Turkish Journal of Agricultural Engineering Research

https://dergipark.org.tr/en/pub/turkager
https://doi.org/10.46592/turkager.2021.v02i01.010

Turk J Agr Eng Res (TURKAGER)
e-ISSN: 2717-8420
2021, 2(1): 133-155

Research Article

Impact of Improved Smoking Kiln Design on Hygiene and Timeliness of Drying of Smoked Fish

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ABSTRACT

The techniques used in processing cat fish in developing economies of the world are not without several drawbacks. The most prominent is traditional method and this has been known to generate high levels of polycyclic aromatic hydrocarbons (PAHs). In addressing the problems faced by processors in the industry, a fish smoker of 50 kg capacity that derives its power from dual heat sources (charcoal and gas) was designed, fabricated, and evaluated. The smoking time was evaluated on the heat sources with and without the use of a suction blower. The fish had a smoking (retention) time of 4 hours when it was processed without the suction blower while the retention time decreased from 4 hours to 3 hours when the suction blower was used. The suction blower also has a significant impact on the moisture content on dry basis (MC d.b.). The MC d.b. values of smoked fish when suction blower was used with charcoal and gas for 4 hours duration were 10.45% and 11.76%, respectively. Without blower, the values were 14.3% and 11.70%, respectively. The processed smoked fish produced was hygienic, not likely to exceed maximum limits of PAHs allowed by the United States Environmental Protection Agency since materials used are stainless steel and the heat sources used were indirectly introduced into the smoking chamber. Hygienic processing and practices of smoked fish and products can ensure food safety in our society.

RESEARCH ARTICLE

Received: 12.10.2020
Accepted: 06.03.2021

Keywords:

- Smoking kiln,
- Suction blower,
- Charcoal,
- Smoked fish,
- Fish processors

To cite: Okusanya MA, Oluwagbayide SD, Ogunlade CD (2021). Impact of Improved Smoking Kiln Design on Hygiene and Timeliness of Drying of Smoked Fish. Turkish Journal of Agricultural Engineering Research (TURKAGER), 2(1): 133-155. *https://doi.org/10.46592/turkager.2020.v02i01.010*

INTRODUCTION

The origin of fish smoking dates back to the antiquity (Ames *et al.*, 1999; Silva *et al.*, 2011; Marzano, 2018). Over the years, various smoking techniques have been used including traditional ovens, drums, external hearth and fire (Marzano, 2018). Despite the comfort of use and low costs linked with the traditional smokestacks, they are not energy efficient. The incessant use even raises the demand for already rare and unavailable firewood. Probable health hazards accompanying smoked fish from firewood are occasioned primarily by carcinogenic components of wood smoke – mostly polycyclic aromatic hydrocarbons (PAHs) and derivatives of PAH (Silva *et al.*, 2011). Therefore, smoking with firewood or other inefficient methods should be discouraged as much as possible. Because this method restricts the cross-border trade of processed fish due to the associated poor quality of the products, low capacity, high time rate of drying, poor energy efficiency and health effect.

Zwick *et al.* (2011) stressed the health effect of using open fire as indoor energy either for cooking or smoke-drying endeavors. The report reveals that twice as many people were reported dead each year from lung disease caused by indoor pollution as those died from AIDS, and open fire is the primary cause of that indoor pollution. Recent records from FAO (2018) and Khoshmanesh (2006) buttress that every year; over 3.3 million people die from illness attributed to indoor air pollution caused by these fire places. Health test conducted to measure smoke level in the lungs reveals 7.55 ppm for women and 6.48 ppm for children – these tally with the results from a person smoking 7 cigarettes in a day. Health effects of inhaling fine particles from wood smoke are Pneumonia, Lung inflammation, bronchitis, emphysema, etc. (Ajav *et al.*, 2018). From the foregoing, smoke drying of fish through means other than mechanical dryer has deleterious impacts on processors' health and as well detracts from environmental sustainability efforts (Olayemi *et al.*, 2011).

A study conducted by Tongo *et al.*, (2017) on hygiene of smoked fish processed in Nigeria discovered PAH4 levels varying from160 μg kg^{-1} to 470 μg kg^{-1} in traditionally smoked fish on informal markets while risks for cancer was discovered to be higher than allowed by the United States Environmental Protection Agency (USEPA). The study connected this discovery to the use of traditional kilns and therefore recommended the utilization of safer subsistence for smoking fish. The implication from this is that risk management action is needed on PAHs in fish smoked on traditional kilns (Bolaji, 2005).

According to Akinneye *et al.*, (2007) and Davies and Davis (2009) the development of right fishing machinery and techniques that guarantee operational production, handling, processing and storage cannot be over stressed particularly now that aqua-cultural development is gaining popularity. Generally, there is copious fish catch in the dry season and at this period, lakes, streams, ponds and other water bodies experience reduction in water level. This creates opportunity for easy harvest and subsequent scarcity of fish during flood and raining seasons. It is vital to process and preserve quota of the fish caught in this season of abundance, so as to safeguard a sustainable supply of fish during off season and increase profit potentials of the fisher folks (Bolaji, 2005).

Major limitations to adoption of enhanced fish processing and preservation know-hows in the developing countries like Nigeria include shortage of upgraded kilns, high cost of kilns where available, the drying time, difficult technical features of the kilns and inadequate awareness due to lack of synergy between research institutions and the fishery industry where these kilns are needed (Olayemi *et al.*, 2011).

Smoking according to Komolafe *et al.*, (2011) can be performed in four ways namely: warm smoking, cold smoking, liquid smoking and hot smoking.

However, this research work is limited to hot smoking of cat fish. The design utilizes either charcoal or gas burner as smoke producer which then flows up as condensates either by free flow or forced aeration. The air flow pattern is laminar, vertical and circulatory. When smoke producer heats up tick metal platform at the base, the suction blower sucks out the hot air and then redirects it back to the lagged chamber to bring about even heat distribution on the materials under process. Processing time in the kiln is normally in three stages which are: the preliminary dry period; anding period when the skin is toughened to prevent subsequent breakage; the smoking and partial cooking period, and the final cooking period.

Effort of this research endeavor is in essence geared toward designing and constructing an improved kiln in Agricultural and Bioenvironmental Engineering (ABE) department, Federal Polytechnic Ilaro, Ogun Nigeria. The incorporation of designed parameters such as suction blower, temperature sensor (micro controller) and dual heat source made this new design different from the conventional smoking kiln designs. The new design will help to achieve improved smoking timeliness, maximize kiln capacity and as well improve hygienic condition of processed fish.

MATERIALS AND METHODS

This section reveals the design philosophy, major component parts of the smoking kiln, design criteria, material selection, parameters to be measured during evaluation, design calculation, experimental procedure, materials used for evaluation and method of analysis of results.

Design Philosophy

Smoked fish is a product that has been cured by smoking. Smoking process involves flavouring, browning, cooking, or preserving food through exposure to smoke to avoid burning or smoldering material, most often wood, charcoal or other alternative sources. Fish smoking can be carried out in four ways. These include cold smoking, warm smoking, hot smoking, and through the employment of liquid smoke. Therefore, the design of smoking kiln can utilize either charcoal or gas burner as smoke producer which then flows up as condensates either by free flow or forced aeration. The air flow pattern is laminar, vertical and circulatory. When smoke producer heats up tick metal platform at the base, the suction blower sucks out the hot air and then redirects it back to the lagged chamber to bring about even heat distribution on the materials under process.

Major Component Parts of the Smoking Kiln

The smoking kiln was designed and constructed at the Engineering Workshop of the Department of Agricultural and Bio-Environmental Engineering, Federal Polytechnic, Ilaro, Ogun State, Nigeria. The kiln cabinet is made from stainless steel metal sheet of 1.5mm gauge. It was lagged with fibre glass as insulator. The smoking chamber consists of set trays with dimension 737 mm × 480 mm arranged into six layers in the chamber. Each layer is made of stainless-steel tray. The cabinet overall dimension is 830 mm × 400 mm × 1250 mm. Wire gauze also made from stainless steel were framed round in the dimension specified above to form each tray. The improved smoking kiln design has dual power, namely charcoal and gas. The heat chamber was separated from smoking chamber by 2 mm thick metal platform beneath the trays layers to prevent direct flow of naked flame from the burner to the tray section where the materials to be smoked will be laid in layers. Even distribution of heat around the chamber is made possible via suction blower introduced at the top of the kiln near the chimney. The blower sucks heated air from the heat chamber and then directs it to the smoking chamber where fish under process are smoke dried. The suction blower capacity is 1.5 hp. The chimney conducts the mist to the surrounding air outside.

Component Parts of the Smoking Kiln

1. Heat Chamber: It is a type of oven that produces temperatures adequate to finish some process, such as hardening, drying, or chemical changes. The heat chamber in this technical report uses dual power, namely charcoal and gas burner. This section of the design is separated from the smoking chamber so as to prevent direct heat contact with the material to be smoked.
2. Smoking Trays: The trays are made with stainless steel materials and the length and breadth are 737.0 mm and 480.0 mm. This is the container into which the fish is loaded and smoked.
3. Tyres for Mobility: It helps in moving the smoking kiln from one place to the other. The smoking kiln therefore consists of four tyres for ease of mobility.
4. Suction Blower: The blower of 60 mm diameter and thickness of 1 mm was chosen. The blower was attached to the side view of the kiln and directly facing the charcoal pot and the gas burner. It also helps in blowing hot air into the smoking chamber so as to enable heat to spread in the smoking chamber. The capacity of the suction blower is 1.5 hp.
5. Chimney: The chimney was made of pipe of 2 mm thickness and diameter of 125 mm rapped under a protection cap. This component allows excess heat and mist in smoking chamber to pass out.
6. Stainless Steel Platform: It is used in transferring heat from the sources of power into the chamber and also helps in moisture drainage.
7. Cabinet framework: The frame supports the other component parts on it in order to make the entire assemble stable. It is made up of stainless steel of 830 mm × 400 mm × 1250 mm. The outer frame is made of mild steel so as to reduce production cost.

Design Consideration

Some relevant factors were considered in the design and fabrication of smoking kiln. Such factors are cost of maintenance, power requirement and ease of replacement of the various components, nature of material for construction and labor requirement. The machine is easy to maintain. Stainless steel of 1.5 mm thick plate was considered for the construction of parts to avoid contamination with the food materials to be processed.

Material Selection

Table 1. Table of material selection.

Machine component	Criteria for material selection	Machine selected	Dimension	Remark
Smoking tray	Must be strong and able to acquire more material	Stainless steel of 5 mm thickness	737 mm x 480 mm x 5 mm	It does not twist and each tray has ability to contain 8.5kg of fish
Heat chamber	Ability to withstand vibration and the heat that comes from heat source.	Stainless steel of 5mm thickness	752 mm x 300 mm x 1016 mm	Durable (fabricated)
Chimney	Must be strong	Galvanized Iron	296.0 mm long	It was constructed
Suction blower	Must be able to blow air into the chamber	Galvanized Iron	960.0 mm long and ф 60	Available (bought ready-made)
Stainless steel platform	Ability for ease of flow of heat from the source of power	Stainless steel of 3mm thickness	737 mm x 480 mm x 3 mm	Durable (fabricated)
Member frame	Must be strong and not flexible	Stainless steel	830 mm × 400 mm × 1250 mm.	Constructed

Figure 1 below shows the pictorial view of the kiln. The view shows the chimney of the smoking chamber, suction blower, tyres and handle. It was designed in such a way that the chamber can process 50 kg of fish per batch of drying. Figure 2 is the autographic projection of the entire assembly. The front view, side view and the plan are shown in the view. From the Figure, the layers of tray in the chamber, dual power section (charcoal and gas burner), oil and moisture spill platform and the draining trough can be seen. The working drawing is as shown in Figure 3 below.

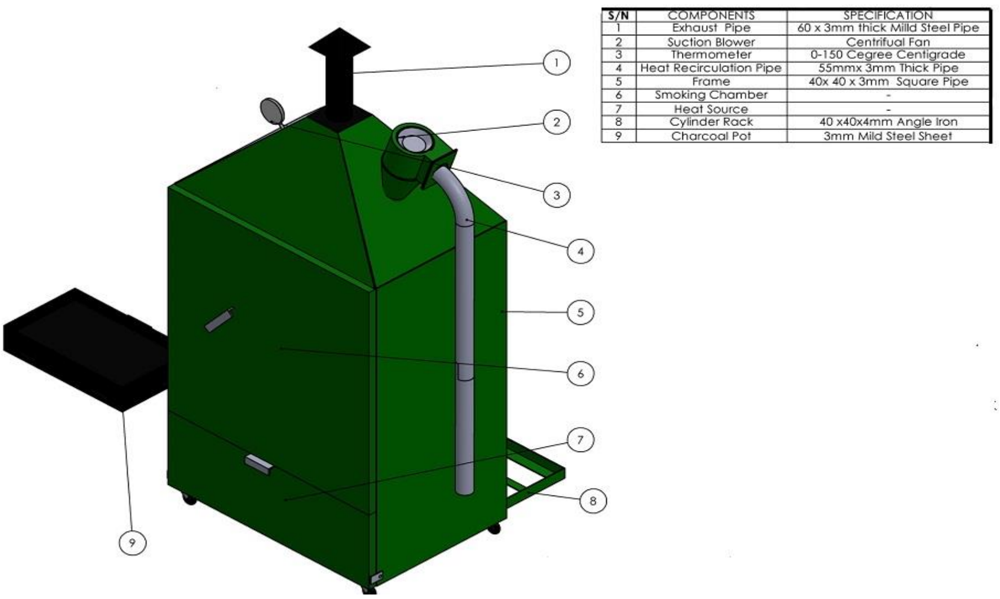

Figure 1. Pictorial view of the fish smoker.

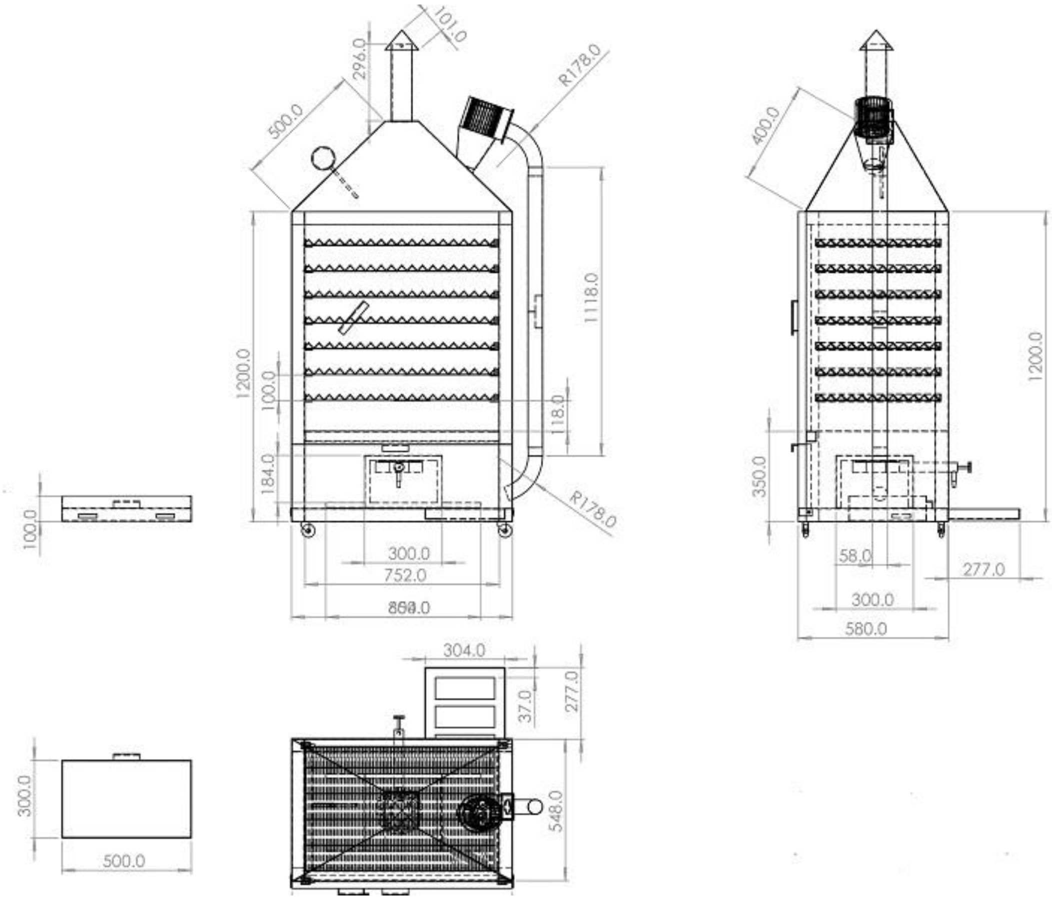

Figure 2. Autographic view of the fish smoker.

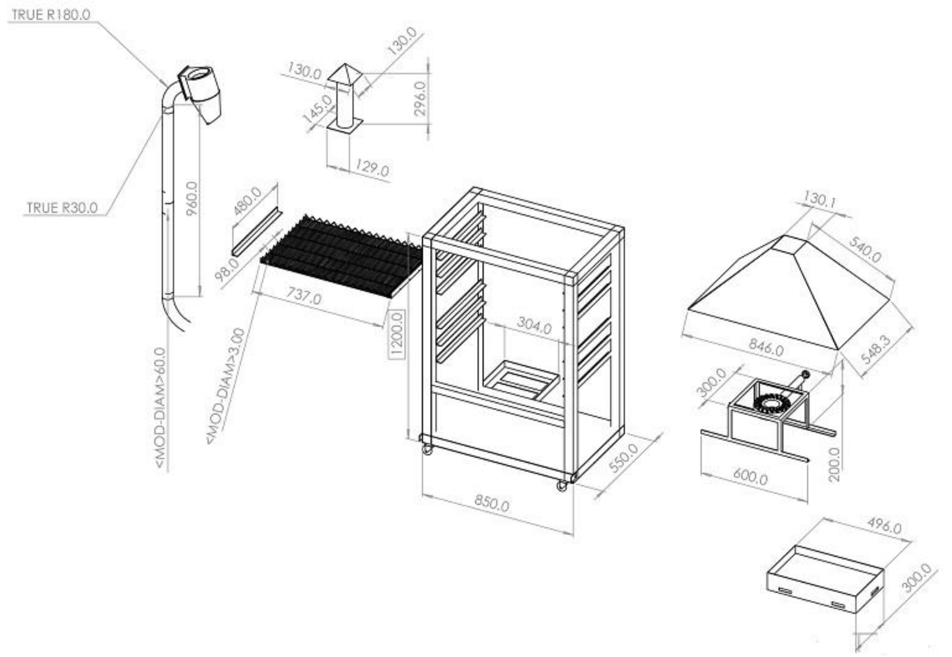

Figure 3. The working drawing of the fish smoker.

Materials and parameters for evaluation

Materials used for the smoking kiln evaluation are fresh cat fish at 70% MC, a microcontroller for temperature measurement, moisture meter for moisture content measurement, sensitive measuring scale, stop watch and recording materials. Variables considered during evaluation are use of independent heat sources (charcoal and gas), smoking with and without suction blower, etc. Parameters measured are time rate of drying, weight at every hour of drying, temperature of each chamber and moisture content.

Fresh sample (28kg) of African catfish (*Clarias gariepinus*) was purchased from a fish farmer by a river site in Ilaro town of Ogun State, Nigeria in August 2019. The sample was brought into the Agricultural & Bio-Environmental Engineering Departmental workshop and 8kg was divided into four equal portions of about 2kg each. The first and second portions were smoke dried with the use of both charcoal and gas. The suction blower was powered for the first two experiments. In the third and fourth experiments conducted for both charcoal and gas, the suction blower was not powered. The quantity of fish processed was increased to 20 kg in the fifth experiment to confirm if quantity processed per batch will affect the time rate of drying. Figures 1 and 2 show some of the experiment runs carried out in this research work.

Design Calculation for the Improved Kiln

Fish tray design

The volumetric capacity of each fish tray was calculated in relation to the volume of fish it occupies. Each tray was designed to contain 8.5 kg of fish per unit operation on the average. The volume of any material was calculated as given by Khurmi and Gupta (2005):

$$V_1 = \frac{M}{\rho} \tag{1}$$

Where:

V_1 = volume of material in mm^3

M = mass of the material in kg = 8.5 kg

ρ = bulk density of fish (kg m^{-3}) = 1080 kg m^{-3} (Kamaldeen *et al.*, 2016)

$$V_1 = \frac{8}{1080}$$

V_1 = 0.00741 m^3

Compartment design

In the design of fish tray volumetric capacity, the shape of the compartment was designed to be rectangle. The dimension of the smoking tray is 737 mm x 480 mm x 5 mm and the skeletal view of the fish tray is as shown in Figure 4 below. The tray is made of stainless-steel wire net of 5 mm thickness.

V_2 = volumetric capacity of the compartment (Kamaldeen *et al.*, 2016)

= 1.5 × V_1 (Kamaldeen *et al.*, 2016)

= 1.5 × 0.00648

= 0.00972 m^3

Volume of the fish tray was multiplied by 1.5 to determine tray volumetric capacity in order to allow for enough clearance and space in the tray.

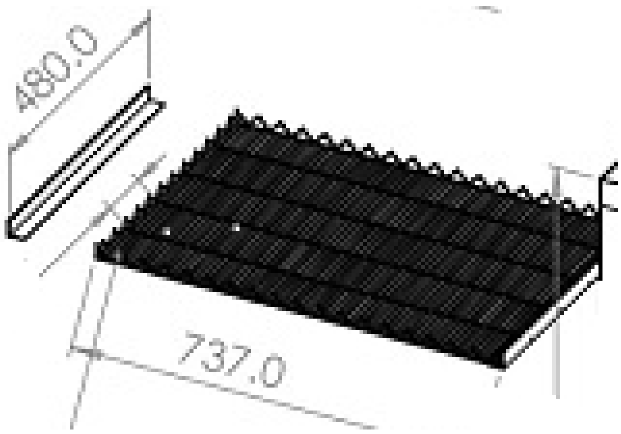

Figure 4. Skeletal view of the fish tray.

Rate of fish smoking by the machine

Since basic concept in smoking operation is to reduce moisture to save level for the purpose of longer storage, which is the same as drying, the drying rate formula can also be employed. Time taken for drying any commodity is given by Donald *et al.*, (1974) as:

$$\frac{C_{fm}\times 60}{V} C_a(T_a - T_e)t = h_{fg}DM(M_f) \tag{2a}$$

$$t = \frac{h_{fg}DM(M_f)}{\left[\frac{C_{fm}\times 60}{V}C_a\right](T_a - T_e)} \tag{2b}$$

(from equation 2a)

C_{fm} = Air flow from blower m³/s. This can be determined using expression given by Joshi (1978) as:

$$C_{fm} = AV \tag{3}$$

Where:

V = Velocity of air required for heat flow (m s^{-1}) = 9.8 m s^{-1} (Ghanem and Shetawy, 2009),
A = Area of air duct or chute (m^2); r = 0.028 cm (radius of the air duct)
$A = \pi r^2 = 3.14 \times 0.29^2$ m^2
$C_{fm} = 3.14 \times 0.028^2 \times 9.8 = 0.024$ m^3 s^{-1} (volume flow rate of hot air through the piping)
V = Heated air specific volume = 13.26 m^3 kg^{-1} (Donald *et al.*, 1974)
C_a = Air specific heat = 240 kJ kg^{-1} °C^{-1} (Donald *et al.*, 1974)
T_a = Charcoal temperature (heated air temperature) = 450°C
T_e = External temperature of smoked fish 27°C ambient air. This can be determined from the equation of heat flow which can be given as:

$$q = KA\,(T_e - T_a) \tag{4a}$$

$$T_e = T_a - \frac{q}{KA} \tag{4b}$$

(From Equation 4a)

Where:
q = Heat produced by charcoal = 3.14×10^4 kJ
K = Fish thermal conductivity = 3.04×10^3 kJ °C^{-1} m^{-2}
A = Fish average surface area = 0.045 m^2 (Kamaldeen *et al.*, 2016)

$$T_e = 450 - \frac{3.14 \times 10^4}{3.04 \times 10^3 \times 0.045} = 220° \text{ C}$$

h_{fg} = Latent heat of vaporization = 1200 kJ kg^{-1} (Donald *et al.*, 1974)

Dry matter calculation for charcoal heat source without suction blower
DM = Fish dry matter in the kiln which can be computed as given by (Donald *et at.*, 1974) as:

$$DM = W\,(1\text{-}MC) \tag{5}$$

Where: *W* = weight of fishes per unit tray = 2.0 kg
MC = Fish moisture content on wet basis which vary from 30 -75% but for this design, 70% fish moisture content on wet basis was selected
DM = 2.0 (1 – 0.70)
= 0.6 kg

Dry matter calculation for gas heat source without the use of suction blower
With reference to equation 5 above,
Where: *W* = weight of fishes per unit tray = 3 kg
MC = Fish moisture content on wet basis which vary from 30 -75% but for this design, 70% was selected
DM = 3 (1 – 0.70)
= 0.9 kg

Dry matter calculation for gas heat source with the use of suction blower
Where: *W* = Weight of fishes per unit tray = 4 kg
MC = Fish moisture content on wet basis which vary from 30 -75% (Kamaldeen *et al.*, 2016) but for this design, 70% was selected
DM = 4 (1 – 0.70) = 1.2 kg

For moisture content M_2 of next level of drying,

$$M_2 = 100 - \frac{W1(100 - M1)}{W2} \tag{6}$$

Where:
w_1 = Weight of un-dried fish,
w_2 = Weight of dried fish,
M_1 = Moisture content of un-dried fish
M_2 = Moisture content of dried fish

Smoking time calculation
From Equation 2b,
Where t = smoking time (min) which is given as:

$$t = \frac{h_{fg} \times DM \times M_f}{\left[\frac{C_{fm} \times 60 \times C_a}{V}\right](T_a - T_e)} \quad (7)$$

$$t = \frac{1200 \times 12.5\ (2.33)}{\left[\frac{(0.049 \times 60)\ 0{,}0024}{13.26}\right](450-220)}$$

$$= \frac{34\ 950}{1.52} = 22\ 993.42\ s \cong 4\text{h } 40 \text{ min}$$

Therefore, if all the six fish trays loaded with equal average size of a fish (0.5 kg) are expected to be completely smoked within 4 hours 40 minutes.
Note: Since uniform distribution of heat is expected in the cabinet using blower, all the trays loaded with fish are assumed to smoke at the same rate.

Smoking cabinet design
In designing the smoking cabinet, the sectioned view of the cabinet is shown in Figure 5 below. The volumetric capacity of smoking cabinet was computed in relation to the equation as given by John (2005) as:

$$V_3 = A \times W \quad (8)$$

Where:
V_3 = Volume of smoking cabinet in m^3
A = Surface area of smoking cabinet in m^2
Surface area (A) was obtained using equation given by John (2005) as:

$$A = \frac{L\ (3H + L)}{2} \quad (9)$$

Where:
L = Length of the smoking cabinet = 830 mm selected for convenient containment of 6 fish trays,1 charcoal pot, 1 oil collector within the chamber and 1 gas burner (for the smoking cabinet)
H = 1250 mm selected for convenient containment of 6 fish trays, 1 charcoal pot and 1 oil collector within the chamber and 1 gas burner
$A = 830\ x \frac{3\ x\ 1250+830}{2} = 1\ 900\ 700$ mm^2
w = Smoking cabinet width = 400 mm selected for convenient containment of 6 fish trays, 1 charcoal pot and 1 oil collector within the chamber and 1 gas burner V_3
= 1 900 700 ×400
= 760 280 000 mm^3
V_3 = 0.76 m^3

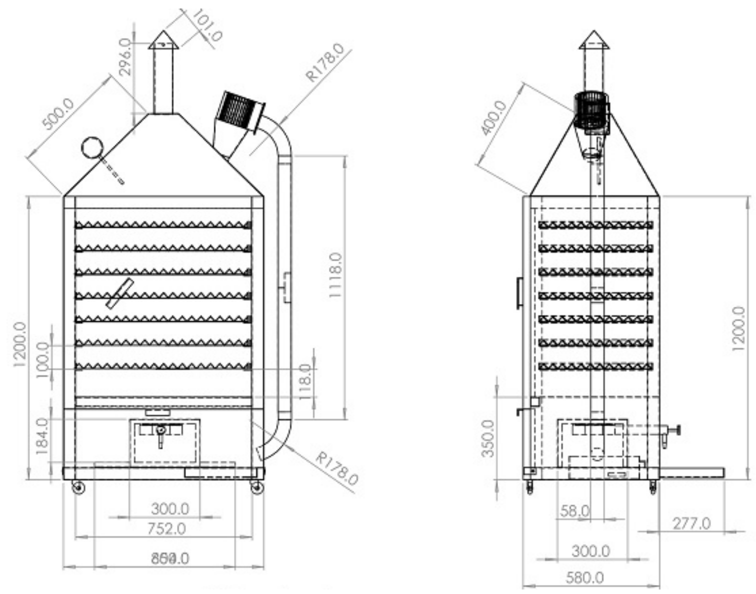

Figure 5. Sectioned view of the smoking cabinet.

The Smoking Kiln Working Principle

To operate the kiln, charcoal was arranged in the fire pot, ignited and kept opened for a while until the amber is uniform before fish are loaded on the tray. For the alternative heat source, industrial gas burner was used. The burner design is achieved by slotting arrangement provided at the base section of the chamber. It can be used in place of the charcoal pot. The ability the smoking kiln has for dual heat source gives it advantage over existing kilns around. Also, the gas burner is fast and supplies blue flews while in operation. On closing the door, the hot air supply either from charcoal pot or gas burner flows upward to obey the principle of heat flow from region of higher concentration to lower concentration.

The smoke chamber is firmly shut and opened at intervals of 1 hour for observation and necessary readings like weight, moisture content, time taken, temperature and other relevant parameters for analysis. The heat transfer was aided mechanically by the use of suction blower incorporated in the design at the top. The suction blower has prime mover of 1.5 hp electric motor attached and is powered by electricity. The heat flow is aided by the blower through heat flow by conduction, convection and radiation. The charcoal pot is positioned by slotting arrangement too. The design is done in a way to prevent dripping of oil and moisture on the hearth so as to reduce smokiness of the chamber or eventual fire outburst. The burner has a 2 mm thick plate on it in the chamber to prevent fire outburst. The plate was designed to be sloppy downward so that it can easily convey both oil and water drips to the draining trough at the peripheral of the chamber.

During smoking endeavor, the trapped hot air goes through the suction blower and then returns back to the kiln chamber through the galvanized iron pipe fitted to the member frame - see Figures 1, 2, 4 and 5 above for details. The lagging ensures that the drying chamber remains hot for a long period after the charcoal is burnt or burner fired. The temperature of the system was measured with the aid of a digital microcontroller sensor inserted in the perforated sides of the chambers. With the aid of materials and other insulators used in the construction, it denotes a partial hermetic heating and smoking process.

Experimental Procedure

Two different sources of power (gas and charcoal) were used to smoke the fish sample (cat fish). The samples were washed thoroughly and salted with 10gm of salt, then permitted to dry before they are laid on the fish tray for smoking endeavor. The charcoal in the pot charcoal was first kindled with the help of kerosene, the kindled charcoal was allowed to burn for 10 to 15 min to allow the kerosene odour to be exhausted. Additional charcoal was supplied to the burning charcoal and put underneath the thick plate platform. Similar operation was carried out for the alternative source (gas). From the experiment, it was deduced that the time to smoke with gas was shorter as compared to charcoal. More also, smoking with gas retained the golden brown colour of the smoked fish compared to charcoal.

For another experiment, suction blower was introduced for the two sources of power (charcoal and gas), the suction blower was driven to injet a fairly hot constant heat. During the smoking, the sides of the fish facing the burning flame are changed routinely by pulling out the burning tray and then turning the fish's upside down. The trays are then pushed back afterwards.

Similarly, the weight of the fish is computed intermittently at an hour interval anytime the arrangement of the fish is to be altered and the corresponding moisture content calculated (Ashaolu, 2014). This situation continued until the final weight and hence the final moisture content is obtained. The final moisture content that is, safe moisture content (10 to 15%) (Olayemi *et al*., 2011) is computed using equations 5 and 6 above when there is virtually no further reduction in the moisture content. The time taken for the smoking was the total time taken including the time for the intermittent computation of moisture content and that of altering the position of the fish.

The result is given in Tables 2 to 6 below. After smoking and determination of final moisture content, the fish is permitted to cool and kept in plastic bucket, well covered carton and polythene bag to compute its storage life. These containers were carefully chosen because they are among the mutual storage materials used for handling fish in Ogun State. The determination of the storage life was carried out in the months of August to November 2019. Figure 6 below shows the flow chart of the smoking process.

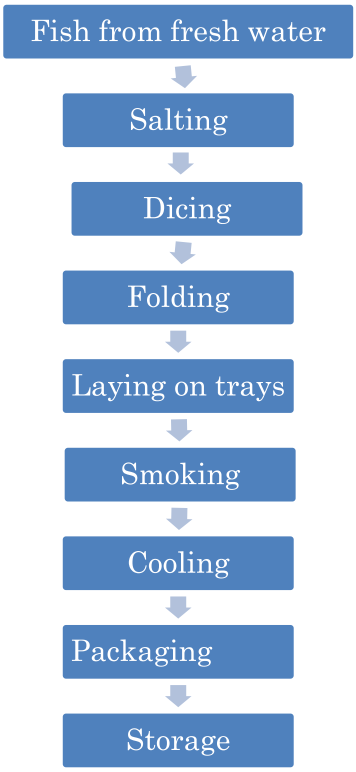

Figure 6. Flow chart of fish smoking process.

Cost Estimation of the Kiln

Cost of engineering products like the newly developed smoking kiln can broadly be grouped under direct or indirect cost. Direct cost is the cost of factors which are directly credited to the manufacture of a precise product (i.e. materials and labor costs). Indirect cost on the other hand is that indirectly credited to the manufacture of a specific product, such as overhead cost (usually expressed in percentage of direct labor cost) (Ajav *et al.*, 2018). The costing of the newly designed and fabricated smoking kiln was based on the detailed factorial estimate method (John, 2005). This is because fabrication of the machine is complete and detailed breakdown and estimation of component parts is possible. The cost analysis of the machine is shown in table 2 below.

Table 2. Bill of Engineering Measurement and Evaluation (BEME) of the improved smoking kiln - mechanical components (Direct Material Cost).

Qty.	Material Specifications	Rate (₦)	Amount (₦)	Amount (USD)
1	Angle Iron One Length, 25 mm x 25 mm x 3 mm	1.500	1.500	4.5
2	Cutting Stones	500	1.000	3.0
3	Grinding Stone	500	1.500	4.5
1	Stainless steel plate 1 mm thickness	22.000	22.000	66.0
2	Mild steel plate 1 mm thickness	11.000	22.000	66.0
6	Stainless mesh	4.000	24.000	72.0
1	Hollow pipe 90 mm diameter	5.000	5.000	15.0
1	Blower	15.000	15.000	45.0
4	Tire	1.250	5.000	15.0
50	Fiber glass per kg	300	15.000	45.0
1	Pkt. Mild Steel Electrode Gauge 12	4.000	4.000	12.0
50	Stainless steel electrode (pieces)	100	5.000	13.0
	Transport	5.000	5.000	15.0
	Sub Total		**₦ 126.000**	**376.0**

Direct labor cost
Fabrication (Bending, Rolling, Shearing, welding, painting) 7 000
Sub Total = ₦7 000 (USD 21.0)

Indirect / Overhead Cost

1. Over head of direct material cost = 20% of ₦7 000 = ₦1 400
2. Over head of direct labor cost = 20% of ₦126 000 = ₦25 200

Sub Total = ₦26 600 (USD 79.8)
Total = ₦126 000 + ₦7 000 + ₦26 600 = ₦159 600 (USD 478.8)

Statistical Method and Result Analysis

Correlation (product moment method) and Regression (least square method) were used as statistical instrument for result analysis. Correlation coefficient, *r* is as given in equation 10 below. Null hypothesis is Ho: $\pm 0.5 \leq r \leq \pm 1$; while alternative hypothesis is H_1: $r < 0.5$. For Ho in the range of values stated above, it means there is a strong relationship between the dependent variable and independent variable. If the correlation coefficient is not within acceptable region, alternative hypothesis is accepted. The implication of this is that the relationship between them is weak or unacceptable.

$$r = \frac{\sum xy - n\ddot{x}\ddot{y}}{\sqrt{\{\sum x^2 - n(\ddot{x})^2\}\{\sum y^2 - n(\ddot{y})^2\}}} \tag{10}$$

$$b = \frac{n\sum xy}{n\sum xy - \frac{\sum x \sum y}{n\sum x^2 - (\sum x)^2}} - \frac{\sum x \sum y}{n\sum x^2 - (\sum x)^2} \tag{11}$$

$$a = \bar{y} - b\ddot{x} \tag{12}$$

$$\bar{y} = \sum y / n \tag{13}$$

$$\ddot{x} = \sum x / n \tag{14}$$

$$y = bx + a \tag{15}$$

Using equations 10 to 13, regression line "*y = bx + a*" (equation 15) can be determined. Relationship between the dependent variables and the independent variables was established through the statistical instrument and table 8 for summary of the relationship between moisture content and drying time.

RESULTS and DISCUSSION

Tables 3, 4, 5, 6 and 7 below show the result of smoking exercise of cat fish at moisture content of 70%. The weights of fish processed for the five experiments are 2 kg, 2 kg, 2 kg, 2 kg, and 20 kg respectively. The final weights for the first four experiments are respectively 0.67 kg, 0.68 kg, 0.68 kg and 0.70 kg. For the fifth experiment, the final weight is 6.72 kg.

In the first experiment, charcoal was used as source of heat with the exception of suction blower. The second experiment involves use of gas burner as source of power for fish smoking without the use of suction blower. The first two experiments were repeated in the third and fourth experiment with the use of suction blower. The last experiment (fifth) was a repeat of second experiment. But this time, the quantity of fish processed was increased to 20 kg as against 2 kg to confirm if quantity of fish processed per batch has impact on drying time. See Figures 7, 8, 9 and 10 for detailed information on the mechanical dryer.

It took four (4) hours to run the first two experiments to safe moisture content of 10.45% and 11.76% respectively. In attaining safe moisture content for prolonged shelf life like the one in the first two experiments, the third and fourth were repeated but this time with suction blower. Their moisture content of 11.7% and 14.3% were attained in three hours. The fifth experiment took less than five hours (4 hours, 30 minutes) to attain moisture content of 10.7%. All the five experiments took less than five hours to attain moisture content recommended in the literature for fish preservation. Figures 11, 12, 13, 14 and 5 are the plots for the five experiments. These results are discussed in the next subsection.

Figure 7. Smoking exercise with the mechanical dryer.

Figure 8. Exercise on weight measurement after smoking endeavour.

Figure 9. Mechanical dryer showing dual heat sources used for the experiment.

Figure 10. Instruments used for measurement of weight, temperature and moisture content.

Table 3. The result of evaluation using charcoal without suction blower.

Time	Weight of tray	Weight of tray with fish	Weight of fish	DM	MC
(h)	W_1 (kg)	W_2 (kg)	W_3 (kg)	(kg)	(%)
0	2.20	4.20	2.00	0.60	70.00
1	2.20	3.70	1.50	0.60	60.00
2	2.20	3.40	1.20	0.60	50.00
3	2.20	2.98	0.78	0.60	23.08
4	2.20	2.87	0.67	0.60	10.45

Table 4. The result of evaluation using gas without suction blower.

Time	Weight of tray	Weight of tray with fish	Weight of fish	DM	MC
(h)	W_1 (kg)	W_2 (kg)	W_3 (kg)	(kg)	(%)
0	2.20	4.00	2.00	0.60	70.00
1	2.20	3.76	1.56	0.60	61.54
2	2.20	3.45	1.25	0.60	52.00
3	2.20	3.00	0.80	0.60	25.00
4	2.20	2.88	0.68	0.60	11.76

Table 5. The result of evaluation using charcoal with suction blower.

Time	Weight of tray	Weight of tray with fish	Weight of fish	DM	MC
(h)	W_1 (kg)	W_2 (kg)	W_3 (kg)	(kg)	(%)
0	2.20	4.20	2.00	0.60	70.00
1	2.20	3.60	1.40	0.60	57.00
2	2.20	3.00	0,80	0.60	25.00
3	2.20	2.88	0.68	0.60	11.70

Table 6. The result of evaluation using gas with suction blower.

Time	Weight of tray	Weight of tray with fish	Weight of fish	DM	MC
(h)	W_1 (kg)	W_2 (kg)	W_3 (kg)	(kg)	(%)
0	2.20	4.20	2.00	0.60	70.00
1	2.20	3.60	1.40	0.60	57.00
2	2.20	3.00	1,00	0.60	40.00
3	2.20	2.90	0.70	0.60	14.30

Table 7. Result of evaluation using gas with suction blower with large quantity processed.

Time	θ	W_1	W_2	W_3	W_t	DM	MC
(h)	(°C)	(kg)	(kg)	(kg)	(kg)	(kg)	(%)
0	40.51	7.00	7.00	6.00	20.00	6.00	70.00
1	109.30	5.88	6.13	5.14	17.15	6.00	65.02
2	112.50	5.05	5.23	4.41	14.6	6.00	59.16
3	115.66	3.90	3.98	3.38	11.25	6.00	46.67
4	147.80	3.19	3.37	2.81	9.37	6.00	35.97
4.30 min.	156.20	2.30	2.40	2.02	6.72	6.00	10.71

Table 8. Summary of the relationship between moisture content and drying time at various conditions.

S/N	Dependent Variable	Independent Variable	Resulting Equation (Regression Line)	Null Hypothesis, r (correlation coefficient)	Inference
1	Moisture Content	Drying Time	*y = -15.6x + 73.91* $R^2 = 0.9649$	$r = \frac{271.04-427.1}{\sqrt{\{10 \, x \, 2521.18\}}}$ = - 0.983 r ≈ - 0.98 *Note: result from using charcoal without suction blower*	Strong negative correlation, Ho is therefore accepted
2	Moisture Content	Drying Time	*y = -15.3x + 74.664* $R^2 = 0.9565$	$r = -\frac{153.02}{\sqrt{24568.92}}$ $r = \approx -0.976$ *Note: result from using gas without suction blower*	Strong negative correlation, Ho is therefore accepted
3	Moisture Content	Drying Time	*y = -20.69x + 71.96* $R^2 = 0.9679$	$r = -\frac{103.48}{\sqrt{11049.2}} = -0.985$ $r \approx -0.99$ *Note: result from using charcoal with suction blower*	Strong negative correlation, Ho is therefore accepted
4	Moisture Content	Drying Time	*y = -18.41x + 72.94* $R^2 = 0.9761$	$r = -\frac{91.9}{\sqrt{8725.7}} = -0.984$ $r \approx -0.98$ *Note: result from using gas with suction blower*	Strong negative correlation, Ho is therefore accepted
5	Moisture Content	Drying Time	*y = -12.078x + 77.6* $R^2 = 0.8717$	$r = -\frac{718.02}{\sqrt{42616.7}}$ $= -0.959$ $r \approx 0.96$ *Note: result from Gas with suction blower with large quantity processed*	Strong negative correlation, Ho is therefore accepted

Results from Table 8 show that there is relationship between the moisture content of the fish and the retention time. Since r value is within the range of null hypothesis, null hypothesis was therefore accepted. The deduction from the evaluation is that strong negative correlation existed between moisture content and drying time irrespective of drying condition or parameter varied. Fish moisture reduces as retention time increases. The colour also kept changing until stable golden-brown colour was attained. Beyond this level (retention time), it was observed that the colour changed to burnt brown.

The rate of moisture removal measures quantity of moisture being removed by the smoking kiln per unit time. The moisture removal was measured hourly using the average value of mass of fish weighed at interval of an hour in each case. From the graph in Figure 11, it can be deduced that it took 4 hours for the smoking kiln to dry 2 kg of cat fish to moisture content of 10.45% when the suction blower is not powered. 10 -14 % is the recommended MC in the literature (FAO, 2018) to prolong the shelf life of the fish to about 3 months or more.

The graph in Figure 12 shows the relationship between moisture content and time rate as well. But this time, the heat source is gas and suction blower was not also used. The weight of fish processed is 2 kg and the final moisture content got is 11.76% at the end of fourth hour of smoke drying. While comparing the first graph with the second, it was discovered that at fourth hour of drying the second sample (11.76%) has less prolonged shelf life than the first (10.45%). But, what the second lacked in shelf life is compensated for in the cost of fuel (gas) used. The hygiene of the fish is even retained using gas since it produces blue flame than using charcoal. There is possibility of carbon (II) oxide forming the coatings for the sample processed using charcoal and this may be dangerous to health.

The graph in Figure 13 shows the relationship between moisture content and time rate as well. This time, suction blower was used, and the heat source is charcoal. The weight of fish processed is 2 kg and the final moisture content got is 11.70% at the end of third hour of the experiment for the sample. The graph shows that the moisture content (MC) peaked at third hour. The implication is that the use of suction blower has positive impact on drying time when compared with the first and second experiment.

The graph in Figure 14 shows the relationship between moisture content and the drying time when suction blower was used with gas burner. At third hour, the moisture content was observed to be 14.30% unlike the first and second that took four (4) hours to bring them to moisture content of 10.45% and 11.76% respectively. Another inference from the third experiment is that introduction of suction blower for even heat distribution brought the time of drying below usual drying hours by one (1) hour. More also, the moisture content at the third hour is in the range of moisture content (10-14%) recommended in the literature for preservation of dried fish (Ashaolu, 2014). It should be noted that oil was part of what sipped out from the cat fish during the smoking process and this was collected through draining trough at the peripheral of the smoking kiln. Fish with very high oil content will affect accuracy of result as oil will be part of weight measured at interval (Ashaolu, 2014).

Lastly, other evaluation method was carried out using gas burner as source of power with large quantity. This time, suction blower was powered. The weight of fish processed is 20 kg and the final moisture content got is 10.71% at the end of four hours thirty minutes (4½ hours). From the evaluation observed, the smoking kiln can process 50 kg of fish and more. Synoptically, the quantity of fish to be processed has moderate impact on drying time when suction blower is used.

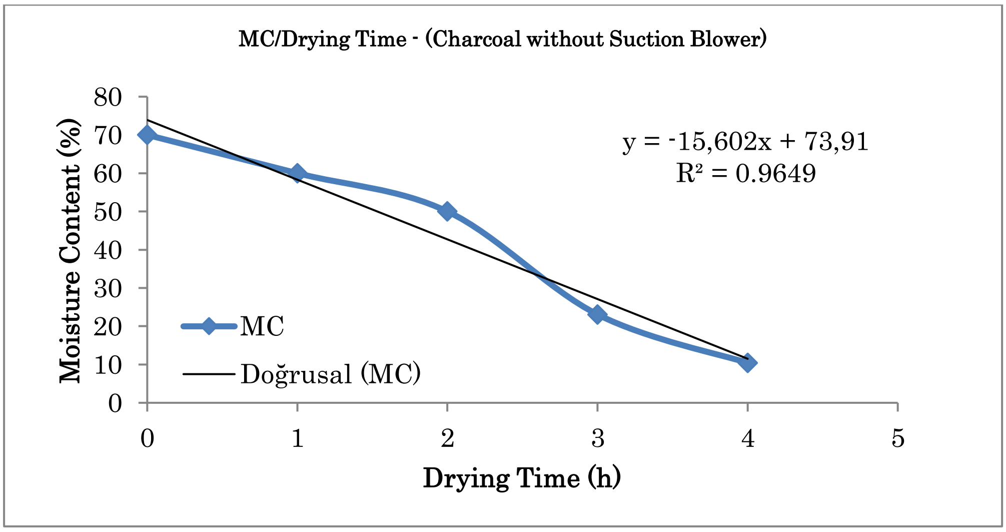

Figure 11. Graph of MC against drying time (charcoal without suction blower).

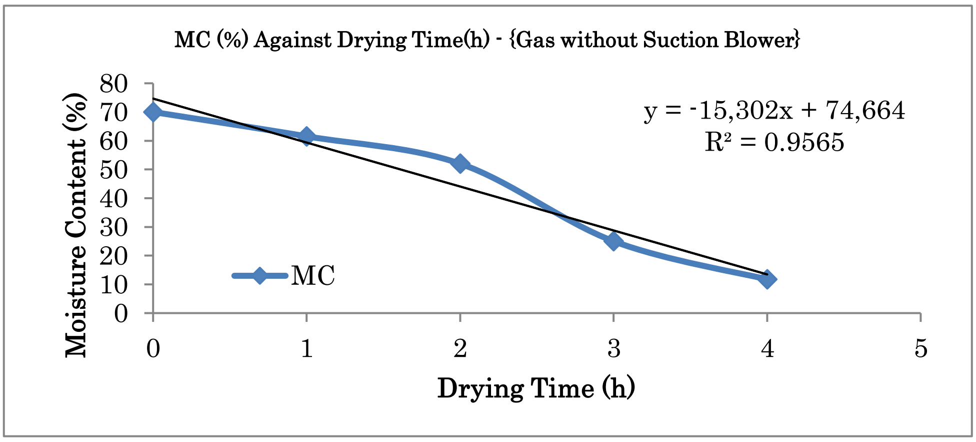

Figure 12. Graph of MC against drying time (Gas without suction blower).

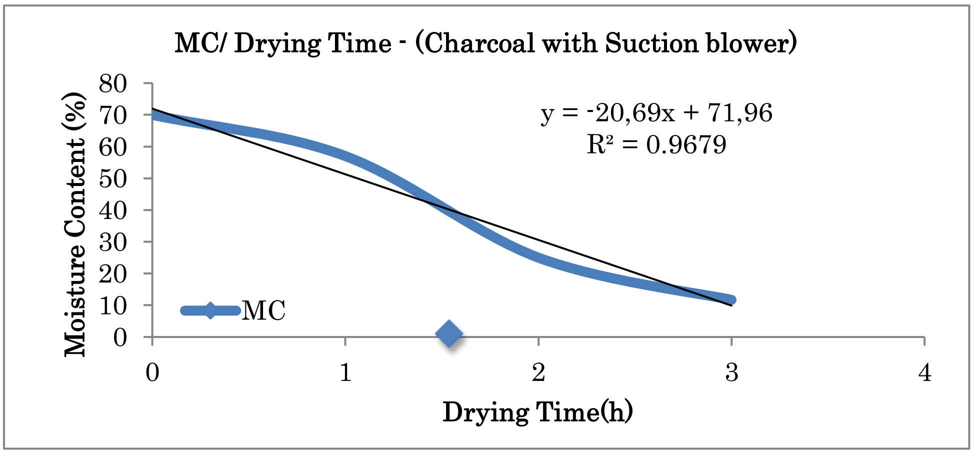

Figure 13. Graph of MC against drying time (charcoal with Suction Blower).

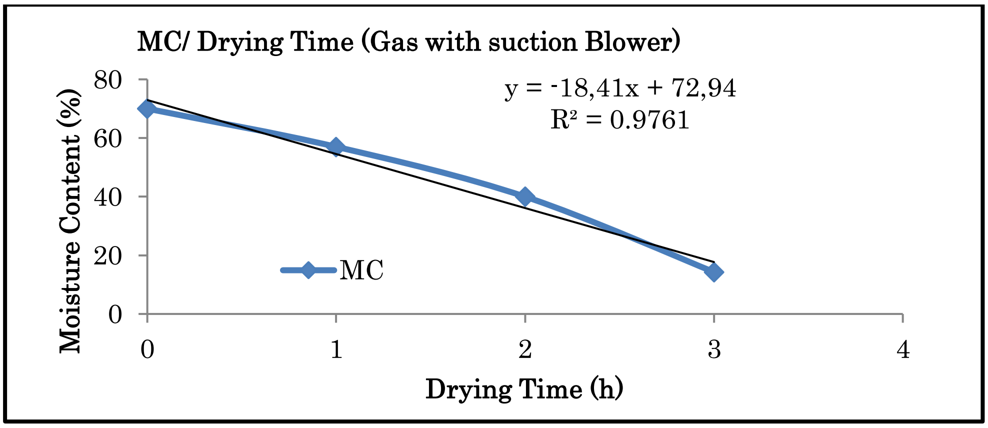

Figure 14. Graph of MC against Drying Time (Gas with Suction Blower).

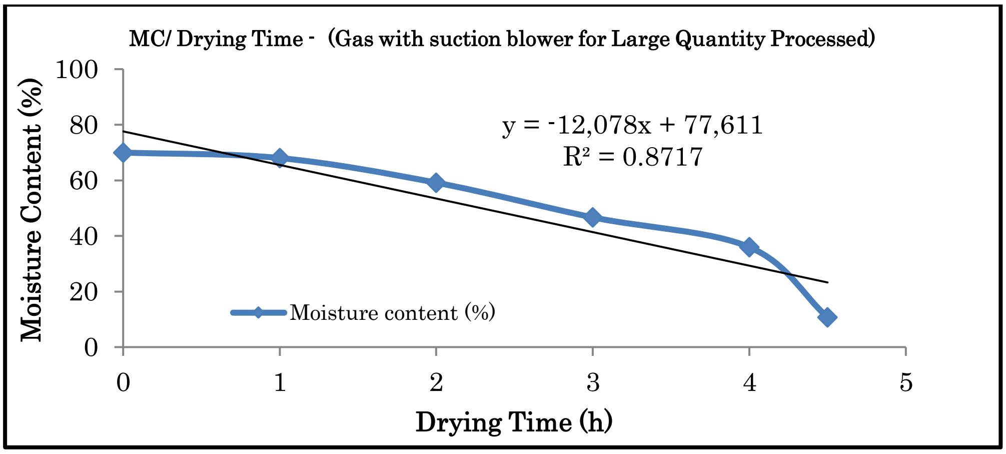

Figure 15. Graph of MC against drying time (Gas with suction blower with large quantity processed).

CONCLUSION

In this study, smoking kiln of 50 kg in the department of Agricultural and Bioenvironmental Engineering, Federal Polytechnic Ilaro, Ogun State was designed and fabricated. Findings from the existing design show that the kiln capacity was not maximized. Also, the time it took to achieve drying effect recommended in the literature was rather too long. It was equally observed that the convenience it takes to draw fish tray in and out of the smoking chamber was not there. Likewise, the tires were not strong enough to bear the weight of the entire kiln and as a result, did not encourage ease of mobility of the entire assembly.

In designing and fabricating an improved kiln so as to take care of the limitations with the existing design, the kiln was designed to kitchen size and for easy of mobility, the tires provided can withstand the entire assembly. The trays were framed round with angle iron and as well cross braised to support the weight of the fish loaded on it. The framing also makes it convenient to draw the tray in and out easily. A 2 mm thick plate was introduced at the base to collect and drain off oil and water spill by gravity to the draining trough which then directs it outwards. Suction blower was introduced at the top section of the kiln to uniformly distribute air round the chamber. The blower is powered by 1.5 hp electric motor directed to electricity source. A gas burner was incorporated into the design as alternative heat source to the chamber. It was designed in such a way that the charcoal pot and gas burner are detachable.

The designed work has impact in the area of smoking kiln capacity, drying time, ease of mobility and heat distribution. The designed kiln can process 50 kg of fish or more at once. Findings from the designed work show that it will only take 3 hours to bring the fish to moisture content recommended in the literature (10-14 %). With introduction of suction blower, the time it took reduced by 1 hour (from 4h to 3h). It is an indication that introduction of suction blower to every smoking kiln will help to achieve shorter time to bring the fish or other similar product to moisture level that will prolong their shelf life. Smoked fish from the designed kiln were easily identified from the fact that it was firmer when chewed and had a characteristic golden-brown colour. The high heat intensity produced by the gas was responsible for the smoky flavour and sweet fragrance of the fish. The dirt like the gills and other unwanted parts were removed before smoking and the weight was measured before and after smoking exercise.

The designed smoking kiln can be used to achieve both hot wet smoking and hot dry smoking. Therefore, the designed smoking kiln can be used by both farmers and elites because of the hygiene and aseptic way of handling the smoked products.

Preservation is very important in aquaculture because it extends the shelf-life of fish. It equally changes the texture and adds more value to the products. Another observation is that smoked fish from the designed smoking kiln have longer shelf life than those from common drum ovens. It takes over three months for mold to appear, but the texture still remains intact. This led to the fact that the water content has reduced greatly, inhibiting the bacteria which often can cause spoilage. The smoking exercise was properly handled so that the protein content is not denatured and the golden-brown colour is retained. Also, the heat chamber design is open to improvement. From the evaluation observed, the smoking kiln can process 50 kg of fish or more. From the experiment, each layer of tray takes 8 kg of fish at an average weight of about 0.5kg. In all the six trays, 48 kg (78 kg x 6) of fish or a bit more can be smoked at once. From the analysis, it is obvious that the improved smoking kiln constructed was maximized in terms of capacity. Also, it takes shorter time to bring the fish to recommended moisture content.

The recommendations on the mechanical dryer are as given below:

i. It is recommended that fish should be processed in the designed kiln between 3 and 4 hours when either of the heat sources is to be used with or without suction blower. Beyond this time range the golden brown colour will turn black.
ii. The suction blower should be used when smoke drying fish since it improves timeliness of drying.
iii. The experiment should be carried out when the kiln is fully loaded to capacity to establish if the time rate of drying if will be affected.

Lastly, it is more economical to use gas as heat source than charcoal but the limitation with gas is that one must be around till the smoking endeavour is completed. Otherwise, there can be fire outburst/outbreak or a situation whereby the material under process will roast to ashes.

DECLARATION OF COMPETING INTEREST

The authors declare that there are no conflict of interest

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

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Oluwagbayide Samuel Dare: Writing of the original draft and data analysis.
Ogunlade Christopher Bamidele: data analysis and editing of drafted copy.

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