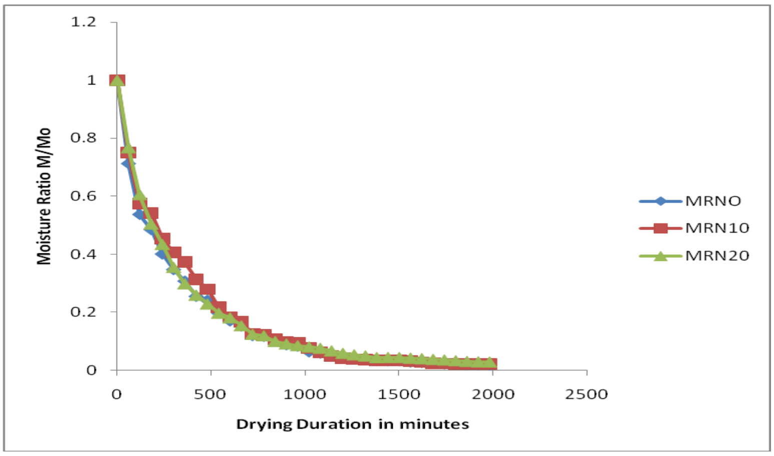

Fig.3 Graph of Moisture Ratio against drying duration for replicate two

At 120 minutes (2 hours) drying time the observed moisture ratio (MR) in replicate one treatment listed as NO, N10, and N20, had the following values 0.5376, 0.5752, and 0.6647 respectively. Also at 600 minutes (10 hours) of drying, the values for the treatments changed slightly to 0.1503, 0.1789 and 0.2616 respectively. Considering NO treatment at 1200 minutes (20hours) drying time, it was found that the moisture ratio was 0.04735, N10 had a value of 0.07611 and N20 had a value of 0.12437.

Moisture ratio at 1800 minutes (30 hours) of drying had the following values of 0.0206, 0.026 and 0.0511 for N0,N10 and ,N20 respectively. From this result, it is evident that as the salt concentration increased the moisture content decreased linearly with increased moisture ratio and hence decreasing drying rate. The decrease in moisture content is consistent with the fact that salt is a hygroscopic substance thus increase in its concentration increases the amount of salt particles for absorbing water molecules from the fish sample.[14].In addition more salt particles will be available to enter any void space in the fish sample to achieve dehydration.[15].

3.2 Mathematical model

***T**he summary statistics of the data analysis is hereby shown on Tables 2,3,and 4*

Table 2 : Statistics Summary for the Experimental data for New and Wang and Singh models

S/n	Treatment	**Newly Proposed model** **$MR = Mo + AT^b + CT^n$** **M_0 = 1.00106429 , A =0.0476335, b = 0.804589 C= -0.0667917 n =0.763676.**				Wang and Singh model statistics $MR = M_0 + at + bt^2$ M0=0.775308 ,a= -0.0010366, b =3.6837x10^{-7}			
		χ^2	SE	R^2	P	χ^2	SE	R^2	P
1	N0	9.12E-05	0.009552	0.9984	0.262	0.005373	0.073333	0.9004	0.4176
2	N10	0.000198	0.001407	0.9969	0.000139	0.003998	0.06323	0.9332	0.142
3	N20	0.000272	0.01649	0.9955	0.06971	0.005664	0.07526	0.9002	0.2152
4	NO	0.000805	0.028369	0.9879	0.458	0.007148	0.084549	0.8842	0.5017
5	NI0	0.00089	0.029827	0.9862	0.1141	0.071997	0.08485	0.8803	0.2054
6	N20	2.22E-06	0.008171	0.9978	0.0226	0.005734	0.0757	0.9101	0.1753
7	NO	0.001176	0.010844	0.9981	0.2151	0.0051	0.071419	0.9102	0.3134
8	NI0	0.000241	0.015538	0.9955	0.0552	0.007194	0.08482	0.8572	0.6626
9	N20	0.000675	0.02583	0.9978	0.2978	0.007456	0.08806	0.8481	0.3981
10	NO	0.000167	0.012932	0.9966	0.389	0.007622	0.0873	0.8278	0.36411
11	NI0	0.000224	0.014953	0.9953	0.1279	0.006266	0.07916	0.8601	0.1046
12	N20	0.00026	0.016115	0.9968	0.1023	0.007825	0.08848	0.8444	0.6825
13	NO	0.000229	0.015139	0.9956	0.6541	0.006136	0.078331	0.874	0.695
14	NI0	0.000341	0.018473	0.993	0.0922	0.008005	0.089469	0.8234	1.498
15	N20	0.000612	0.025196	0.9903	0.0251	0.003505	0.059206	0.9424	0.0092

Table 3: Statistics Summary for the Experimental data for Thompson and Geometric models

S/N	Treat ment	Thompson model statistics $t = a\ln(MR) + b[\ln(MR)]^2$ a=-166.022, b=96.397				Goemetric model statistics MR=at^{-n} a=8.9789, n=-0.6008			
7		χ^2	SE	R^2	P	χ^2	SE	R^2	P
1	N0	2332.475	48.2957	0.99347	0.342	0.03438	0.1854	0.3429	0.621
2	N10	5522.313	74.3123	0.985	0.4452	0.036166	0.190175	0.3762	0.5412
3	N20	2798.438	52.9	0.9924	0.3367	0.034	0.18441	0.3812	0.3321
4	NO	3153.517	56.1564	0.9901	0.195	0.03672	0.191651	0.3836	0.4351
5	NI0	4010.333	63.3298	0.9882	0.442	0.03516	0.1875	0.3953	0.1841
6	N20	4808.333	69.3438	0.9854	0.321	0.036093	0.189985	0.4145	0.2345
7	NO	3859.677	62.1274	0.9889	0.3332	0.035564	0.1885	0.3527	0.3456
8	NI0	2173.677	46.622	0.9937	0.1845	0.003392	0.18417	0.3043	0.6789
9	N20	4052.903	63.6644	0.9883	0.1534	0.033551	0.1831	0.3209	0.4456
10	NO	6818.333	82.57	0.9689	0.4567	0.04425	0.21036	0.3211	0.2156
11	NI0	2915.487	53.9953	0.9918	0.1562	0.025118	0.1808	0.2465	0.3456
12	N20	1667.397	40.8338	0.9954	0.3215	0.032809	0.18113	0.3269	0.5678
13	NO	5507.579	72.9223	0.9827	0.21672	0.037969	0.194858	0.1923	0.8943
14	NI0	10980.5	104.788	0.9665	0.3367	0.036024	0.189801	0.1779	0.579
15	N20	6236.167	78.9696	0.981	0.2341	0.03958	0.198949	0.3268	0.7634

Table 4: Statistics Summary for the Experimental data for Logarithmic model

S/N	Treatment	Logarithmic model statistics $MR = a\exp(-kt) + c$ a=0.902788 ,c=0.9721, k= 1.0			
		χ^2	SE	R^2	P
1	N0	0.031346	0.177049	0.4197	0.345
2	N10	0.037999	0.194935	0.365	0.672
3	N20	0.03465	0.18616	0.3891	0.234
4	NO	0.036815	0.1918	0.4035	0.445
5	NI0	0.03688	0.19204	0.3869	0.621
6	N20	0.041772	0.20438	0.3449	0.2134
7	NO	0.03375	0.183713	0.4056	0.5321
8	NI0	0.026396	0.16247	0.476	0.332
9	N20	0.02777	0.16665	0.456	0.456
10	NO	0.01834	0.1354	0.5857	0.3322
11	NI0	0.024	0.154935	0.4641	0.2134
12	N20	0.02782	0.1668	0.447	0.135
13	NO	0.02326	0.152538	0.5221	0.3456
14	NI0	0.01886	0.137357	0.5838	0.456
15	N20	0.03806	0.195115	0.3741	0.1453

3.3 Mathematical modeling

Tables 2, 3 and 4 show the results of the regression analyses performed on the experimental data. In Table 2, the statistical parameter estimations showed that, χ^2 , SE R^2, and P values ranged from, 2.22x10^{-6} to0.001176 ,0.008171 to 0.010844 ,0.9978 to 0.9981,0.0226 to 0.2151 for the new model and 0.003505 to 0.007199,0.0592 t0 0.08485, 0.9424 to 0.8803 and 0.0.0092 to 0.2054 for Wang and Singh model respectively. . The model that best described the thin layer drying characteristic for salted fish fillets is the one that gives the highest R^2,the lowest χ^2 , SE and P ≤ 10%. Based on these criteria, the new model equation was found best to described the drying curves with χ^2 varying between 2.22x10^{-6} to 0.0089 , SE varied between 0.008171 to 0 02982, R^2 was between 0.9978 to 0.9862, and P varied between 0.022 6 to 0.1141 respectively. The second best model that could predict the drying curve was Wang and Singh model as shown on Table 2.All other models, Thompson, Geometric and Logarithmic shown on Tables 3 and 4 were unable to predict the drying curve of salted tilapia fish fillets as judged by the prediction statistics on those tables.

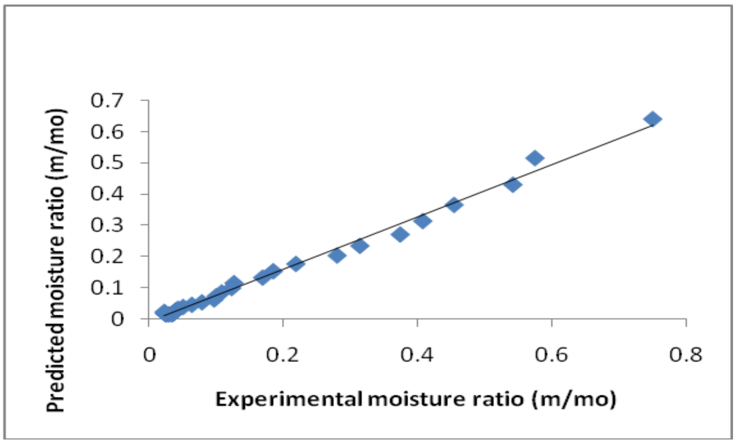

Fig.4 Comparison of Experimental Moisture Ratio with Predicted Moisture

Ratio for direct passive solar drying of salted fish fillets for New Model (χ^2 SE, R^2, and P Values of 0.000198, 0.001407, 0.9969, 0.000139)

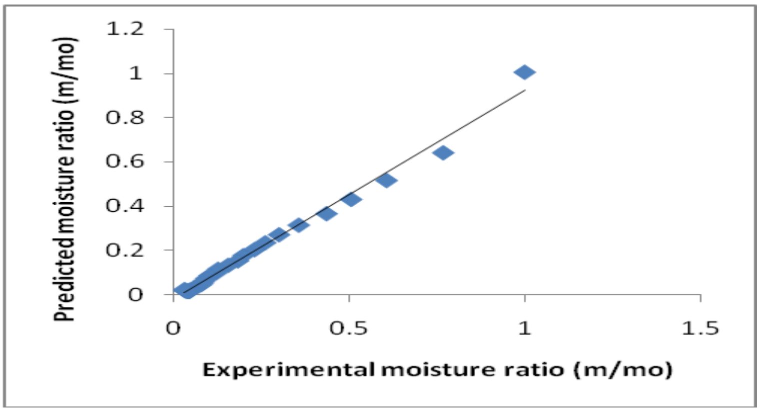

Fig.5 Comparison of Experimental Moisture Ratio with Predicted Moisture

Ratio for direct passive solar drying of salted fish fillets New Model (χ^2 SE, R^2, and P Values of 0.000212, 0.01649, 0.9955, 0.06971

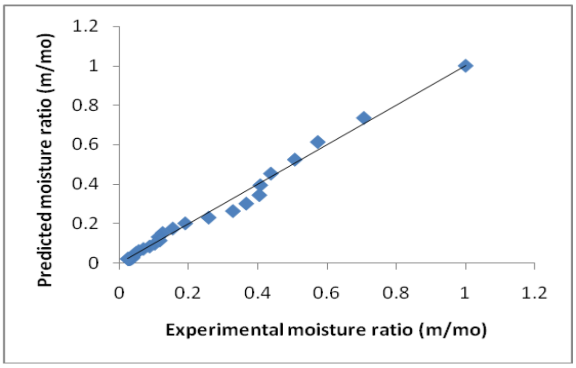

Fig.6 Comparison of Experimental Moisture Ratio with Predicted Moisture

Ratio for direct passive solar drying of salted fish fillets New Model (χ^2 SE, R^2, and P Values of 0.000612, 0.025196, 0.9903 and 0.0251

IV. Conclusion

Non linear regression analysis was carried out to determine and select the thin layer model that best describe the drying kinetics of salted tilapia fish fillets in a direct passive solar dryer.
Results showed that the new model proposed in this work was able to describe the drying kinetics of the fish fillets with χ^2 , SE R^2, and P values ranging from, $2.22x10^{-6}$ to 0.001176 ,0.008171 to 0.010844 ,0.9978 to 0.9981 and 0.0226 to 0.2151

Acknowledgment

We are grateful to the authorities of the University of Nigeria Nsukka, Nigeria and .in particular the Department of Agricultural and Bioresources Engineering for providing the necessary tools and environment to enable us accomplish this work. The contributions of the project supervisor ,Prof.C. O. Akubuo is also highly acknowledged.

References

[1]. FAO, Food and Agric. Organisation: Fisheries Country Profile for Nigeria FIDCP/NIR (1999) Rev. 4 pp 99
[2]. FAO,: The Prevention of Losses in Cured Fish, FAO Tech. (1981) Paper. 6(219) pp 87.
[3]. Olatunde, A A: Approaches to the Study of Fisheries Biology in Nigeria Inland Waters. Proc. Nat. Con. of Two Decades of Research on Lake Kainji (Ayeni and Olatunde (Eds) (1989)pp 1538-541
[4]. Eyo, A. A. Fish Processing Technology in the Tropics. Published by National Institute for Fresh-Water Fisheries Research (2001).(FFR)PM. B. 6006 New Bussa, Nigeria.
[5]. Tiwari, G N; Tribeni Das, Bikash Sarkar: Experimental Study of Greenhouse Prawn-Drying under Natural Convection. Agric. Engineering International: The CIGR Ejournal. Manuscript FP06 16, (2006) Vol. VIII.
[6]. Oparaku, N E: Solar Drying of Some Marine Fish and Quality Changes During Storage Period. Nig. J. of Solar Energy (2006)Vol. 16 pp 79-89.
[7]. Yaldiz,O,Ertekin C,Uzun H B Mathematical modelling of thin layer solar drying of sultana grapes :Energy 26,4(2001) 57-465
[8]. Ozdemir, M.; Devres, Y.O. The thin layer drying characteristics of hazelnuts during roasting. Journal of Food Engineering (1999). .vol.42, pp.225-233,
[9]. Thompson, T. L., Peart, R. M., Foster, G. H.. Mathematical simulation of corn drying – a new model. Transaction of the ASAE (1968),vol.11 n2 pp 582–586.
[10]. Chandra, P. K., and Singh, R. P.. Applied numerical methods for Food and Agricultural Egineers. Boca Raton, FL: CRC Press, (1995) pp. 163–167.
[11]. Rozis,Jean-Francois Drying Food Stuffs Techniques, Process, Equipment, Technical Guide Book Geres French.Ministry of Co operation Neda-CTA,(1997)-Bachuys Publishers Leiden
[12]. Komolafe, G O; Osunde Z D: Design and Performance Evaluation of Small Size Natural Convection Solar Vegetable Dryer. Proc. of The Nig. Inst. of Agric. Engrgs. (2005) Vol 27 pp 215-221.
[13]. Oparaku, N F: Development and Performance Evaluation of Medium Scale Solar Fish Dryer. Nig.. J. of Solar Energy (2008) Vol. 19-1
[14]. Graivier N, Pinotti A, Califona A. and Zaritzky N. "Diffusion of Sodium Chloride in Fork Tissue" J. of Food Engrg. Vol. 77, Issue 4 (2006)pp 910-918 Science Direct, Elsevier Publisher
[15]. Kituu G M; D Shitanda; C L Kanali; J T Mailutha, C K Njoroge; J K Wainaina and P. M. O. Ondote: Influence of Brinning on the Drying Parameters of Tilapia (Oreochromis Niloticus) in a Glass-Covered Solar Tunnel Dryer. Agric. Engrg. Inter: The CIGR Ejournal. M Manuscript(2009) No. EE1349, Vol XI