A STUDY ON HEAT DISTRIBUTION IN BIOMASS FIRED KILN AND PREDICTION OF THE DRYING KINETICS OF CATFISH (*Clarias gariepinus*)

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A Study on Heat Distribution in Biomass Fired Kiln and Prediction of the Drying Kinetics of Catfish (*Clarias gariepinus*)

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Abstract— An investigation was done on the biomass fire kiln. Three energy sources were used to power the kiln, and data were recorded. The kiln also has three compartments, namely, deck 1, deck 2, and deck 3. Experimental data of the kiln-dried catfish were fitted into Lewis, Henderson, and Page models. The R2 values for the Lewis, Henderson, and Page models are 0.831, 0.8310, and 0.247. Meanwhile, the X2–chi-square values for the three models are 0.0037, 0.0037, and 0.0210, respectively. Thus, Lewis and Henderson are the best models for predicting the drying kinetics of catfish. Catfish, like most other biomaterials, fall under the falling rate period. The hypothesis that the three energy sources affect the drying kiln was validated with X2-chi-square. The hypothesis was accepted because the calculated value (0.093071) was far less than the table value (9.49), which is a basis for the justification. We also discovered that the drying time for gas is shorter than that for other energy sources, followed by charcoal and electricity. The experimental data was plotted against the predicted R2 of 0.854, and the points clustered around the slope showed a good prediction.

Keywords— Biomass Kiln, Moisture Ratio, Drying Kinetics, Catfish.

I. INTRODUCTION

With a global use of over 1.86 billion in 2016, fuelwood is still a significant source of energy for economic activity and cooking in a broad portion of the world [1]. According to [2], fish is extremely perishable and begins to degrade as soon as it is killed. It can be affected by several variables, such as high moisture content, the presence of nutrients for the growth of microorganisms, the surrounding temperature, and inadequate handling, all of which contribute to fish spoilage. As a result, fish processing is conducted to enhance the value and longevity of the fish product [3, 4]. Methods for preserving fish, like canning and freezing, are utilized in many advanced nations to enhance the quality and prolong the shelf life of fish. In less developed countries, particularly in tropical regions, traditional fish smoking is still practiced. Fish smoking, one of the oldest preservation methods, continues to be commonly employed [5]. Fish smoking usually prolongs a fish's shelf life by reducing its water activity, which allows for storage during the lean season. It also improves flavor and increases the number of fish that are consumed. It improves the nutritional content and encourages protein digestion. In Ghana, the predominant method for fish processing involves smoking the fish at temperatures exceeding 65°C. This ensures that the fish products are thoroughly cooked [6]. According to [7], the process of smoking fish typically lasts between 7 to 10 hours, on average. The duration depends on factors such as the size of the fish, its moisture content, the temperature, and the efficiency of the fuel used [8]. The drying kinetics and heat dispersion in biomass-burned catfish (Clarias gariepinus) kilns have been studied using a variety of methodologies. The modified Henderson and Pabis model was the most suitable for representing the drying curves [9]. The ideal drying period for biogas smoking was 2.5 hours. In a cross-flow kiln driven by sawdust or maize cob and heated to 120–200°C, fish can be dried in 4–6 hours [10]. The Midilli model was the most suitable for the drying data, explaining as much as 99.7% of the factors [11].

Biomass is the fourth-largest energy source in the world. It meets rural communities' basic energy needs for heating and cooking in underdeveloped nations. Biomass energy is primarily used in developed nations for power generation and space heating. If used efficiently, biomass fuels have the potential to provide a significantly greater range of energy services than they currently do. Large quantities of biomass, primarily in the form of waste and agricultural leftovers currently being burned or discarded, can significantly increase biomass energy supply and improve the efficiency of existing energy systems. Fish can be divided into oily, white, and shellfish. In the majority of underdeveloped countries where malnutrition rates are high, fish is a nutritious food source since it is typically less expensive than meat and can therefore be taken by a more significant number of people [12]. It provides roughly 6% of the world's total protein. Ovens are divided into two categories based on how they heat: direct and indirect. Ovens that are heated indirectly circulate air and combustion products either naturally or with the use of blowers.

Indirect heating ovens are often powered by natural gas; however, they can also run on propane, butane, fuel oil, or solid fuels. A kiln is an oven that keeps hot fires and maintains the heat required to force almost all moisture out of biomaterial cooked in its interior. The steam tubes in the baking chamber are responsible for heating the air, whereas electric ovens use induction heating radiator plates or bars. The walls and base are heated in batch ovens, but the heaters are positioned above, alongside, and below a conveyor in continuous ovens. The heated air is typically circulated through the baking chamber and a separate heat exchanger. Alternatively, combustion gases pass through banks of radiator tubes in the baking chamber, or fuel is burned between a double wall, and the combustion products are then exhausted from the top of the oven. This study seeks to examine the heat distribution within a biomass-fired kiln and predict the drying kinetics of catfish (Clarias gariepinus) utilizing three different energy sources: charcoal, gas (butane), and electricity. The objective is to identify the most efficient energy source based on drying time and heating capacity while validating the drying kinetics through empirical models, specifically Lewis, Henderson, and Page.

II. Materials and Methods

A. *Sample Collection and Experimentation*

Studies of the investigation of heat distribution in the biomass-fired kiln were carried out during the period of February-March 2019. Each run started at 9:00 am and continued until 4:00 pm at the Department of Mechanical Engineering, Niger Delta University. The area lies at 4.970 North, 6.110 East, and 75 m above sea level. The relative humidity is 85% with a maximum temperature of about 30°C; over 10 pieces of catfish were bought from Tombia Market in Yenagoa, about 25 km from the university. The fish were prepared and washed with clean water. The washed fish weighed five due to the sizes and the precision of the weighting scale of 50 kg capacity (Model: Camry Emperors); the investigation was carried out to study the heat distribution in the kiln at the top, center, and bottom chambers. The ten pieces of the pre-weighed fish were placed at the meshes. The charcoal was also weighed to fill the coal pot capacity of 3.5 kg. Fresh coal from mangrove charcoal was added every hour.

B. *Drying Analysis*

This research used a biomass-fired kiln to dry a catfish of a specified weight and thickness. The three sources of energy are used with the intent of determining the one that dries faster and has a higher heating capacity. The three sources of energy employed are charcoal (mangrove), gas (butane), and electric heating (coil), which were used to power the biomass-fired kiln. Observed in this work is the weight loss concerning time. At a specified interval, the biomaterial was taken out of the kiln for measurement until it attained equilibrium moisture content about the amount of heat supplied. The drying kiln has three layers: deck 1, deck 2, and deck 3. An equal-sized biomaterial was placed on each mesh to study whether the three decks would attain equilibrium moisture content simultaneously. The data from the experiment was used to create three distinct empirical models for forecasting the kiln-drying kinetics of catfish. The models are Lewis, Henderson and page model:

Lewis Model

$$MR = e^{-kt} \quad (1)$$

Henderson Model:

$$MR = ae^{-kt} \quad (2)$$

Page Model:

$$MR = e^{-kt^n} \quad (3)$$

Where MR: Moisture ratio, R^2 is the coefficient of determination, X^2: is Chi-square, a is the initial moisture ratio, k is the drying rate constant, and t represents time.

C. *Statistical Analysis*

The good fit of the model will be on the premise of how close the experimental values are to the predicted value and the higher the R^2 values; X^2 - Chi-square would also be considered, whose criterion is how its value is in terms of model validation.

$$X^2 = \sum_{i=0}^{n} \frac{(MR_{pre} - MR_{exp})^2}{N - K} \quad (4)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(Measured\ MR\ value - PredictedMR\ values)^2}{\sum_{i=1}^{n}(Measured\ MR\ value - Average\ MR\ values)^2} \quad (5)$$

To predict the three models correctly, the models were linearized, and straight-line graphs were plotted. For Lewis model $\ln MR$ against time, while for Henderson $\ln MR$ Versus time. But for page, log $(-\ln MR)$ against $\log(t)$. Let us take the hypothesis that the three energy sources are affected by the drying kiln.

III. Result & Discussion

Most biomaterials are present during the falling rate phase; this work is no exception. Similar results have been opined by [9] on pumpkin seeds [10]. Figure 1 shows that gas dried the biomaterial faster among the three sources of energy (Charcoal, Gas, and Electricity). It was followed by charcoal. Finally, electricity attains its equilibrium moisture content (EMC) at 420 min.

Table 1. Observed Values for Chi–Square Analysis

	Moisture Ratio		Moisture Ratio	Moisture Ratio
Charcoal	0.94	0.94	0.80	2.68
Gas	0.73	0.91	0.66	2.30
Electricity	0.44	0.89	0.58	1.91
Total values	2.11 2.74		2.04	6.89

Sources: $(X)^2 = \sum_{i}^{n}(\mathrm{O} - \mathrm{E})^2 = 0.093071$

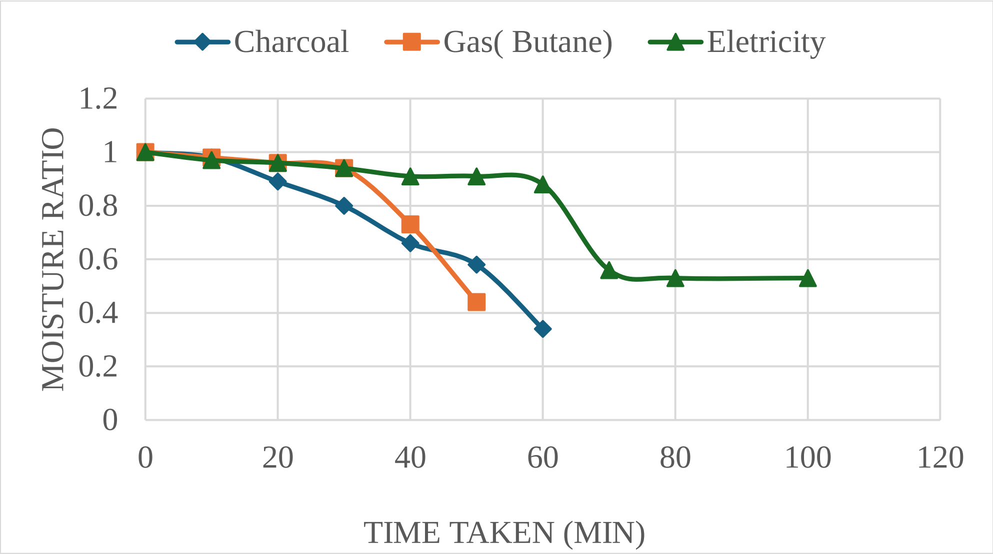

Fig. 1. Moisture Ratio for Catfish at Different Energy Sources

The calculated value is 0.093071, while the table value 9.49. the computed value is much less than the table value. The hypothesis is accepted. Chi-square analysis was done based on the experimental data to ascertain whether the energy sources affect the drying kinetics of catfish. A hypothesis was given on the objectives above. Thus, the chi-square analysis showed that three energy sources do not have the heating value. The premise for the justification is that the calculated value must be smaller than the table value. Hence, the hypothesis is accepted. The calculated value is 0.09307, while the table value is 9.49. Thus, the hypothesis is accepted.

Table 2. Model Parameters

Lewis Model	**Source of Energy**	**X^2**	**R^2**	**Constants & Coefficient**
	Charcoal	0.00037	0.831	0.013
	Gas (Butane)	0.01648	0.427	0.028
	Electricity	0.00045	0.696	0.001
Henderson Model	Charcoal	0.00037	0.831	0.013
	Gas (Butane)	0.01648	0.427	0.028
	Electricity	0.00045	0.696	0.001
Page Model	Charcoal	0.02470	0.030	0.001
	Gas (Butane)	0.04120	1.130	0.017
	Electricity	0.0210	1.590	0.010

The drying data were inserted into the three models, and the drying kinetics of the catfish were predicted. The results are in Table 2. Shows that Lewis and Henderson's model predicted the drying kinetics of the catfish equally. Thus, Lewis and Henderson are the best-fit models for predicting the drying kinetics of catfish. The validation was based on the R2, X2, and how close the predicted values are. The R2 values for the three models (Lewis, Henderson, and Page) are 0.831, 0.831, and 0.03, respectively. Meanwhile, the X2 Chi-Square values are 0.0037, 0.0037, and 0.0247 [10]. Also reported that Henderson was the best model for predicting the drying kinetics of Frogs. Furthermore, table 2 shows the model parameters according to the energy sources. The values of the three energy sources were fitted into the three models (Lewis, Henderson, and Page). For Lewis, Henderson, and Page, Charcoal values had the highest prediction. Lewis and Henderson's R2 values for charcoal, gas, and electricity are 0.831, 0.427, and 0.696. For Page models 0.03, 1.130, and 1.590, and the X2 values, charcoal, gas, and electricity for Lewis and Henderson models are 0.0037, 0.0164, and 0.0045. For page models, the chi-square values are 0.0247, 0.0412, and 0.0210. The base for selection of the best-fit model is the higher the R2 and lower the chi-square values.

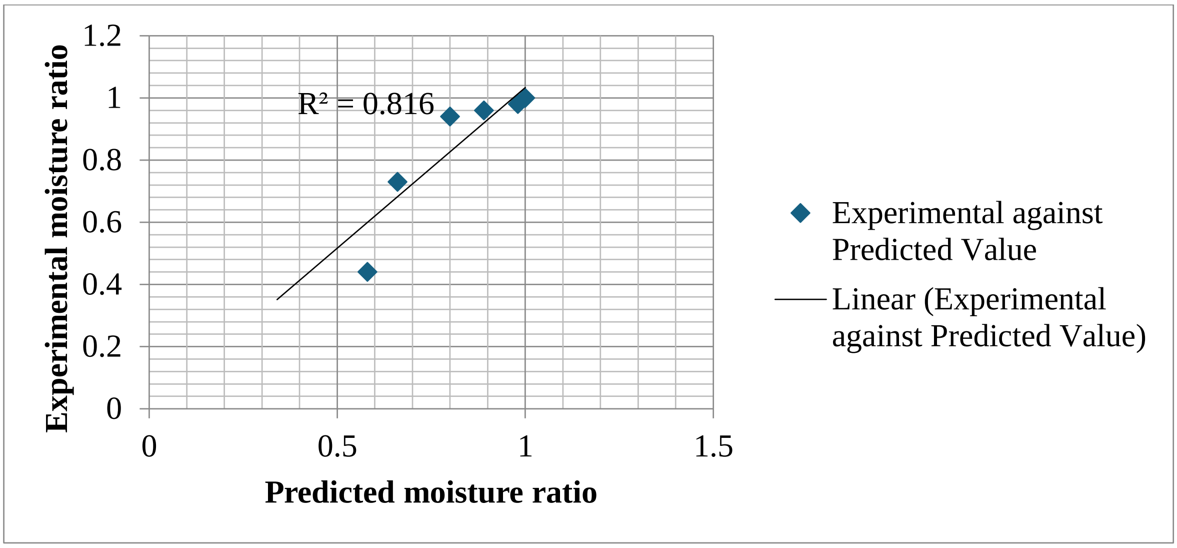

Fig. 2. Comparing the Experimental and Predicted Moisture Ratio

Figure 2 compares the actual moisture content with the forecasted moisture content of Lewis and Henderson models. The points cluster around the slope of the graph. The R2 value for the comparison is 0.854, which is close to 1. This shows a good fit of the models' predictability.

IV. CONCLUSIONS

The study investigated the drying behavior of catfish using a biomass-fired kiln. The study highlights the significance of biomass as a sustainable energy source, particularly in rural communities, and emphasizes the importance of effective fish processing methods to enhance the shelf life and quality of fish products. The findings from a study on the drying behavior of catfish suggest that similar to other biological materials, catfish drying follows the decreasing rate phase. Furthermore, the Lewis and Henderson model demonstrated superior performance compared to the other two thin-layer models in forecasting the drying kinetics of catfish. The findings indicate that the drying kinetics of catfish predominantly follow the falling rate period, which is consistent with the behavior of other biological materials. Among the three energy sources tested, charcoal, gas (butane), and electricity were the most efficient, resulting in the shortest drying time, followed by charcoal and electricity. The study successfully applied three empirical models, Lewis, Henderson, and Page, to predict the drying kinetics, with the Lewis and Henderson models demonstrating superior performance based on their R^2 values and chi-square analysis. The research validates the hypothesis that the choice of energy source significantly affects the drying kinetics of catfish, with statistical analysis confirming that the energy sources do not differ in their heating values. The results underscore the potential for optimizing fish drying processes in developing regions where traditional methods are still prevalent. Overall, the study contributes valuable insights into the design and operation of biomass-fired kilns for fish processing, promoting sustainable practices that can enhance food security and economic viability in local communities.

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