Performance of a biofuelled detachable fish smoking kiln

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Abstract: The most widely employed traditional method of processing and preserving fish for human consumption in the third world are smoking and drying. However, the traditional smoking and drying methods restrict the cross border trade of preserved fish due to the associated poor quality of the products, low capacity and poor energy efficiency. A detachable smoking kiln that uses solid biofuel as energy source and enables processing of fish into good quality and highly competitive shelf stable smoked dried fish and fish oil was developed. It consists of insulated walls, segmented compartments and a solar powered fan that circulates heat and smoke. The fan is powered by solar photo voltaic (PV) cell and/or DC cell. The equipment is detachable enhancing its portability feature. It has an overall ground size of 95 cm × 90 cm; the height excluding hood and chimney, is 136 cm and the gross weight is 211 kg. The no-load temperature profiling of the equipment showed an even distribution of heat within the smoke drying chamber. Performance evaluation conducted on the equipment using fresh water catfish (Clarias gariepinus) (average live weight of 350 g ± 50 g per piece) as test organism showed that the kiln has a batch capacity for processing 50 kg live weight (average moisture content, 72% w. b.) of Clarias gariepinus to smoked dried fish (average moisture content, 5.5% w.b.) in 10 h when operated at 110oC ± 10oC. The observed batch capacity agrees with the design calculation. About 57% of the total oil content of the test fish samples was collected using the oil collecting system of the equipment. The equipment reduced frequent rotation of fish by operator and the associated drudgery during smoking operation. The smoked fish were uniformly dried.

Keywords: detachable kiln, smoked dried, drying time, fish oil, energy

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1 Introduction

Fish provides about 3.0 billion people with almost 20% of their intake of animal protein, and 4.3 billion people with about 15% of such protein (FAO, 2014). Several hundred million people depend on fish as their main source of income. Over the last 15 years, there has been global rising demand for fish and fisheries products. Prepared and preserved fish have nearly doubled their share in total quantity traded in the last four decades, going from 9% in 1980 to 16% in 2010 (FAO, 2012). Improvements in processing technology that prevent spoilage of fisheries products contribute to increasing consumption by making fish available in markets at a distance from the source of production, complementing the growing Aquaculture which has been instrumental in making fish widely available in developing countries.

The most widely employed traditional methods to preserve and process fish for consumption and storage in the third world are smoking and drying. In Nigeria for example, smoking is the most widely practiced method: practically all species of fish available in the country can be smoked and it has been estimated that 70%-80% of the domestic marine and freshwater catch is consumed in smoked form (Abdullahi, et al. 2001). The advantages of smoking fish are manifold. Fish smoking prolongs shelf life, enhances flavour and increases utilization in soups and sauces. It reduces waste at time of bumper catches and permits storage for the lean season. It increases protein availability to people throughout the year and makes fish easier to pack, transport and market. In the developing countries small scale farmers have no access to ice or cold storage facilities, over 80% of fish

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harvested is preserved by smoke drying to enable the trader sell at distant markets (Tobor, 1984). The use of sun drying and smoke from smouldering wood for the preservation of perishable food dates back to civilization (Eyo, 2001). This is so, because smoked and dried fish is a traditional part of the diet of a large section of the world population (FAO, 1986). According to Olley et al. (1988), smoke imparts aroma, taste and colour on processed fish. Clucas and Ward (1996) reported that hot smoking of fish combines three effects: Preservative effect of the smoke, drying and cooking. The long storage life of some smoked fish products is however, due more to drying and cooking than to the preservative value of the chemical compounds deposited on the fish from the smoke.

Traditionally, fish is smoked in pits or on raised smoking “tables” where the control of heat is difficult and at times impossible (Afolabi, 1984). Such drying also has often taken place in round mud or extended-drum ovens (crested by joining two open-ended drum ovens), or even on galvanized iron sheets supported by planks. Each of these technologies comes with significant drawbacks. For example, though extended-drum ovens are simple to construct, workers must be present all the time to rotate the fish and monitor the flames’ intensity to ensure that the drying of the fish takes place evenly. Because smoking in traditional ovens may take up to 48 hours, monitoring can prove a formidable task. A lot of problems such as charring of fish, the laborious process of interchanging trays positions during smoking, heat loss, increased deposition of tar on the smoked product, poor hygiene, low capacity and long processing time are associated with traditional ovens. Processors of traditional products have been losing market share as a result of long term shifts in consumer preferences as well as in processing and in the general fisheries industry.

To overcome the shortcomings associated with the traditional methods of smoking, a number of interventions have been made to upgrade the traditional smoking techniques. Different models of improved ovens were developed in various parts of Africa (FAO, 1971, Maembe, 1982 and Wood and Tariq, 1990). A detailed description of traditional and improved smoking kilns is given by ILO-WEP (1982). Improved smoking kilns were developed to address the problems inherent in all traditional smoking technologies –lengthy drying periods, low capacities, poor smoked fish quality and inefficient energy use. However, local and regional fish smokers have continually rejected most of the improved kiln designs introduced by national and international agencies because the designs have failed to consider critical socio-economic and cultural factors.

Also, concerns about food safety and environmental sustainability have provoked major fish consuming countries to introduce institutional innovations for controlling trade in fisheries items, including Sanitary and phytosanitary (SPS) measures, consequently, processing is becoming more intensive, geographically concentrated, vertically integrated and linked with global supply chains. This, in turn dictates the need for improved fish processing technologies as a coping strategy to meet the increasing stringent requirements and opportunity to play in the local and global markets. The improved processing technology can increase the economic and nutritional value of fish products, which will in turn increase the incomes of small scale processors. Hence, the aim of this work was to develop a cost effective, portable and affordable smoking kiln capable of producing uniformly dried, stable and high quality smoked fish that meet local and international standards, with added features of enabling processors to collect oil from the fish and also reducing operational hazards through minimizing operators’ exposure to heat and smoke in infrastructural disadvantaged developing countries.

2 Materials and methods

2.1 Design criteria

In addition to the known limitations of traditional smoking kilns, the opinion of a number of fish processors and stakeholders were sought to identify their specific needs and new areas for improvement in order to ensure adoption of the innovation. These expectations include elimination of drudgery, improvement in batch capacity, ensuring uniform drying, improving ergonomics in kiln operation and reduction in operational hazards, enhancement of portability features and enabling collection of fish oil during smoking. Fish oil often constitutes problems during smoking as it drips on the flame. In addition, customers have improved knowledge of the benefit of fish oil for industrial use (soap stock) or to improve their nutrition. Consequently, the desire for fish oil collection has now become a critical feature required in fish smoking kiln.

These stakeholders' requirements were then translated to engineering characteristics and features of the smoking kiln using the Quality Function Deployment (QFD) approach (Akao, 1990). Table 1 shows the function deployment matrix translating the stakeholders' wants to the engineering characteristics of the smoking kiln that fulfil the requirements. Figure 1 shows the design considerations for the smoking kiln in terms of the social, engineering, developmental and ecological parameters and their inter-linkages according to Verhaart (1983).

2.2 Design calculation

The design calculations were based on the following specifications and assumptions:

1. The kiln operates at dry bulb (db) temperature of 85^{o}C
2. Density and specific heat capacity of catfish are 1059 kg m^{-3} and 3.63 kJ kg^{-1}.^{o}C (Adeyemi and Akande, 2011)
3. Moisture content (m.c.) of raw fish is 75%, m.c. of dried fish is 8%
4. Air inlet condition is 30.1^{o}C db, relative humidity (RH) is 85%
5. Cross flow circulation of air
6. Tray size is 0.5 m (length) by 0.81 m (width) and each tray can contain about 10 kg raw fish
7. Trays are arranged vertically, 0.11 m apart in the drying chamber

Table 1 Function deployment matrix translating the stakeholders' wants to the engineering characteristics of the smoke drying equipment

	Relationship Matrix ⊛=Strong, ⊙=Moderate, O=Weak	**Engineering Characteristics**									
	How to satisfy wants / **What customers want**	Locally sourced materials	Energy loss prevention: Lagging	Dismounting capability: detachability; Casters	Stacked trays arrangement	uniform heat distribution: Fan	Oil collection device	Prevention of drips from falling on flames	prevention of high smoke deposition: smoke filter/damper	Improvement in draft and positive suction: Chimney	Use of renewable energy sources: biomass briquettes, solid biofuels
Stakeholders' requirements	Reduced process time		⊛			⊙				⊙	⊙
	No drudgery, eliminate hazards				⊛	⊙		⊛			
	Ergonomics			⊙	⊙			⊛			
	Portable			⊛							
	Effective		⊛	⊛	⊙	⊛	⊛	⊛	⊛	⊛	⊙
	Affordable, durable										
	Improve energy usage		⊛			⊙				⊛	⊛
	Uniform drying		⊛			⊛		⊛		⊙	⊙
	Fish oil collection capability				⊛		⊛				
	High quality product		⊙			⊛	⊙	⊛	⊛	⊛	⊙
	Products compliant to regulatory specifications							⊙	⊛	⊙	
	Health and safety				⊙			⊛	⊙		⊙
	Environmental friendly energy source										⊛

2.3 Batch capacity and moisture to be removed

The batch capacity of the kiln was estimated according to Crapiste and Rotstein (1997):

From the specifications and assumptions made,

No. of trays, n = 5,

Tray depth, d = 0.0254 m

Product Area, A_p

$$A_p = nLw \text{ ------------------------- } (1)$$

A_p= 2.03 m^2

$$\text{Capacity}, W = \rho_p A_p d \text{ --------------------- } (2)$$

W = 54.5 kg or 13.6 kg solid, i.e. W_D = 13.6 kg

where, L= Tray length, w = Tray width, ρ_p = bulk density of raw fish, A_p = Area to be occupied by fish in the drying chamber, W_D = bone dry weight

The moisture to be removed, MR, was determined using Equation (3).

$$MR = W_D\left(\frac{(x_i - x_f)}{(1 - x_f)}\right) \text{------------- } (3)$$

MR = 9.9 kg

where W_D, x_i, x_f are respectively weight of bone dry fish, initial moisture content and moisture content at any time (t).

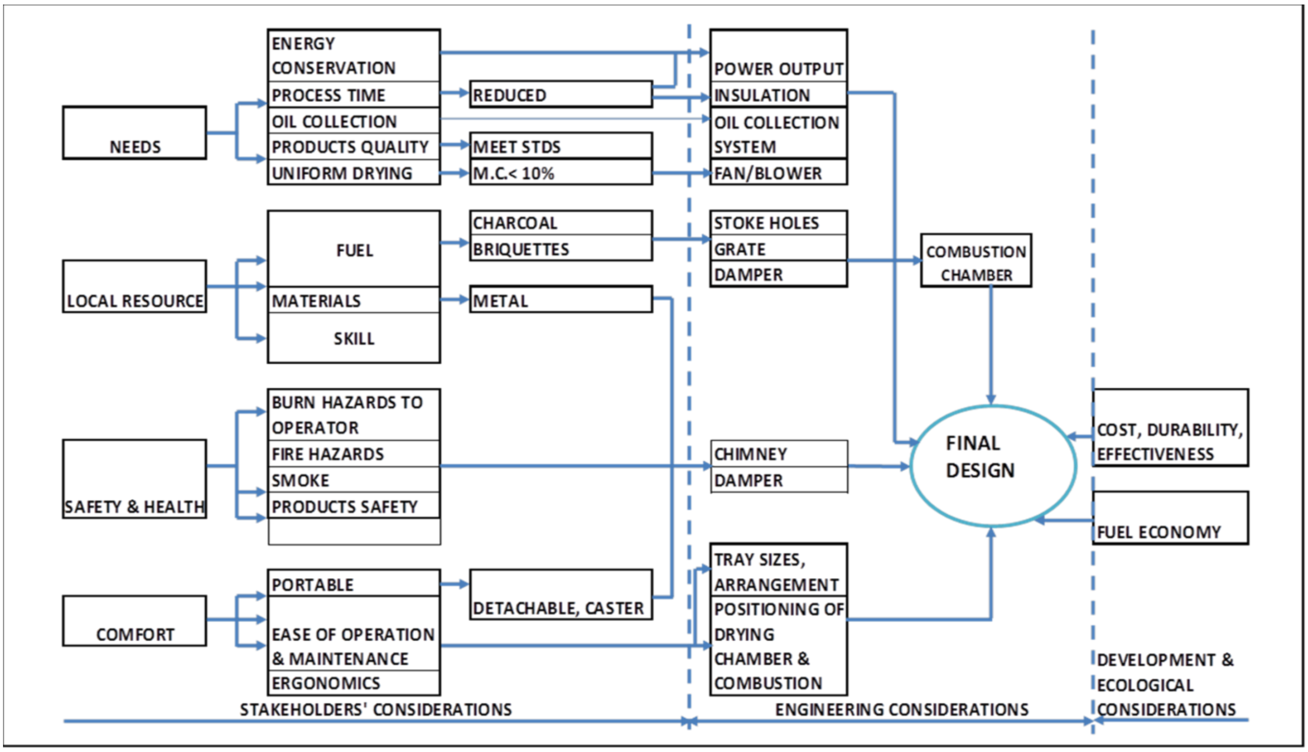


Figure 1 Design considerations for the biomass fueled detachable smoke drying equipment

2.4 Air requirements determination

Drying Air area within the smoking/drying chamber, A_a, was estimated according to Crapiste and Rotstein (1997) for cross flow configuration:

$$A_a = nb'w \text{ -------------------------- } (4)$$

A_a = 0.3426 m^2, where b' is difference between the vertical trays and the tray depth.

Drying rate, d_r, was estimated from Equation (5)

$$d_r = {}^{MR}/_{t_d} \text{ -------------------- } (5)$$

where t_d is assumed drying time, 8 h, d_r = 1.24 kg hr^{-1} or 0.021 kg min^{-1}

The air properties at inlet and drying conditions were obtained from the Psychrometric chart based on barometric pressure of 101.325 kPa at sea level.

Mass of air required for drying, $\dot{m}_a$

$$\dot{m}_a = \frac{d_r}{(W_f - W_i)} \text{ ------------------- } (6)$$

where, W_i, W_f are initial humidity ratio and final humidity ratio respectively and $\dot{m}_a$ is mass flow rate of air.

$\dot{m}_a$ = 87.20 kg h^{-1} or 0.024 kg s^{-1}

The volume of air required, $\dot{v}_a$ (m^3)

$\dot{v}_a = \dot{m}_a \times v$ -------------------- (7)

where v (m^3 kg^{-1}) is the specific volume of air, $\dot{v}_a$ is the volumetric flow rate of air

$\dot{v}_a$ = 91 m^3 h^{-1} or 53.6 CFM, where CFM means cubic feet per minute.

The air velocity, V (m/h) is:

$V = \dot{v}_a / A_a$------------------- (8)

V = 265.59 m/h

2.5 Fan selection

The fan aids in heat distribution by circulating heated air within the smoking/drying chamber and aiding discharging of saturated air through the chimney to the atmosphere. A proper fan has to be selected so that proper distribution of heat is achieved (Holman, 1998). The volumetric flow rate, CFM value, was used to determine the static pressure (in H_2O), P_w from a fan performance curve. The power required to drive the fan was determined according to Henderson and Perry (1966) as simplified by Eckelman and Baker (1979) in Equation (9):

$HP = \frac{P_w \dot{v}_a}{6356e}$ ---------------------- (9)

where P_w is the pressure in inches of water, e is the fan efficiency.

From the fan curve, $P_w = 0.129$ in H_2O at the corresponding 54 CFM. At an assumed efficiency of 50%, the fan power, HP, was determined as

HP = 0.004 hp or 2.8 W

The closest higher value to our determined CFM and the corresponding P_w was selected from a fan performance data obtained from a fan manufacturer. An axial fan assembly that met these specifications was selected and was sourced from a local market in Lagos, Nigeria. A 20 W mono-crystalline photovoltaic (PV) cell was also purchased at a local market in Lagos to power the fan assembly while a 12 VDC battery was also provided as an alternative or an aid to the PV cell at the time of no or low insolation.

2.6 Heat requirements determination

The quantity of heat required to effect drying can be determined by Equation (10) (Ehiem et al., 2009):

$Q_r = (W \times C_f \times \Delta T) + (H_L \times MR) \ldots\ldots\ldots (10)$

where Q_r is the heat required to effect drying in kJ, W is the kiln batch capacity (54.5 kg), C_f is the specific heat capacity of catfish (3.63 kJ $kg^{-1}.^{o}C$), ΔT=54.9°C, H_L is the latent heat of vaporization (2413.7 kJ kg^{-1}) and MR is the moisture to be removed (9.9 kg). Hence, Q_r=35695.8 kJ.

The actual quantity of heat required for drying was determined using Equation (11)

$Q = \dot{m}_a \times (h_f - h_i)$------------------- (11)

where, h_i, h_f are initial and final enthalpy of air respectively at the stated conditions,

$h_f = 186.27$ kJ/kg, $h_i = 89.59$ kJ/kg, $\dot{m}_a$ =87.2 kg/h, Q = 8173.83 kJ

The insulation thickness of 5 cm for rock wool with packing density of 80 kg m^{-3} was used. This was selected based on the recommendation of the TIASA (2001) as economic thickness of the lagging material for the equipment.

2.7 Mass transfer rate

The mass transfer rate W_{tr} in kg is determined using Equation (12)

$W_{tr} = m_c \times A_p \times (W_i - W_f) \times \dot{v}_a \ldots\ldots (12)$

where m_c is the mass transfer coefficient of a free water surface (0.083 $kgm^{-2}s$), A_p is the total surface area of the five trays (2.03 m^2), $(W_i - W_f)$ = 0.0147 kg kg dry air, and $\dot{v}_a$ = 1.52 m^3/ min

W_{tr}= 6.324 $\times 10^{-4}$ kg

2.8 Fabrication and description of the smoke drying equipment

The design for manufacture involves the translation of the physical characteristics and dimensions resulting from the previous design stages into a unit which can be built at low cost. The process entailed selection of materials of construction and the most suitable mechanical arrangement (Autocad® drawings) and estimation of bill of quantity for constructional materials. The actual fabrication was done according to the specifications resulting from the design stages.

2.8.1 Description of the smoke drying equipment

The equipment is cuboid shaped and detachable. It is double walled with rock wool placed as lagging material between the inner and outer walls. The equipment is skeletally formed from angle bars, 25.4 mm by 25.4 mm. The materials of construction for the entire body are made of gauge 16 and gauge 18 galvanised iron sheets for the inner and outer walls respectively, while the base is made of mild steel, 2 mm thick. The fish trays are made from galvanised wire mesh and galvanised pipe, 20 mm diameter. The equipment consists of four major segments namely the drying/smoking chamber, the combustion chamber, the oil collection/dried fish storage chamber and the hood/chimney unit. The important component parts include the damper, the fan, the solar panel and battery hangers for hanging the solar PV cell and battery respectively; and the insulated partitions that separate different segments and also act as heat shield to prevent heat losses. The damper acts as filter for the smoke.

The drying chamber has a length of 0.9 m, width of 0.91 m and height of 0.85 m. The inner wall is made of galvanized steel. The selection of galvanized steel in this regard is due to its strength, heat transfer properties and cost. The compartment was constructed to house five fish trays and an oil collection tray vertically arranged parallel to one another, 11 cm apart. The oil collection tray is made of galvanized sheet, 1.2 mm thick, and positioned at the bottom of other trays. Each fish tray is made of expanded metal welded to 1 inch diameter galvanized pipe as support. This also allows for free movement of the tray on the rack. A tray has a length of 0.50 m, width of 0.81 m.

The oil collection tray is provided with oil drain pipe. The oil collection chamber is located at the lower region of the equipment and is separated from the fire place and the smoking chamber by insulated walls. The oil collection chamber also accommodates dried fish storage basket made of expanded metal sheet. The heat source (combustion chamber) is separated from the smoking/drying chamber by smoke damper. The heat source is not directly placed under the smoking chamber; the hot air/smoke from the combustion chamber is conveyed to the smoking chamber by an axial fan centrally positioned on the rear wall facing the smoking chamber door. The fan is powered by solar PV cell. The fan also ensures uniform distribution of heat and smoke within the smoking chamber. Figure 2 shows the perspective views of the equipment.

The Combustion chamber is located at the lower rear end of the equipment. It contains two stoke holes, 5 cm diameter each, to allow ingress of air from the environment. The chamber is provided with air heater.

The chimney was designed to enhance the extraction of humid air/smoke mixture from the smoking chamber. It also conveys the exhaust air high above to reduce inhalation of smoke by the operator.

2.8.2 Choice of materials of construction for the equipment

The materials for the construction of the smoke drying equipment were chosen based on availability, cost, durability and functional properties. The materials used include:

a. Angle iron: used to provide support for the body and to support the fish trays.

b. Mild steel: has good strength. It was use as the base for the combustion chamber.

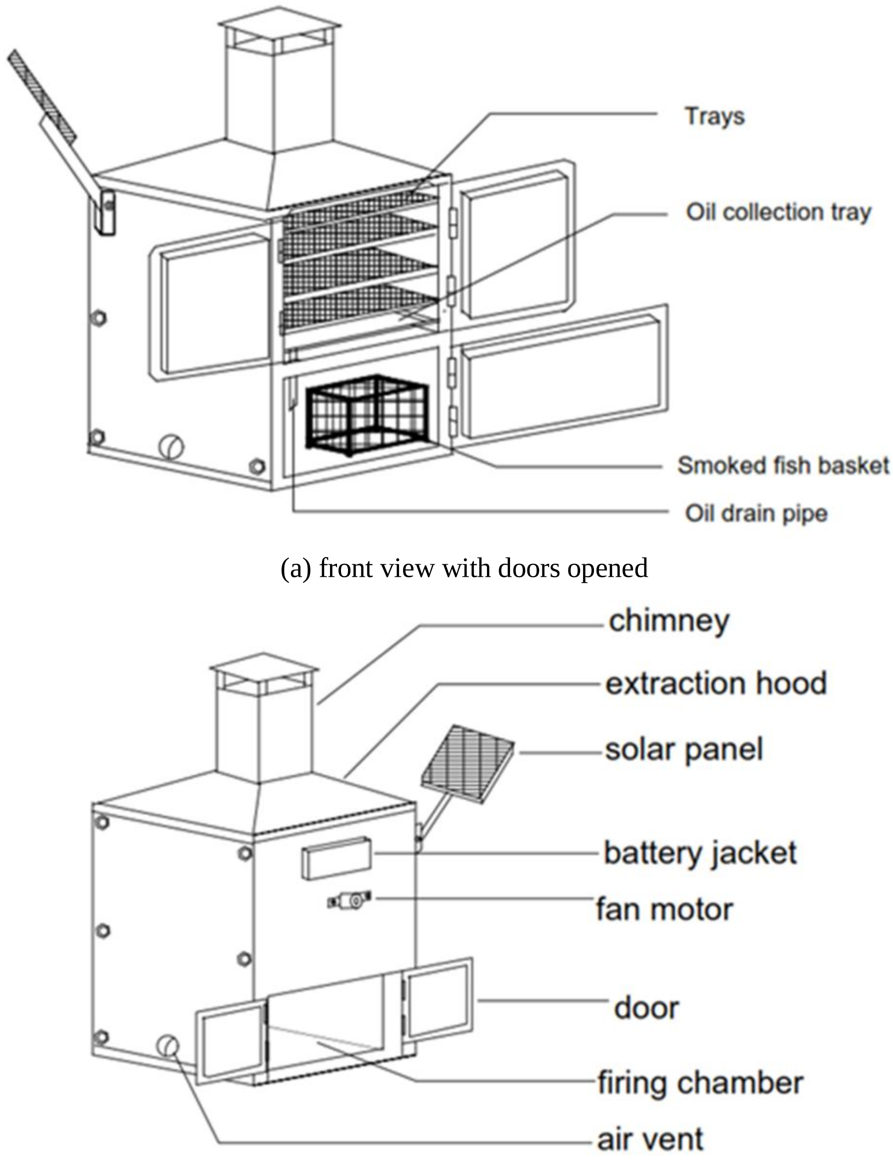
c. Galvanized sheet metal: used because of its toughness and ability to conduct heat. It was used to construct the walls and the hood. Gauge 16 was used for the inner wall while gauge 18 was used for the outer wall.

d. Rockwool: used as lagging material due to its poor thermal conductivity and ability to conserve heat at high temperature.

e. Wire mesh: used to construct the trays because of its ability to allow air and drippings to pass through. It was also used to construct the biomass fuel stoker because of its ability to allow air and ash to pass through it.

f. 13 mm bolts and nuts: used to fasten the four panels (sides) together into a unit.

g. Solar PV cell, a dc electric motor and axial fan were also used; the assembly was used to ensure circulation of filtered smoke and hot air for uniform distribution of heat in the smoking chamber.



(a) front view with doors opened

(b) back view with doors opened

Figure 2 Perspective views of the equipment

2.9 Performance evaluation of the equipment

The performance studies were carried out in three experimental runs and the average values of data obtained were used.

2.9.1 Heat distribution study

A temperature profile in the smoking chamber of the equipment at no load condition was determined to ascertain uniformity of heat distribution in the chamber. Temperature probes (type k thermocouples) were inserted at different points (top, middle and lower) corresponding to different tray positions in the smoking/drying chamber. The thermocouples were either separately connected directly to digital thermometers or a data logger (LogIT Voyager™ SX) with K-Type thermocouple adapter (model D100067). Temperature readings were recorded every 10 minutes for probes attached to thermometers while the logger readings were downloaded and read at the end of the experiment. The probes positioning were coded as follows:

T_1= measures temperature (^oC) at tray position #1 from bottom of the chamber

T_2= measures temperature (^oC) at tray position #2 from bottom of the chamber

T_3= measures temperature (^oC) at tray position #3 from bottom of the chamber

T_4= measures temperature (^oC) at tray position #4 from bottom of the chamber

T_h= measures temperature (^oC) at a position slightly above tray #5 from bottom of the chamber

Charcoal was used as energy source for this study. Measured quantity of charcoal was put in the stoker and ignited. It is allowed to glow before it was positioned in the combustion chamber where incoming air is heated and predominantly moved by natural convection and aided by fan draught to the smoking/drying chamber. The smoke and hot air mixture pass through the damper to filter off soothe before entering into the smoke/drying chamber.

2.9.2 Batch capacity study

Fresh water catfish (Clarias gariepinus) was used for the test because this species is the most cultured fish species in Nigeria and therefore commercially important.

Fresh catfish were cropped from Nigerian Institute for Oceanography and Marine Research (NIOMR) aquaculture farm and an average weight of a catfish was 500 g. The fish was tranquilized with salt, de-slimed physically with thorough cleaning, bled and gutted to remove blood and guts and cleaned in potable water. The cleaned fish were folded into horseshoe shape and spread on the fish trays; they were allowed to drain for about 10 min and then transferred to the smoking kiln where the trays were arranged on the racks provided. The weight of the cleaned fish occupying the fish trays were determined by weighing on a scale (OHAUS® Pioneer™) with an accuracy of ±0.1 g.

2.9.3 Construction of drying curve

The moisture content of randomly selected samples from the test species were determined using air oven method (AOAC, 2001) before the samples were smoked dried. The samples, in the smoking chamber, were exposed to hot air/filtered smoke while the fan blows and maintains hot air speed in the smoking chamber. The fish was allowed to dry to equilibrium moisture.

Changes in weight of fish samples on a tray were monitored using electronic balance (OHAUS® Pioneer™) with an accuracy of ±0.01 g at intervals during the smoking/drying period to equilibrium. The drying process was terminated in each case when equilibrium moisture content (EMC) of the dried fish samples was achieved. The drying curve was constructed from the change in weight versus time data.

2.9.4 Oil collection capability study

Catfish (Clarias gariepinus), 20 kg (live weight), was used to study the capability of the equipment to collect fish oil. The dripping oil was collected in a clean container. The oil was later filtered to clarity by passing through cloth sieve after the sediments have been separated. It was later dried in an air oven (Gallenkamp, UK) at $102^oC \pm 2^oC$ for 1 h to remove the remaining moisture in the oil. It was then cooled and measured using laboratory measuring cylinder.

2.9.5 Determination of total weight and detachability of the equipment

The total weight of the equipment was determined by measuring the component parts using weighing scale after detaching them and then sum up the individual weights. The component parts were also re assembled into a unit of fish smoke drying equipment.

3 Results and discussion

Figure 3 shows the developed detachable fish smoke drying equipment and the design features. The equipment, which is provided with casters at the corners of the base, has an overall ground size of 0.95 m × 0.9 m; the height excluding hood and chimney, is 1.36 m and the gross weight is 211 kg. The four sides (panels) are fastened together with bolts and nuts, which also enable the panels to be disassembled. The possibility of assembling and disassembling enhances the portability feature of the equipment.

(a) (b) (c) (d)

(a) front view (b) back view (c) front doors opened to show inside of the kiln

(d) product storage basket and oil collecting pipe

Figure 3 Developed detachable fish smoking kiln

3.1 No load temperature profile of the detachable smoking kiln

Figure 4 shows the heat distribution pattern in the smoking chamber of the detachable fish smoke drying equipment at no load condition.

The fan also ensures uniform distribution of heat and smoke within the smoking chamber and consequently, uniform drying and better product quality. This is evident in the closeness of the curves (Figure 4). The implication is that there is no need for the rotation of trays or fish during the smoking cycle. Also from Figure 4, it is observed that the smoking chamber attained and maintained a temperature above 120^{o}C between 10 to 50 minutes of operating the kiln. The temperature started to fall slowly when the fuel has been exhausted. The heat conservation was made possible due to the presence of insulating material. 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 fan took advantage of the abundant renewable solar energy in Africa. 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.

The distinguishing features of the improved design include oil collection trays positioned at the bottom of the fish trays, oil drain pipe, oil collection chamber separated from the fire place and the smoking chamber by insulated walls.

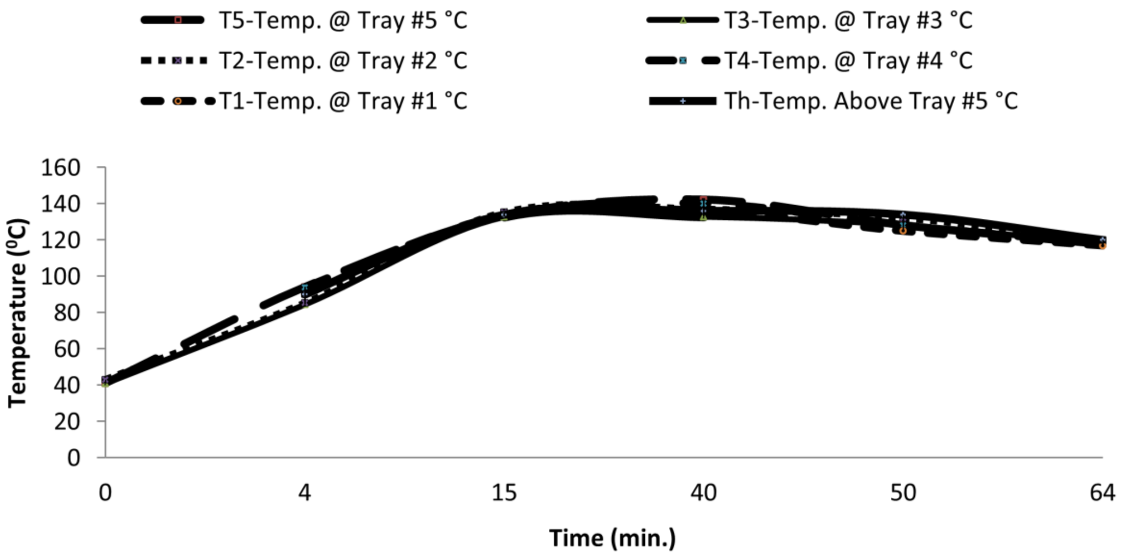


Figure 4 Heat distribution pattern in the smoking chamber of the fish smoking kiln at no load condition

3.2 Oil collection capability study

From 20 kg of fish, 0.35 L of clarified and dried oil was obtained. The technology offers hygienic collection of fish oil. The oil collected represented 57% of the oil content of the fish. This reasonable percentage affords processors the opportunity to offer fish oil to discerning consumers; otherwise, the oil would have been wasted or dripped into the fire source resulting in poor quality product and discomfort to the operator.

3.3 Drying curve and drying rate

Figure 5 shows the drying curve for catfish smoked dried at 110°C ±10°C. 54 kg of dressed catfish (73% w.b. moisture) was dried to 15.5 kg smoked dried fish (6% w.b. moisture) over a period of 10 h.

The drying curve (Figure 5) shows that the moisture content decreases with the increase in processing time. This indicates that the higher the moisture, the longer the drying time and vice versa. It is also observed that the rate of drying was constant between 100 to 200 minutes of drying the fish.

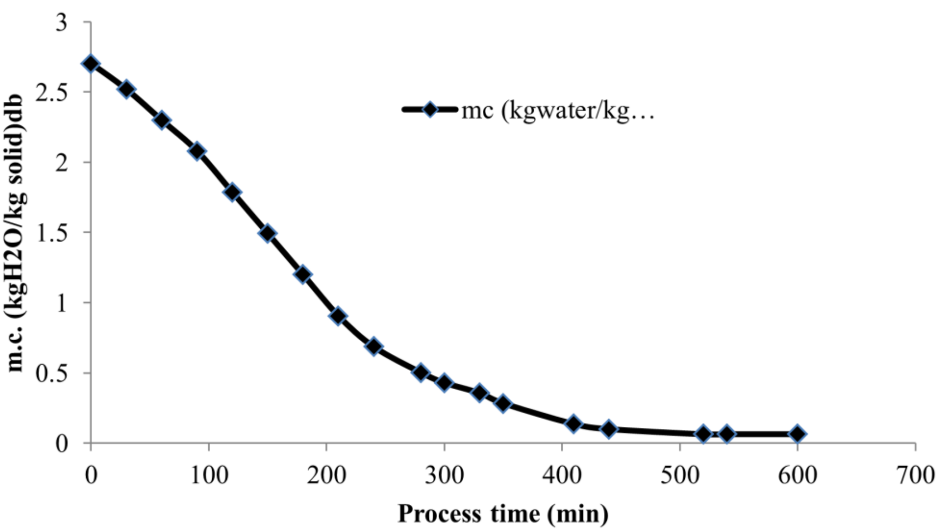


Figure 5 Drying curve (moisture vs time) for catfish at 110 ±10°C

4 Conclusions

A detachable fish smoking equipment that can use biomass and derivatives (charcoal, briquette) as source of energy and smoke was designed and fabricated. The equipment offers advanced fish smoking technique, providing processors with better working conditions and enabling them to produce good quality and highly competitive smoked dried fish and fish oil for local and international markets. Not only is uniform heat distribution within the smoking chamber achieved, processors can also minimise their exposure to heat, burns and smoke. In addition, it provides the possibility to collect oil hygienically, and to store smoked fish prior to packaging. The detachability offers opportunity to dismantle the equipment into the component parts for easy transportation from one point to another. The materials of construction were locally sourced and are durable.

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Nomenclature

t processing time or smoked drying time, h

T temperature, ^oC

m.c. moisture content, % wet basis (w.b.)

x_i, x_f moisture content, kg/kg solid; i, f denote initial and final conditions respectively

W_D bone dry weight, kg solid (kgs)

MR moisture removed

W_{tr} mass transfer rate, kg/m^{2}s

Q energy, kJ

CFM cubic feet per minute