Development Of an Automated Dual Powered Kiln for Drying and Preservation of Fish

OGUNDANA O. S[1], ADEJUMO B. A[2], ORHEVBA B. A.[3], BORI I.[4]
[1] *Department of Agricultural Technology, Federal College of Freshwater Fisheries Technology, New Bussa, Niger State*
[2, 3, 4] *Department of Agricultural and Bioresource Engineering, Federal University of Technology Minna, Niger State*

Abstract- Fish smoking is a major activity in the fish industry. In most river-reining communities in Nigeria, where fish business is very prominent smoking operations are mostly carried out manually and under unhygienic conditions. The concept of the smoking kiln development is to ease the drudgery associated with traditional methods in the fish processing communities. The materials for the developed automated dual powered kiln for fish smoke-drying are locally and cheaply sourced. The developed automated dual powered kiln was made from angle iron and lagged with (composite materials) insulator to prevent heat loss, the smoking chamber consists of 3 set of trays of 0.57 x 0.57 x 0.021 m. It was a dual powered kiln of gas and electric heat sources (DC), its heating elements (heaters) are connected with the aid of wire gauze made from stainless steel placed in a compartment in the heating chamber. The developed automated dual powered kiln was tested with Cat Fish (Clarias Gariepinus) using gas and electric heat sources. Test results indicated an average operational temperature of 80^{o}C and moisture loss of □50% on the smoked fishes. The kiln gave higher drying rate and quality of finished product was good in colour and dryness, indicating a long shelf life.

Indexed Terms- Mechanical Kiln, Fish, Traditional Kiln, Processing, Composite Materials.

I. INTRODUCTION

Fish is any member of paraphyletic group of organisms that consist of all gill bearing aquatic animals that lacks limbs, living in fresh or salt water bodies. More than 25,000 fish species have been identified and 15,000 more species are yet to be identified [3]. Common edible species are catfish, croaker, mackerel, sardines, tilapia among others. Fish is an important source of food for humans, containing high amount of protein. It is cheap and highly acceptable with little or no religious biases which give it an advantage over pork or beef [4]. Fish has high nutritional value and contain all the essential amino acids [11]. In addition to being a great source of cheap protein, fish contains many other nutritious elements that are critical to human health and development such as iodine, vitamin D, omega 3 and omega 6 polyunsaturated fatty acids. Although an excellent source of nutrition, one of the major challenges with fish is that it is extremely perishable and is prone to autolytic deterioration [9].

Catfishes *(Clarias gariepinus)* are named due to its prominent barbels which resemble cat's whiskers [8]. Catfish has been reported to be a very important freshwater fish in Nigeria. It has enjoyed wide acceptability in most parts of the country because of its unique taste, flavour and good texture. It is widely distributed, extensively cultivated in ponds [1]. African catfish is important in Nigeria such that it provides source of income, create employment opportunities and contributes to the Gross Domestic Product (GDP). It provides animal protein to the majority of African populace thereby addressing the issue of malnutrition [2].

Fish post-harvest handling provides livelihoods and income to many people in the world, especially countries gifted with aquatic resources [5]. Fish processing and preservation are important because fish is perishable and prone to quality decline immediately after harvest and to deter economic, quality and nutrient losses [6]. Proper handling of fresh fish is vital to achieve the best quality and highest profits [6]. Regardless of these immense contributions, it is estimated that the world's fisheries suffer approximately 35% post-harvest loss each year [6]. Throughout the world there are many techniques used to reduce post-harvest loss, such as freezing, icing, refrigerating, canning, drying, salting and smoking. Because of its relative simplicity, cost, and effectiveness, smoking of perishable item such as fish is a common process throughout Africa.

Smoking prolongs shelf life of fishes, which permits storage in the lean season; enhances flavour and increases utilization of fishes in other diets, such as soups and sauces. It enhances the nutritive value and promotes digestibility of protein. The traditional way of smoking fish is done by leaving the fish to be processed naturally with smoke generated by burning wood. And usually, smokehouses (smoking kiln) are built for the purpose of smoking fish [7]. However, it is not getting a lot of prominence for export and it is gradually being replaced with modern mechanical methods of preserving fish. Mechanically, fish are smoked with the use of a smoking kiln. It can be relied upon to produce a high-quality, uniform product that conforms to internationally acceptable standard.

II. MATERIAL AND METHOD

2.1 Description of the smoking kiln

The fabrication and assembly of the machine was carried out at Tractor shed, Department of Agricultural and Bio-resources Engineering Federal University of Technology, Minna Nigeria. The developed automated dual powered kiln for fish smoke-drying consists basically of the smoke-dry chamber, combustion chamber and chimney. The control system compartment consists of battery bank, solar charger control, temperature monitor, temperature control, blower control and main switch. The dual powered kiln (Plate V) is a double walled structure having a dimension of 0.62 x 0.62 x 0.94 m (L x W x H) completely insulated all round with formulated composite materials of 0.10 m thickness to conserve heat within the drying chamber as well as preventing the operator from being exposed to high level of heat. The use of locally available composite materials for constructing automated dual powered kiln makes it affordable and culturally acceptable by the fish processors. The composite materials used also solved the problems of cracks and heat loss thereby increase the efficiency of the kiln which results in reduction in processing time.

The kiln has three (3) tray shelves made of wire gauge of dimension 0.57 x 0.57 x 0.021m. The trays were constructed of durable and light weight frame and properly finished edge fine wire mesh which prevents the dried fish products from falling through. Each tray was fixed at a distance of 0.05 m from each other, in the smoking chamber and the total surface area available for drying is 1.26 m^2. The drying efficiency of the kiln per batch is 90 %. The kiln has a single door to allow for easy opening and closure. The interface between combustion chamber and smoking chamber prevents oil and water droplets from directly falling on the fire. The use of an interface (covered with a sheet of steel) between the combustion chamber and smoking dry chamber solved the problem of increase in Polycyclic Aromatic Hydrocarbon (PAHs) in the dried fish. Using an interface drastically reduce the amount of smoke/fume emission thereby reducing the PAHs in the dried fish to meet up with both local and international market standards. The receptacle also served as a receptacle for the collection of fish oil.

The automation control system compartment consists of battery bank, solar charger controller, blower controller, temperature monitor and regulator, and main switch. The system is powered by solar energy received by solar panel mounted on the shed roof, the panel was inclined at angle of 19.4º were maximum solar energy was received by the solar panel. The main switch controls the flow of electric power into the automated control system, when switched-on, it allows current to flow into the system and prevents the inflow when switched-off. The light indicator serves as signals to the kiln operator. It indicates if current flows uninterruptedly into the heating element. The blower control the flow of heat generated through the gas burner or heater. Whenever, the temperature reach preset value, the temperature controller switched off the heaters to maintain the preset temperature value while for gas source of heat, the system controller switched on the exit blower to reduce the temperature back to preset. The kiln temperature was monitored and regulated digitally with the developed kiln control system with the temperature range between 0 ºC and

150 ºC, this solved the problems associated with lack of control over temperature and drying rate in the mechanical kilns and traditional kin. The temperature variation inside the smoking chamber was displayed on the control panel as it increases or decreases. The temperature display help in the monitoring of the changes in smoking chamber temperature hence alleviate the drudgeries encountered in fish smoking.
All the material and component part used for the developed automated dual powered kiln are locally available hence it can be mass produced and the problem of availability of spare parts will be completely eliminated. The total cost of the developed automatic dual kiln is Five Hundred Thousand Naira (₦500, 000). The detailed bill of quantity is as presented in Appendix I. The total cost of developed automatic dual kiln was relatively cheaper than the imported kilns which cost between Two million and Three million (₦ 2,000,000 and ₦ 3, 000, 000) depending on the volumetric capacity of the kilns.

Developed Automated Dual Powered Kiln for Smoked-dried Fish

2.2 Design calculations

2.2.1 Volume of the drying chamber

The drying chamber are design to have three trays to smoked 30 kg each. The kiln is expected to smoke 90 kg of fish per batch.

Volume of drying chamber = $L \ x \ B \ x \ H$ (1)

Volume of drying chamber = 0.62 x 0.62 x 0.94 = 0.361 m³

2.2.2 Total Surface Area of Chamber (A)

A= 2(lb + bh +lh) (2)

= 2[0.62 x 0.62) + (0.62 x 0.94) + (0.62 x 0.94)]

= 2[0.384 + 0.582 + 0.582]

= 3.096 m^2

2.2.3 Thickness of Heating Chamber wall

D_x = KA$\frac{dT}{Q}$ (3)

$\frac{1.8 \ x 3.096 \ x \ 95}{1170}$

$\frac{529.416}{1170}$

Thickness of heating chamber D_x = 0.588 m ≈ 0.6 m

2.2.4 Power required by the heating coil

Power = $\frac{Quantity \ of \ heat}{Time}$ [10] (4)

Power = $\frac{5.187 \ x \ 10^3}{3600}$

= 1.1441 kJ / Sec

= 1144 w

III. PROCUREMENT AND SAMPLING OF FISH

Catfishes *(Clarias gariepinus)* were purchased at fish farm located at Lapia-Gwanri near Federal University of Technology, Gidan-Kwano, Minna, Niger State.

3.1 Initial testing of the smoking kiln

The smoking kiln was test run by igniting the gas burner at the combustion chamber, the temperature was measured and it was discovered to be stable at 85ºC after about 30 minutes. Also the smoking kiln was connected with solar powered electricity and test run and it was discovered to be stable at 54ºC about 30 minutes.

IV. EXPERIMENTAL DESIGN

The experimental design used for this project is 1 x 3 x 2. One type of fish (Catfish) were smoked with 3 replicates and 2 sources of heat. The parameters obtained are: retention time, temperature range, moisture loss rate and drying rate.

4.1 Experimental procedure using gas as source of power

The smoking kiln was fired by igniting gas burner in the combustion chamber. 10 kg of Catfish was measured and loaded on the trays of the developed automated dual powered kiln and the weight of the smoked fish was measured at intervals of 1 hour until a constant weight was obtained.

4.2 Experimental procedure using electricity as source of power

Nine 120w heaters were installed in the smoking kiln, making total of 1080w. The smoking kiln was then connected with electricity. 10 kg of Catfish was measured and loaded on the trays of the smoking kiln at stable temperature and the weight of the smoked fish was measured at intervals of 1 hour until a constant weight was obtained. The overall time spent in smoking was noted and recorded

5.0 Heat transfer by conduction

$$q = \frac{KA(T_1 - T_2)}{L} \quad (5)$$

Where

Thermal conductivity K= 59 $^{wm}/_{k}$

A = area of the fish tray = 0.57 x 0.57 x 0.021 = 0.0682 m

L= distance between the smoking chamber and the combustion chamber = 0.2 m.

T_1= temperature inside smoking chamber = 70ºC

T_2= temperature outside = 25ºC

$$q = \frac{4.0238(25-70)}{0.2}$$

q = 905.4 $^{W}/_{m^2}$

6.0 Heat passing through the Kiln structure

$$Q = \frac{KA\Delta T}{t} \quad (6)$$

Where Q = heat passing per unit length ($\frac{w}{m^2}$)

K = thermal conductivity of the insulated brick

A = area of the brick (m^2)

ΔT = temperature difference between hot face and cold face of the brick (c^0)

T = Time (m)

$$Q = \frac{182.7\,(25-70)}{360}$$

Q = 22.84 $^{W}/_{m^2}$

7.0 Drying efficiency of the kiln

$$\text{Drying efficiency \%} = \frac{\text{Energy required to evaporate water}}{\text{Energy supplied to the dryer}} \quad (7)$$

$$\text{Drying efficiency \%} = \frac{1144}{1170}$$

$$= 97.7777 \approx 98\%$$

V. RESULT AND DISCUSSION

Performance of the kiln

The results of the performance of the smoking kiln conducted at 'NO Load' and Loading conditions were presented below.

8.1 Thermal property of the Smoking Kiln at 'No Load' Condition

The temperatures obtained in the smoking kiln at five different conditions of operation at 'No-Load' with gas source and solar source are shown in Figure 1. The initial temperatures of the kiln at 'No-load' were 28 ^{0}C respectively and the temperatures increased to 85 ^{0}C and 54 ^{0}C after 30 minutes respectively. The temperature continues to increase as the time increase. At 60 minutes, the temperature increases to 110 ^{0}C and 75 ^{0}C respectively. At 120 minutes, temperature recorded was 145 ^{0}C and 110 ^{0}C respectively. The kiln temperature increased progressively as from the start time till after 2 hours when the kiln temperature level remained stable at 145 ºC which has been preset by temperature controller. The evaluation was necessary to know if the designed kiln is able to meet the required drying conditions for fish as recommended by [8]. Fish are required to be heated to an internal temperature of 70 ^{0}C for 3 hours so as to eliminate the harmful pathogens; while the smoking kiln must be able to provide temperature between 80^{0}C and 100 ^{0}C. From the results obtained it was observed that the solar system does not supply steady power to the kiln due to poor weather condition. The electrical components of the kiln run on battery bank. Hence; to achieve the maximum power requirement for fish smoking, solar power heater will perform better during dry season.

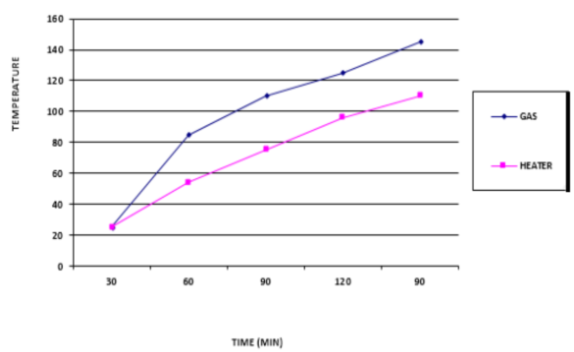

Figure 1: Temperature Distribution in Smoking Kiln at No Load

8.2 Thermal property of the Smoking Kiln at 'Load' Condition

The thermal performance of the kiln using gas source of power with blower in operation when loaded with catfish comparing the same operation at 'No Load', it was observed that there was a temperature drop from 40 to 32 ^{0}C at the start of operation. This sharp drop in the kiln temperature might be due to the wetness of the fresh catfish which pick-up the heat energy to equilibrate with the drying chamber of the smoking kiln; this was in accordance with the reports of [8]. Hence, there was a heat transfer between the fresh catfish and the smoking kiln, while the catfish was gaining heat energy, the smoking kiln was losing.

The temperature controller was set to 40 ^{0}C for 2 hours to carry out cold smoking. The blowers installed in the smoking chamber also ensures uniform distribution of heat and smoke within the smoking chamber and consequently, uniform drying and better product quality. The implication is that there is no need for the rotation of trays or fish during the smoking cycle. Also it was observed that the smoking chamber attained and maintained a temperature above 40 ºC between 30 to 60 minutes of operating the kiln, this was in accordance with the reports of [7] which stated that the smoking temperature suitable for cold smoking ranges from 30 ºC to 40 ºC. To achieve hot smoking, the kiln temperature was preset to 70 ºC.

The heat conservation was made possible due to the presence of insulating material used (Composite materials). The composite materials used for lagging improves heat conservation and reduces energy loss to the environment. This ensures reduction in energy cost and reduced processing time. The use of solar panel to drive the electrical component parts of the kiln took advantage of the abundant renewable solar energy in Nigeria. This feature prevents absolute dependence on alternating current derivable from the epileptic supplies from national grid or the high expenses incur for running PMS or AGO powered generators while achieving better quality products.

CONCLUSION

Developed automated dual powered smoking kiln that is easy to operate, cheap, portable, environmentally friendly and easily maintained with capacity of 90 kg was designed and constructed. The automated dual powered smoking kiln was tested using one of the most available types of fish in the area (Catfish) using gas and electric heat sources and found to perform efficiently while drying the fish with a safe moisture content of 10% to 18%. The smoking kiln was constructed using locally available composite materials and powered with low alternate source of power (solar energy). The kiln temperature, retention time were fully automated. The use of this automated dual powered kiln is found to be efficient when compared to the mechanical kiln method of smoking fish.

REFERENCES

[1] Abdullahi, S. A., Abolude, D. S. and Ega, R. A. (2001). Nutrient Quality of Four Oven Dried Freshwater Catfish in Northern Nigeria. *Journal of Tropical Bioscience*., pp: 70

[2] Adebayo, O. O., and Daramola, O. A. (2013). Economic analysis of catfish (Clarias gariepinus) production in Ibadan metropolis. *Journal of Agriculture and Food Sciences.* Vol. 1(7): 128-134

[3] Cambray, J. A. (2003). The Need for research and monitoring on the impacts of translocated sharptoothed catfish (Clarias gariepinus) in South Africa. *Africa Journal of Aquatic Science*, 28 (2): 191 – 195.

[4] Eyo, A. A. (2001). Fish Processing Technology in the Tropics. National Institute of Fresh water Fisheries Research (NIFER) Publications, New Bussa, Nigeria. University of Ilorin Press. pp. 66-70.

[5] Food and Agriculture Organization (FAO) (2016). Further processing of fish; Fisheries and Aquaculture Department. www.fao.org/docrep/016/i2727e/i2727e.pdf. Assessed on 24/06/20203.

[6] Food and Agriculture Organization (FAO) (2020). Nigeria at glance. Assessed on 25/07/2023.

[7] Ogundana O.S., Yahaya M.J., Owolabi T.E. and Owa T.A. (2023). Development and assessment of a locally designed fish smoking kiln using insulating materials. PNgAS. Vol 16, No 1, 2023.

[8] Olayemi F. F. (2012). Shelf-Life and Quality Characteristics of Smoked Catfish (Clarias Gariepinus) Stored in Composite Packaging Materials. PhD Thesis. University of Ibadan, Nigeria, Pp. 39.

[9] Osibona, A. O., Kusemiju, K., and Akande, G. R. (2009). Fatty acid and proximate composition of Africa catfish. *African Journal of Food and Agriculture*, 9(1): 608-621.

[10] Soe S. A., Han P. W., and Nyem N. S. (2008). Design calculation and performance testing of heating coil in induction surface hardening machine. *Journal of world Aeadenry of Science, Engineering and Technology, Science Publication*/soesandarag@gmail.com. 416-421.

[11] Strilankshmi, B. (2003). Food Science. 3rd Edition. New Age International Publisher, Chennai. Pp: 162-167.