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Performance Evaluation of a Fabricated Smoking Kiln

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Abstract

Smoking is the technique of seasoning, or preservation of food either by exposing it to heat from a burning or smoldering substance, usually wood or cold air at reduced temperature. Smoking is a unit operation that has gained overwhelming acceptance across the globe. The conventional method for smoking is often stressful and unhygienic while posing health risks to processors. In view of this, a low cost smoking kiln was developed and was evaluated to be effective, user friendly, hygienic, free health risk to processors and improve product quality. The machine was fabricated using locally available materials with charcoal as the heat source. Machine heat capacity, thermal resistance and heat requirement for various fish and meat products were determined. Heat capacity, thermal resistance and heat requirement of the machine were found to be 2337.57 kW, 2.16 K/W and 1123.20 kJ (fish); 1000.35 kJ (beef); 1584.24 kJ (chicken) respectively. Consumer's perception for smoked products at 5% level of significance showed that there was no significant difference (p > 0.05) in the sensory attributes considered for the products.

Keywords: Design, fabrication analysis, product, evaluation, food, machine, drying, quality, and charcoal

1.0 INTRODUCTION

Smoking is the technique of seasoning, or preserving food either by exposing it to smoke from a burning or smoldering substance, usually wood [1] or cold smoking at reduced temperature of 12ºC to 25ºC [2]. This is to impart flavor and preservative characteristics to food. Smoking can also be done by bringing food into contact with vapourized liquid smoke [3]. In Africa, smoking is the most significant method for preserving fish and wildlife. Wood smoke is made up of a variety of organic chemical components, some of which are known to be antibacterial [4]. When wood smoke is condensed into water, it produces liquid smoke, which can be utilized for food smoke flavoring. The danger linked to the illegal use of chemically preserved wood is one of the concerns associated with smoked foods [5]. Smoked foods are safe if they are made from fresh raw materials free of natural toxins, chemical pollutants, pathogens, and parasites; and if the storage conditions do not promote microbial proliferation or toxin production [6].

Smoking is a combination of salting, drying, and heating of fishery products [2]. The regulation of physicochemical parameters such as pH, VBN, TBARS, fatty acid content, and texture profiling using the smoking preservation process increases sensory quality, allowing for longer storage times of high-quality final fish products [7]. Smoked food slows oxidative changes and prevents microbiological development [8]. When smoke from incomplete combustion of wood or sawdust is deposited on the surface of processed fish, volatile chemical compounds are released, which help to suppress bacterial growth [9]. Due to the unique color and flavor, smoked items have a high demand among consumers. Smoking wood or sawdust releases a variety of complex chemicals such as phenols, ethers, esters, hydrocarbons, acids, alcohols, and ketones, which are responsible for food color and flavor development [10]. Smoking can be classified into three types based on temperature: cold (12–25°C), warm (25–45°C), and hot (40–100°C) [11, 7].

The heating procedure determines effective way to maintain food product's quality. However, heating can promote protein denaturation in food products, resulting in a reduction in both nutritional and functional qualities [9]. To obtain a premium grade smoked product, it is vital to optimize the time, temperature, and sawdust material in the hot smoking procedure. Sensory evaluation (color, texture, odor, flavor, and overall acceptance); physicochemical assessment (pH level, VBN level, TBARS level, TMAO and fatty acid content); and microbial growth measurement also established qualities of smoked fish products [12]. Smoked products have been identified as mutagenic and carcinogenic, polycyclic aromatic hydrocarbons (PAHs) found in wood smoke and smoked foods have been investigated to be potentially genotoxic and carcinogenic to

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human. PAHs are processed by enzymes in human body, resulting in promutagenic and carcinogenic DNA adducts [13, 14].

Fish is the most often smoked commodity in Nigeria, with kilns ranging from traditional open fire to mud brick, cylindrical drum, and brick [15]. In most regions of the world, fish processing via hot smoking or kiln has been practiced for centuries. Due to a lack of suitable technology and infrastructure, Nigerian fish smoking procedures have not gained quality acceptability. Locally accessible technologies like mud bricks, stone, and firewood are commonly employed, but with negative impact on the quality of the finished product [16]. Market value declines owing to damaged and unappealing appearance of processed fish, while quality control and enhanced hygienic conditions are difficult to maintain [15]. Based on these limitations, a low cost smoking kiln suitable for small and medium scale production of fish and meat was developed and evaluated.

2.0 MATERIALS AND METHODS

2.1 Material Selection and Design Consideration

Considerations made while coming up with the machine design and materials to be used includes the strength, durability, flexibility, weight, resistance to heat and corrosion, ability to cast, machinability, heat conductivity as well as the cost of the material to be selected for use. The smoking kiln was fabricated using mild steel and galvanized steel. Galvanized steel was used for the wired rack that comes in contact with the food being smoked because mild steel is susceptible to corrosion making it unsuitable for contact with food.

2.2 Machine Description

The fabrication and assembly of the machine was carried out at Engineering workshop, Bells University of Technology, Ota, Nigeria. The smoking cabinet is double jacketed giving a thickness of 15 mm and is made from mild steel. It is lagged with a fibre glass insulator purposely to prevent heat loss to the environment during smoke drying. The smoking chamber consists of set trays arranged into three rows and also a smoking rack with the same length and breath. The cabinet overall dimension is 600mm × 515mm × 650mm and the dimension of the trays is 425mm × 325mm × 150mm. The trays have a trough fabricated to their ends to allow for flow of food product drippings during smoking flowing out without accumulation. This trough is connected to a pipe which runs from the top to the bottom at the back of the smoking kiln through which the trough of the others tray connects, collecting all product drippings and expelling them to the outer part of the smoking kiln. The heat source of the smoking kiln is charcoal which is contained in two pots, each with a dimension of 484mm × 120mm × 70mm, placed by the sides of the rack system that carries the trays. Air circulation by convection is made possible in the combustion chamber and carries heated air in all directions of the loaded trays with air inlets at the lower front of the smoking kiln facilitating the flow of heat. The chimney is fitted with an adjustable valve that controls the amount of heat build-up within the smoking kiln and conducts the smoke to the outdoor environment. The total cost of fabrication of the machine was ₦98,450 (Ninety Eight Thousand, Four Hundred and Fifty Naira only). The isometric projection and orthographic projection of the smoking kiln assembly is shown in Figure 1 and 2 respectively.

The machine was fabricated with tray arrangements at the center of the kiln, so that heat source can be placed by their sides to allow indirect mode of heating. The region between the charcoal pots was perforated to allow inflow of fresh air to support combustion and mobility of smoke in the kiln. A tray system slightly sloped backward was adopted to allow oil leaching from product flow into trough where it is collected.

2.3 Design Calculation

Volume of the fish tray (VT) and is calculated as:

$$VT = l \times b \times h \quad (1)$$

Where l = length of the tray = 42.5cm, b = width of the tray = 32.5cm and h = height of the tray = 150cm
Volume of the Charcoal Pot (VC): is calculated as;

$$VC = l \times b \times h \quad (2)$$

Where l = length of charcoal pot = 48.4cm, b = width of charcoal pot = 12cm and h = height of charcoal pot = 7cm

Determination of heat transfer by conduction, convection, radiation and thermal resistance is in accordance with Ibarz and Barbosa-Canovas, [17].
Heat transfer (q) by conduction is obtained as:

$$q_{cond} = \frac{-KA(T_2 - T_1)}{l} \quad (3)$$

Where: K = thermal conductivity of the material (45 W/m °C), A = area of the fish tray (0.41m^2), l = thickness

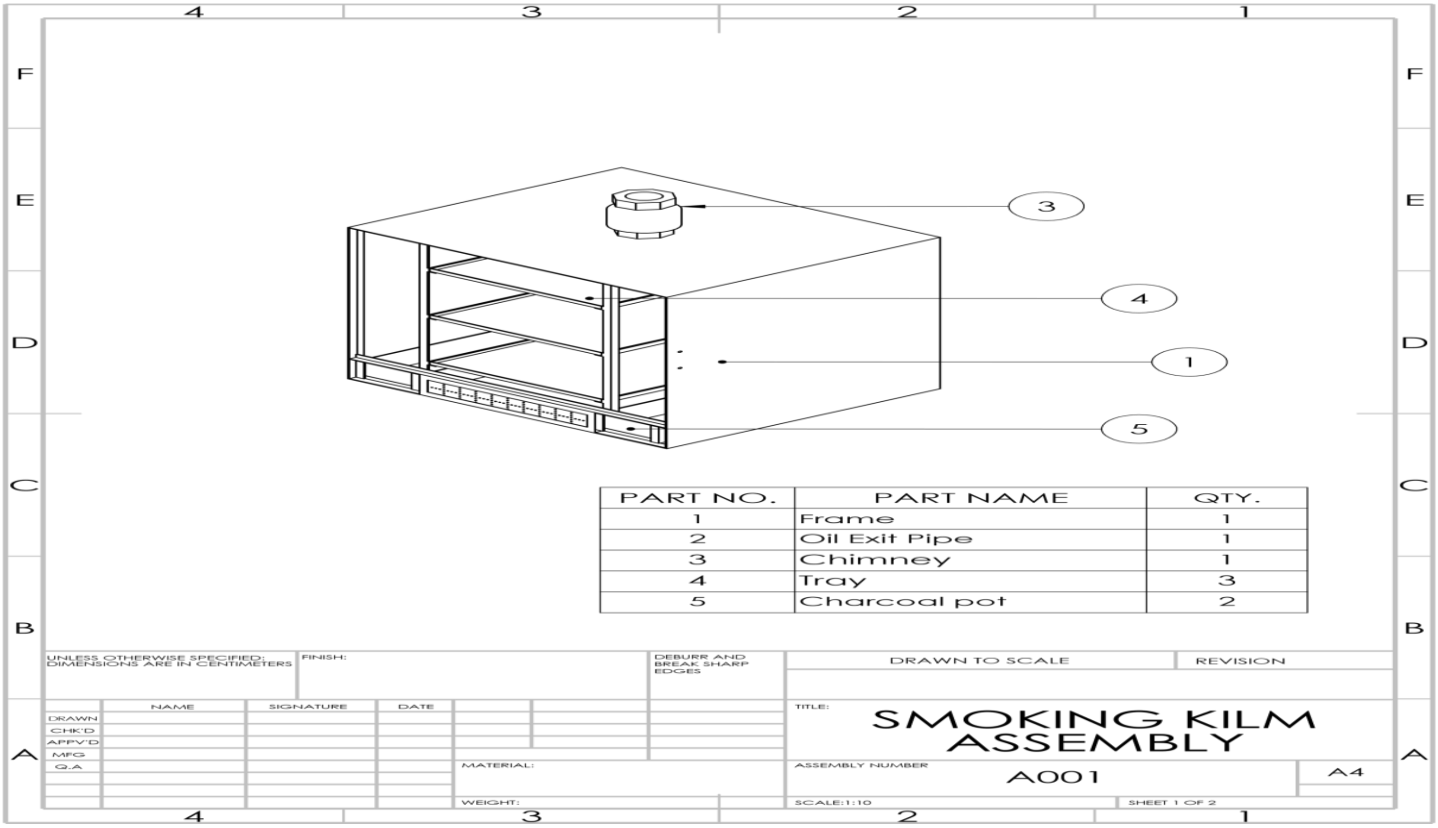

Figure 1: Isometric projection of smoking kiln assembly

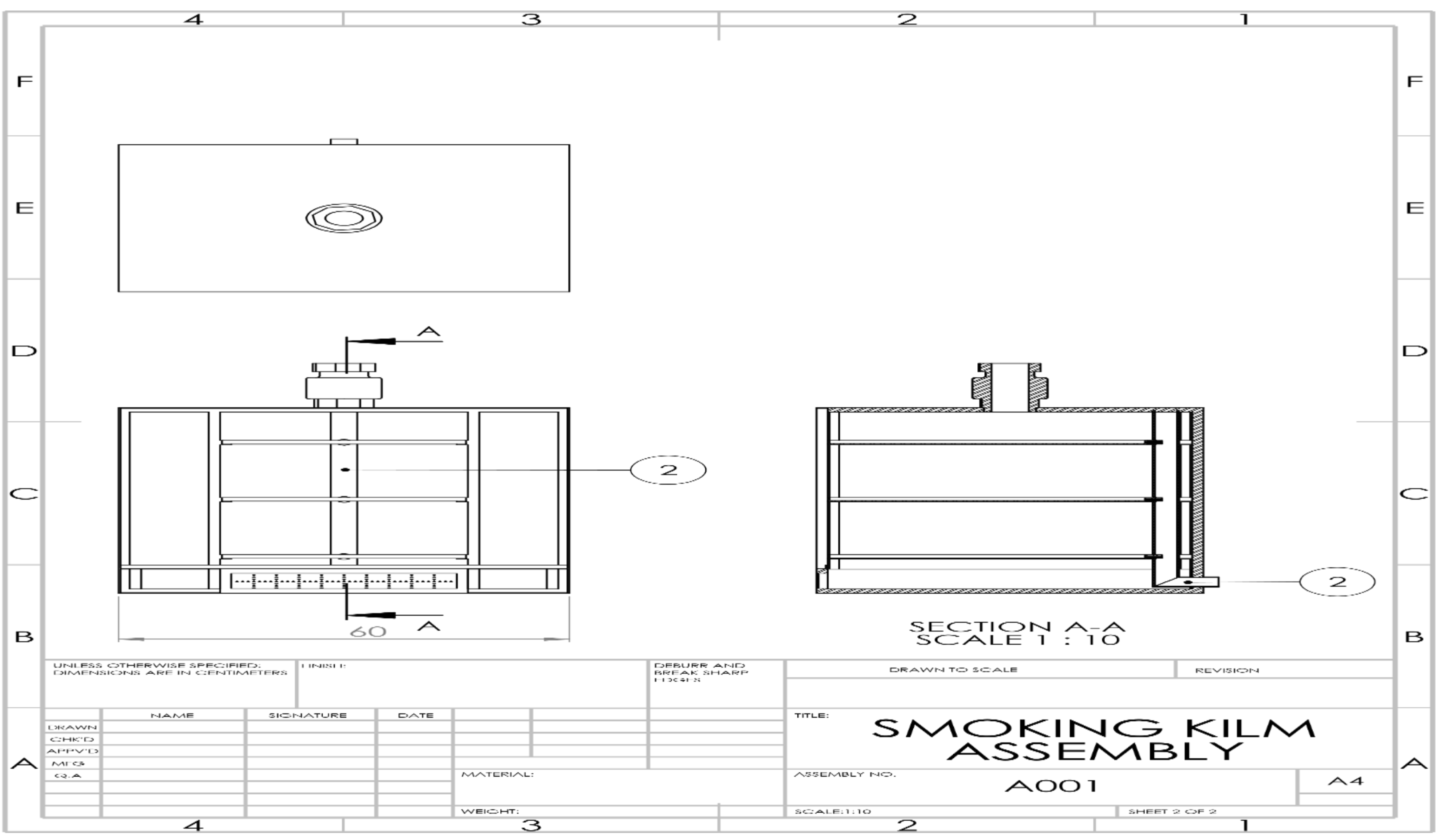

Figure 2: Orthographic Projection of Smoking Kiln Assembly

of fish tray (0.0015m), T_1 = Temperature of the inside smoking kiln (280°C) T_2 = Temperature of the inside smoking product (90°C) while negative sign of K is to take care of the decrease temperature along the direction of heat flow.

Heat transfer (q) by convection is obtained as:

$$q_{conv} = hA(t_s - t_f) \qquad (4)$$

Where: h = Coefficient of convective heat transfer (free convection) (20W/m^2 °C), A = Area of the charcoal pot (0.12m^2), T_s = Surface temperature (280°C) and T_f = Fluid temperature (90°C)
Heat transfer (q) by radiation is obtained as:

$$q_{rad} = F\delta A(T_1^4 - T_2^4) \qquad (5)$$

Where: F = Emissivity coefficient of mild steel (0.20), δ = Stefan Boltzmann's constant (5.67 × 10^{-8}), A = Area of the charcoal pot (0.12m^2), T_1 = Temperature of the inside smoking kiln (553K) and T_2 = Temperature of the outside smoking kiln (303K)
Heat capacity q_{total} of the machine is obtained by:

$$q_{total} = q_{cond} + q_{conv} + q_{rad} \qquad (6)$$

Value of thermal resistance is obtained by:

$$(R_{th})_{rad} = \frac{T_1 - T_2}{q_{rad}} \qquad (7)$$

Heat required for smoking products:

$$q = M \times C_p \times \Delta T \qquad (8)$$

Where M = mass of sample in the smoking kiln at a time (Fish =5.20 kg, Beef = 5.85 kg and Chicken = 8.20 kg), ΔT = Change in temperature (°C) and C_p = Specific heat capacity of products: Fish = 3.60 kJ/kg°C; Beef = 2.85 kJ/kg°C and Chicken = 3.22 kJ/kg°C [18].

The heat capacity q_{total} of the machine is given as 2337.57 kJ and this exceeds the heat requirement for each of the products smoked: fish = 1123.20 kJ, beef 1000.35 kJ and chicken = 1584.24 kJ.

2.4 The Smoke-Drying Procedure

Samples (beef, Atlantic mackerel fish, chicken and herring fish) were obtained from Ota market; the samples were thoroughly washed and salted, and eviscerated to remove the impurities and intestine of the fish and meat product. The charcoal in the charcoal tray was first ignited with the help of kerosene, the ignited charcoal was allowed to burn for 10 to 15 min to allow the kerosene odor to be exhausted. More charcoal was added to the burning charcoal in the charcoal container and placed inside the smoking kiln before loading it with products to be smoked. The products were then arranged on the rack on which oil has been rubbed (to avoid sticking of products to the rack). The products were smoked dried until desired dryness was achieved and determined. At this level, the products turned brown with sweet smelling flavour. Charcoal was added at intervals (hourly) during the smoking process to ensure there was no temperature drop. The smoke drying was stopped and the heating chambers (charcoal pots) were removed and smoked products were allowed to cool before packaging. Flowchart for the smoking of fish and meat is presented in Figure 3.

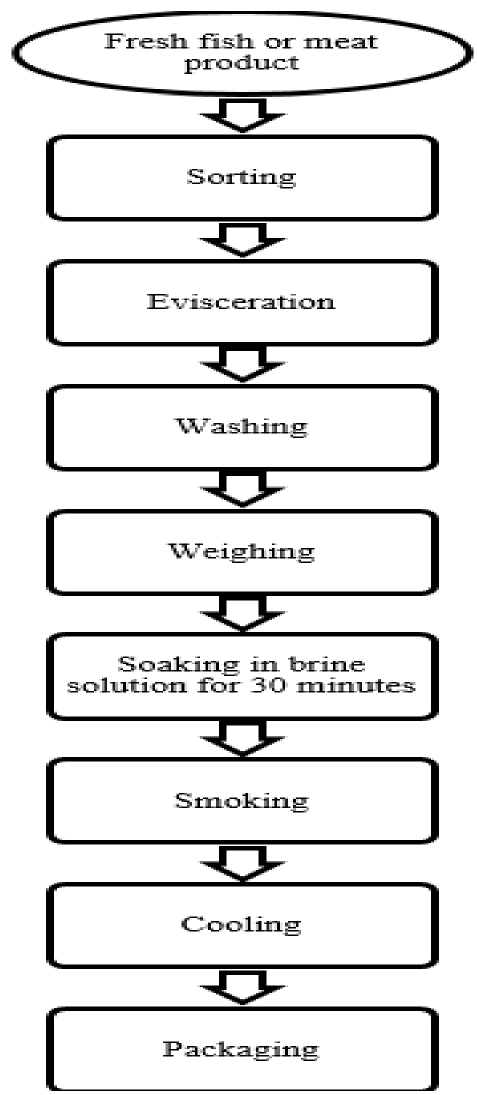

Figure 3: Flowchart for the smoking of fresh fish or meat product

2.5 *Machine Performance Evaluation*

The samples were weighed (Initial weight) and arranged on a rack before being placed in the smoking kiln. Smoking/drying continued until a final weight was achieved and hence the percentage moisture loss during smoking was determined from both the initial and final weight. The percentage moisture loss is calculated using the equation given by Ikenweiwe, [19].

$$Mois.loss\,(\%) = \frac{Initial weight - Final weight}{Initial weight} \times 100 \quad (9)$$

Moisture removal rate (MR) of the smoking kiln is given as:

$$MR = \frac{Moisture\,loss}{t} \quad (10)$$

2.6 *Sensory Evaluation*

Consumer assessment of overall acceptability of smoked products was done in accordance to [20]. Twenty (20) students of Bells University of Technology, Ota Nigeria were chosen. These are regular consumer of smoked products and randomly selected for evaluation. Four samples coded as SMBE, SFTI, SMCH and SFSH were presented on a clean plate and placed on a clean table. A questionnaire was designed and distributed among the Twenty respondents to score attributes namely appearance, aroma, taste, texture, and overall acceptability on a Hedonic scale of 9 points: 9 like extremely, 8 like very much, 7 like moderately, 6 like slightly, 5 neither like nor dislike, 4 dislike slightly, 3 dislike moderately, 2 dislike very much and 1 dislike extremely. Each of the samples was presented at different times to each of the respondents to avoid any bias in judgement. The responses were collated to compare the consumer preferences of the products.

3.0 RESULTS AND DISCUSSION

Smoking kiln for the production of smoked fish and meat was design, fabricated and evaluated. The design of the machine was in such a way that heat transfer by conduction from the source through trays to the smoking product. Heated air circulations in all direction to the product by convection while the escape of air from inside of the machine to the surrounding through chimney by radiation. Heat capacity of the machine was calculated to be 2337.57 Kw. Heat requirements for smoking fish, beef and chicken was calculated to be 1123.20 kJ, 1000.35 kJ and 1584.24 kJ respectively. The rate of moisture removal of the smoking kiln was calculated to be 25.87 %/hr, 23.37 %/hr, 28.05 %/hr and 24.51 %/hr for Atlantic mackerel, herring fish, beef, and chicken respectively as shown in table 1. Smoking temperation was determined to be 90ºC; this was in accordance with discovery of Rahaman, [21] who reported that smoking temperature suitable for effective drying ranges from 80ºC to 90ºC. It was observed that at the various tray levels of the smoking kiln, there was slight temperature difference. This could be due to the fact that hot air is of lighter density than cold air and floats upwards.

In the smoking kiln, since the heat source is not directly under the rack system, it floats to the upper part of the smoking kiln and the products at upper tray dry faster.

The results of the sensory evaluation of the machine as shown in Table 3 depicted that parameters tested have no significant difference ($p>0.05$) except for the texture. Beef (SMBE), Atlantic mackerel (SFTI), chicken (SMCH) and herring fish (SFSH) has 6.59, 7.50, 7.07 and 7.45 in the appearance respectively. Samples; SMBE, SFTI, SMCH and SFSH has 7.35, 7.75, 7.30 and 7.50 in aroma respectively. Taste of the samples showed 7.45, 7.95, 7.50 and 7.55 for SMBE, SFTI, SMCH and SFSH respectively. Texture of the samples shows significant relationship at 7.10, 8.10, 7.40 and 7.45 for SMBE, SFTI, SMCH and SFSH respectively. There was no significant difference in overall acceptability of the samples with preference for Atlantic mackerel fish. Exploded view of the machine and point of loading fresh products are shown in Figure 4 and 5 respectively. Bill of engineering material for the smoking kiln is shown in Table 2.

Values are means ± standard deviation of duplicate determinations. The mean values of the samples within a column with different superscripts (letters) are significantly different ($p < 0.05$).

LEGEND

SMBE: Smoked beef, SFTI: Smoked Atlantic mackerel fish, SMCH: Smoked chicken
SFSH: Smoked herring fish

Table 1: Machine evaluation

Samples	Time taken (hrs)	Initial weight (kg)	Final weight (kg)	Moisture loss (%)	Moisture removal (%/hr)
Beef	2	5.85	2.57	56.10	28.05
Atlantic mackerel	2	5.20	2.51	51.73	25.87
Chicken	2	8.20	4.18	49.02	24.51
Herring fish	2	5.20	2.77	46.73	23.37

Figure 4: Exploded view of the smoking kiln

Figure 5: Fresh fish sample being loaded into the smoking kiln

Table 2: Bill of engineering material for Smoking Kiln

MATERIAL	DIMENSION/QUANTITY	COST (₦)
Mild steel plate	1.5mm	24,000
Fibre glass	1 roll	20,000
Angle iron	2mm	10,000
Electrode		6,000
Hinges	3	450
Castor wheel	4	4,000
Wire gauze	Roll	9,000
Steel ball valve	1	8,000
Galvanized steel pipe		2,000
Workmanship		15,000
TOTAL		98,450

Table 3: Sensory evaluation of smoked samples

Sample	Appearance	Aroma	Taste	Texture	Overall Acceptability
SMBE	6.95 ± 1.36^{a}	7.35 ± 1.28^{a}	7.45 ± 0.83^{a}	7.10 ± 1.41^{a}	7.65 ± 0.88^{a}
SFTI	7.50 ± 1.10^{a}	7.75 ± 1.16^{a}	7.95 ± 1.00^{a}	8.10 ± 0.79^{ab}	8.00 ± 0.79^{a}
SMCH	7.07 ± 1.08^{a}	7.30 ± 1.30^{a}	7.50 ± 1.28^{a}	7.40 ± 1.47^{ab}	7.65 ± 1.04^{a}
SFSH	7.45 ± 1.28^{a}	7.50 ± 1.19^{a}	7.55 ± 1.19^{a}	7.45 ± 1.19^{b}	7.50 ± 1.15^{a}

4.0 CONCLUSION

A smoking kiln for production of smoked fish and meat was designed, fabricated and evaluated on the basis of moisture loss per unit time. Charcoal was chosen to be source of heat and delivered by conduction and convection within the smoking chamber and by radiation through chimney to the surrounding.

The following conclusions were made from the study:

1. Design calculation pointed out that heat capacity of the machine exceeds heat requirement for each of the smoking products.
2. The smoking kiln was fabricated on the basis of zero tolerance to heat loss and this was implemented with the use of fibre glass insulator between double jacketed walls of the kiln.
3. Consumer's perception of the smoked products indicated that Atlantic mackerel fish was most preferred and acceptable to the panelist.
4. The machine cost ₦98, 450 (Ninety Eight Thousand, Four Hundred and Fifty Naira only) and considered to be relatively cheap. More importantly, it is easy to maintain, does not require special training or education and therefore recommended for small and medium scale processors.

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