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MODELING OF THIN LAYER DRYING OF CATFISH (*CLARIAS GARIEPINUS*) IN CONVENTIONAL AND HYBRID SOLAR DRYERS DURING THE WET SEASON

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Abstract
Mathematical modeling and computer simulation of fish drying make it possible for insight to be gained into the comparative performance of various drying systems. Fish is a perishable food which spoils immediately after harvest, especially during the wet season. This paper, therefore, aimed at providing quantitative description of drying behaviour and to predict quality changes during catfish drying. Thin layer drying of catfish in conventional and hybrid solar dryers (CSD and HSD) was conducted with sun drying (SD) as control. The experiments were conducted in completely randomized design (CRD) with three replicates during the wet season. Eight popular thin layer models were selected and tested with the drying data obtained from the fish species. Results indicated that, in all drying methods, the Wang and Singh model was taken as the best model for predicting the moisture ratio with the lowest standard error of estimate and the highest co-efficient of determination R^2 in the CSD as 0.063 and 0.994; in HSD 0.049 and 0.997 while in SD, 0.042 and 0.982, respectively. The hybrid solar dryer was the best to understand the heat and mass transfer phenomena in the drying of Clarias gariepinus during the wet season.

Keywords:* *conventional, hybrid, catfish, thin layer, sun drying

INTRODUCTION
Fish is one of the major animal protein foods available in the tropics. This has made fishery an important aspect of study. According to Olatunde (1989), in Nigeria, fish constitutes 40% of animal protein intake; unlike any other animal protein source with one problem of religious taboo or health hazard, fish is eaten across the country. Unfortunately, however, fish is one of the most perishable of all stable commodities, and in the tropical climate of most developing countries it will become unfit for human consumption within about one day of capture, unless it is subjected to some form of processing (Ames *et al.*, 1999). According to Abba (2007), Nigeria has the resource capacity (12 million has inland water and aquaculture) to produce 2.4 million MT of fish every year with an estimated demand at 1.4 million MT which currently exceeds supply. Fish is highly perishable and can be stored only by proper refrigeration or drying. Most of the fishermen living at the coastal belt are below the poverty line; therefore, refrigeration is distinct dream to them. The only alternative available is drying (Senadeera *et al.*, 2003) which is the most important techniques of food preservation (Menon and Muzumdar, 1987). Drying is defined as a process of moisture removal due to simultaneous heat and mass transfer. It is a

classical method of food preservation, which provides longer shelf, lighter weight for transportation and small space for storage (Erteken and Yaldiz, 2004). To reduce the post-harvest losses during drying and retain the quality of dried products, it is necessary to dry fish in an enclosed chamber, by preventing product from dust, insect, larva, birds and animals. Solar drying is a good alternative for fish farmers in Nigeria and other developing countries as the dryers can generate relatively high air temperatures and low relative humidity, both of which are conducive to improved drying rates. Solar drying is a form of convective drying in which the air is heated by solar energy obtained from the sun. However, it differs from sun drying in that a simple structure, with a collector is used to enhance the effect of insolation and minimizes loss to the surroundings. Sun drying is dependent on weather, temperature and relative humidity of the environment. While solar drying has many advantages over sun drying, as renewable energy sources and economical, particularly during energy crises, when the cost of fuel energy increases sharply (Saravacos *et al*., 2002). Drying kinetics of food is a complex phenomenon and requires simple representations to predict the drying behaviour, and for optimizing the drying parameters. The prediction of drying rate of agricultural materials under various conditions is important for the design of drying systems. Researches on the mathematical modeling and experimental studies had been conducted on the thin layer drying processes of various agricultural products (Abalone *et al.*, 2004). However, little information is available on thin layer drying behaviour of fish. The study was, therefore, undertaken to evaluate the best drying models in describing thin layer drying of Catfish (*Clarias gariepinus*) in conventional and hybrid solar dryers during the wet season.

MATERIALS AND METHODS

Study Area

The thin layer drying experiment was conducted in North eastern zone of Nigeria. Borno State is a state in north-eastern Nigeria. Its capital is Maiduguri (also known as 'Yerwa'), it lies within latitude 10°N and 14°N and longitude 11° 3^{1}E and 14° 4^{1}E and at an altitude of 280.0 m above sea level. Borno State which has an area of 61, 435sq. km is the largest state in the federation in terms of land mass. It has a two distinct seasons; rainy season with annual rainfall of about 600mm from July- October and a hot dry season from march-July. The dry season is preceded by a period (November- February) of Harmattan with very low temperature (N.M.A. 2015).

Experimental Solar Dryers

The orthographic projection of the convention solar dryer (CSD) used in this study, as shown in figure 1. The dryer consisted of three main compartments: the drying chamber, the collector area and the dryer stand. CSD uses only natural convention to remove moisture from the fresh fish and dry the product to a lower or safe moisture content level.

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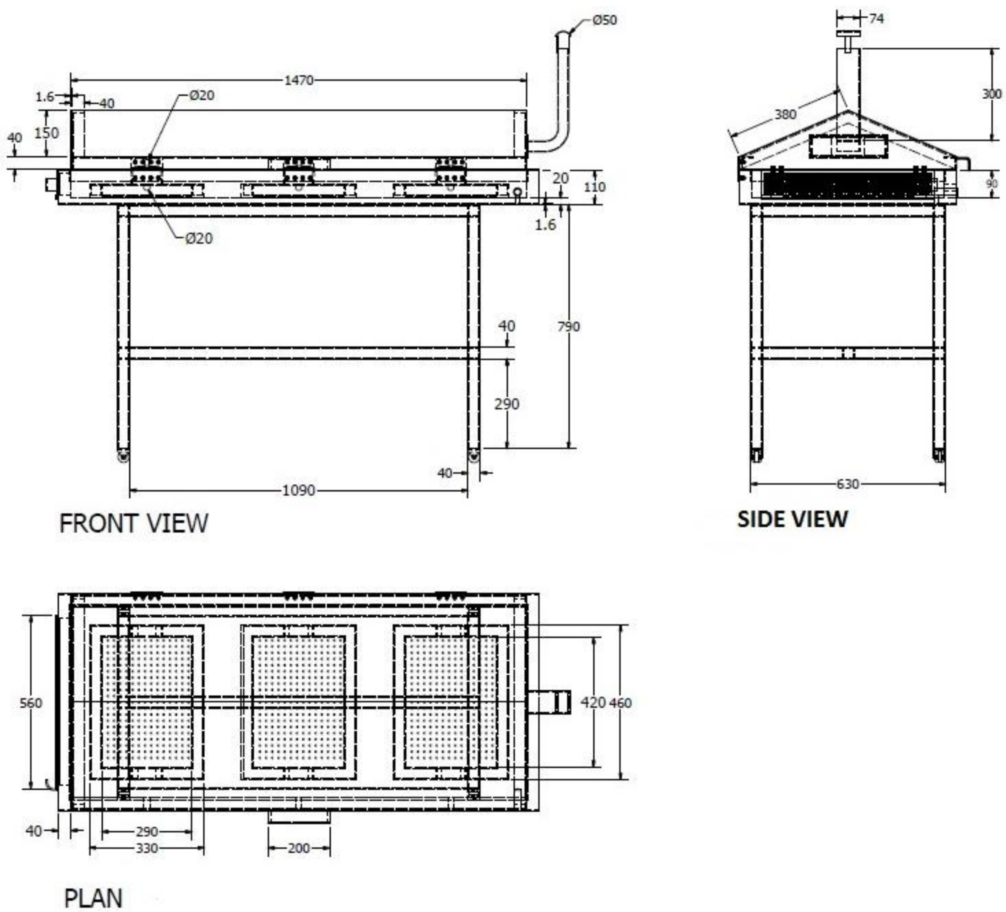

Figure 1: Orthographic Projections of the Conventional Dryer

The hybrid solar dryer (HSD) orthographic projection is represented in figure 2. It is a base-like structure consisting of a solar collector, top drying chamber, absorber base, as well as natural convention air inlet units, a chimney for the exhaust of the moisture laden air at outlet and a stove with connecting duct which utilizes charcoal as fuel. The stove enhanced further drying during the rainy /cloudy days and when the sun had set to enhance further drying at night. The thermal profile of the dryers was also investigated using laboratory type, mercury-in-bulb thermometer (accuracy ±0.5°C) at the regular interval of one hour between the hours of 6.00 and 18.00 local time for a period of three days.

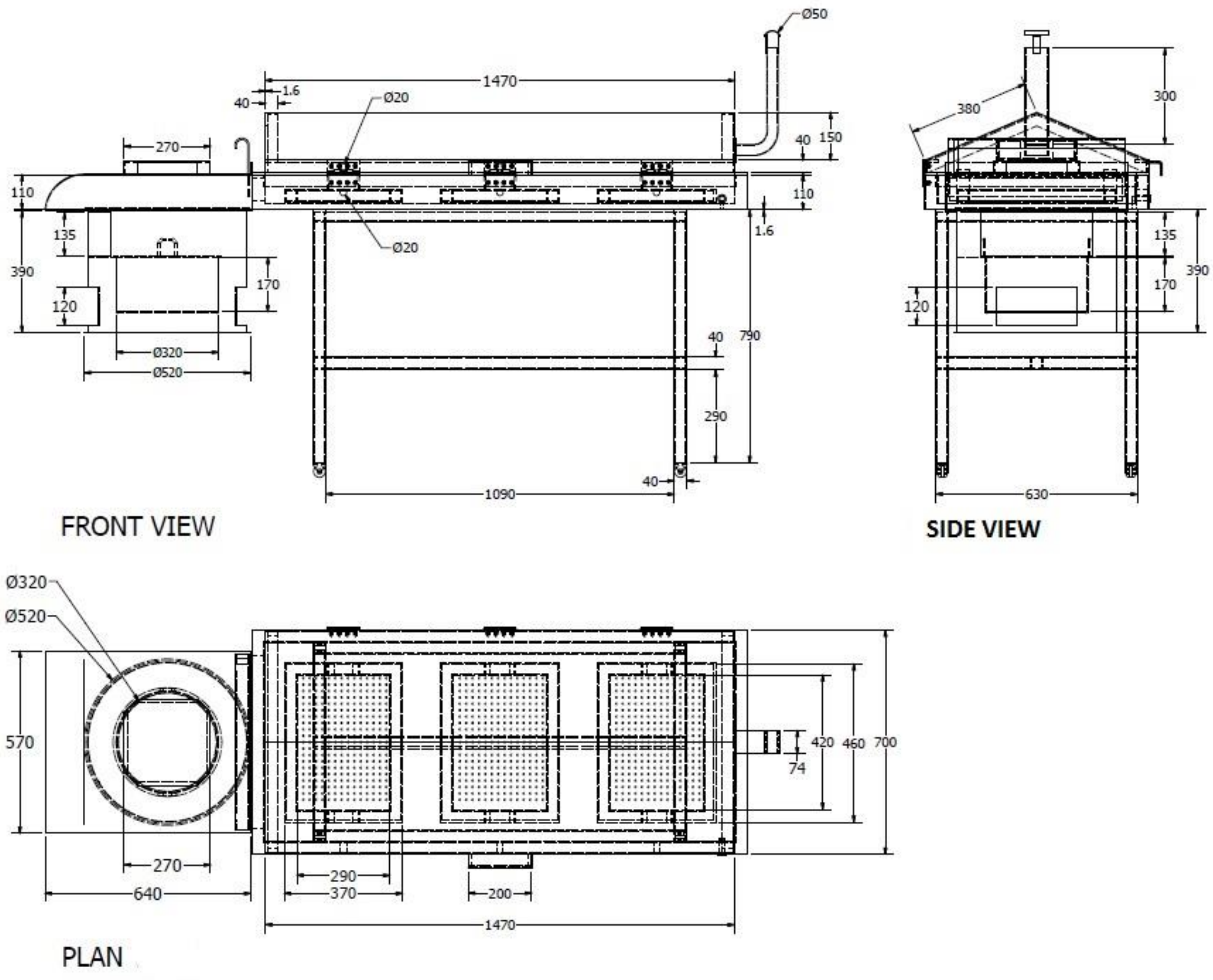

Figure 2: Orthographic Projections of the Hybrid Dryer

Sample Preparation and Drying Conditions

Clarias gariepinus were procured from fishermen at the bank of Lake Alau, which is located 12km away from Maiduguri in Konduga Local Government Area of Borno State, Nigeria. The fish was transported in cold flask from the bank to the drying site, to retain its freshness and wholesome conditions prior to drying. The fish was prepared by washing thoroughly inside water, several times until it became clean, free of dirts and blood. The fish species of 2400g was weighed and divided into three equal parts of 800g each. The 800g fish was spread in thin layer and the three trays were placed in the drying chamber. The chamber was firmly closed to avoid escape of heat. Through the inlet, dry air enters the chamber, which was heated up by the collector, and the air move over the fish to remove moisture and the moist-laden air was raised and moved out of the chimney. Changes in fish weight were monitored throughout the experiment by weighing periodically using an electronic balance. Weighing of fish samples and temperature readings were carried out with respect to time as follows, 10,30,50… 240minutes (20minutes interval) and subsequent measurement and reading continued hourly until dynamic equilibrium moisture content was attained and drying terminated, the time taken was also recorded. Intermitted turning was also carried out on the fish to ascertain effective drying. The process was the same for the different drying methods, except in the hybrid dryer, where 2kg of charcoal was introduced inn to the stove. Already ignited charcoal was introduced into the middle to ignite other charcoal for gradual burning and the opening for the stove was carefully closed. The charcoal was allowed to burn all through the night until it gets exhausted.

Prediction Accuracy of Thin Layer Models

Thin layer drying is the process of removal of moisture evaporation, in which drying air is passed through a thin layer of the material until the equilibrium moisture content was reached. Numerous mathematical models have been developed by various researchers to describe the rate of moisture loss during the thin layer drying of agricultural products. The moisture ratio (MR) of the fish been dried is presented by Equation 1, where M is the moisture content of the fish at a given time (minutes), Mo is the initial moisture content and Me is the equilibrium moisture content.

$$MR = \frac{M - M_e}{M_o - M_e} \qquad (1)$$

Where,

M =moisture content, % (db) at specified time from the commencement of drying,

M_o = the initial moisture content of the product, % (db), and

M_e =dynamics equilibrium moisture content % (db) obtained at the end of the drying run.

It plays an important role in drying rate and drying time prediction and in the determination of the suitability of a drying model for the description of the drying curve of a given material. The moisture ratio data was obtained for the rainy season, for *Clarias gariepinus* at different drying times and temperature. For mathematical modeling, the thin layer drying models in table 1 were tested to select the best for describing the drying behaviour of *Clarias gariepinus*. Modeling the drying behaviour of different agricultural products often requires the statistical methods of regression and correlation analyses. Regression analyses were done using Statistix 10.0 software. The coefficient of determination (R^2), reduced chi-square ($\chi 2$) and root mean square error (RMSE) were used to determine the quality of the fit. The higher the values of R^2, and lower the values of $\chi 2$ and RMSE, the better the goodness of fit.

Table 1: Thin layer models considered.

S/n	Model name	Model equation	References
1	Newton's	MR= exp (-kt)	(Henderson 1974)
2	Pages	MR-exp ($-kt^n$)	(Page, 1949)
3	Henderson and Pabis	MR= aexp (-kt)	(Zang and litchfield, 1991)
4	Logarithmic	MR= aexp (-kt) +C	(Karathanos, 1997)
5	Wang and singh	MR=1 + at + bt^2	(Wang and Singh., 1978)
6	Midilli *et al.,*	MR = aexp ($-kt^n$) +bt	(Midilli *et al*, 2002)
7	Thompson	t = ALn (MR) +B $[Ln (MR)]^2$-1	(Thompson *et al*., 1968)
8	Diffusion Approach	MR=aexp (-kt) + (1-a) exp(-kgt)	(Karathanos, 1997).

Where,

MR= moisture ratio, dimensionless

A,B = constant in the Thompson model

a, c = constant logarithmic model

k = drying constant, min^{-1}
N = index in the page model
T = time, in minutes

Data analysis

The models were subjected to non- linear regression using a software package (Statistix 10.0). The least squares estimate or co-efficient of terms were used as the initial parameter to estimate the non-linear regression procedure. The goodness of fit of the models on the experimental data was evaluated using residual plots, standard error of estimate (SE) and co-efficient of determination, R^2. A model was considered acceptable if the residuals were uniformly scattered around the horizontal valve of zero showing no systematic tendency toward a clear pattern. A model was considered better than another if it had a lower standard error of estimate and higher co-efficient of determination. The drying constant K and index N of the fishes were then investigated for their relationship with dryers using regression procedure. It has been shown that the mechanism of moisture movement in thin layer drying of fish is mainly diffusion.

Results and Discussion

Table 2 compares the temperatures developed inside the solar dryer and the ambient air for the thermal profile.

Table 2**:** Thermal profile within the solar drying compartments and ambient temperatures

T (hr)	**T_M CSD**	**SD (±)**	**T_M HSD**	**SD (±)**	**T_M AMBIENT**	**SD (±)**
6am	31.3	1.033	32.7	1.722	31.0	1.414
7	36.7	1.966	36.8	1.940	32.5	0.7071
8	33.3	2.422	52.7	3.204	38.0	2.828
9	63.0	3.898	62.5	3.564	39.0	4.242
10	73.8	4.996	75.1	3.920	41.5	2.121
11	81.7	3.669	83.5	3.782	44.0	1.414
12	85.2	4.401	89.7	1.862	45.0	2.828
13	82.7	10.152	88.5	6.625	44.5	2.121
14	78.7	3.777	80.8	2.714	43.0	2.828
15	75.0	3.286	74.8	4.119	42.5	2.121
16	58.5	1.517	59.8	2.041	41.5	0.707
17	48.8	2.041	49.8	2.041	40.5	0.707
18	44.0	0.632	44.0	1.264	40.0	0

Tis the time (hr), **T_M** is the mean temperature (°C) and **SD** is the standard deviation

The temperatures inside the dryer and the solar collector were much higher than the ambient temperature during most hours of the daylight. The highest mean temperature recorded for conventional dryer (CSD) was 85°C while the lowest temperature was 31.3°C while the hybrid dryer (HSD) had 89.7°C as its highest and 32.7°C as the lowest and the ambient temperature (SD) had its highest mean value as 45°C and lowest as 31°C at insolation of 6.46kw/h/m^2/day. This goes in line with the result of Oparaku (2010) which stated that the highest mean temperature that could be attained in dryer was 70°C, while the ambient temperature was 33.5°C at the insolation of 857.6wm^2. Sengar *et al.*, (2011) reported that the temperature profile inside the dryer indicated maximum temperature of 57°C and minimum 38.7°C, whereas maximum ambient temperature observed was 35.3°C. In general, these indicates prospect for better performance than sun drying methods. Bello *et al*., (2006) revealed that unloaded solar dryer had higher mean temperature of 50.4°C compared to sun-drying which was 36.0°C.

In CSD, the Wang and Singh model had the lowest standard error of estimate (0.0630) and the highest co-efficient of determination R^2 (0.9939) which was taken as the best model for predicting the moisture ratio. This was followed closely by Midilli *et al*., (2002) and logarithmic model. In HSD, the Wang and Singh model has the lowest standard error of estimate (0.0489) and the highest co-efficient of estimation R^2 (0.9968), which was taken as the best for predicting the moisture ratio. This was followed closely by logarithmic model and Midilli *et al.*, (2002) model. In sun drying, Wang and Singh model had the best fit followed by the logarithmic model and Midilli *et al*., (2002) model.

The reliability of the best model for describing the thin layer drying curves of the *Clarias* was evaluated by comparing the predicted moisture ratio with experimentally observed moisture ratio in the dryers during the wet season as represented in figures 3, 4 and 5.

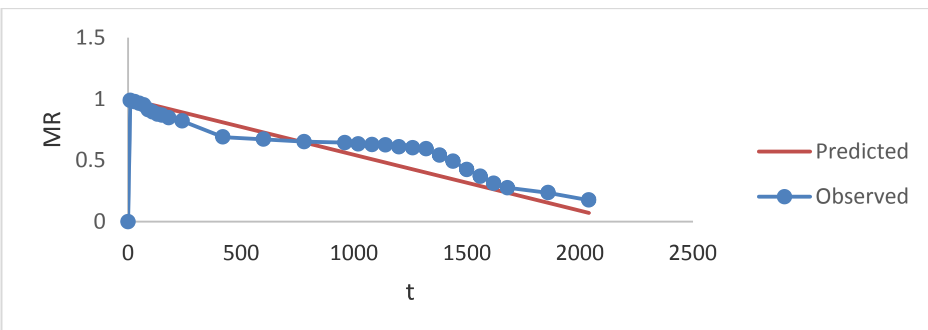

Figure 3: Moisture ratio against drying duration in conventional solar dryer

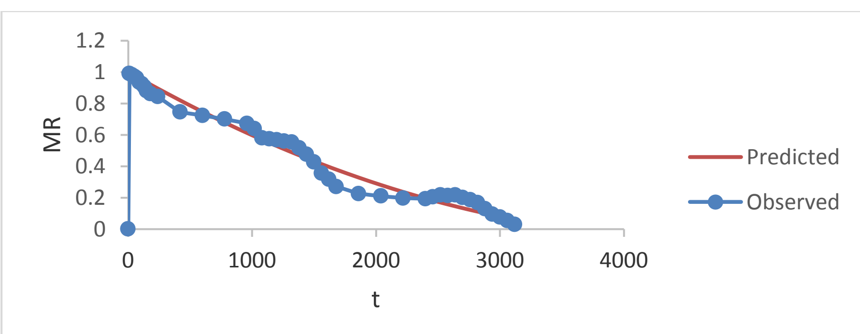

Figure 4: Moisture ratio against drying duration in hybrid solar dryer

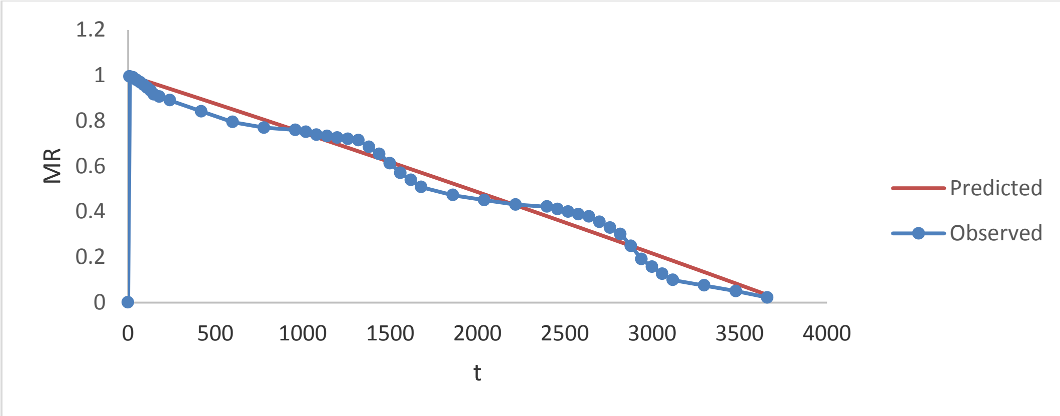

Figure 5: Moisture ratio against drying duration in sun drying

The moisture ratio reduced faster in the beginning than that at the end. This observation is consistent with previous results, as observed by (Kituu *et al*., 2010; Zhiqiang *et al.*, 2013), that the Tilapia fillets contain a large quantity of bulk water in the beginning, and relatively easier to be transferred to the surface and evaporated. According to Babiker, *et al.*, 2016 Lewis drying model was found to be satisfactorily describing solar drying curves of fish with a correlation coefficient (R^2) of 0.9827 .

CONCLUSION

The observed data for Wang and Singh model in hybrid solar dryer well banded around the straight line representing data by computation, which best describes the suitability of this model in describing the drying behaviour of *Clarias gariepinus* in the wet season. It can, therefore, be concluded that the Wang and Singh model best described the drying model of *Clarias gariepinus* in the hybrid solar dryer and so, it can be used to understand the heat and mass transfer phenomena in the drying of the *Clarias gariepinus* using these dryers.

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