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Development of an Electrically Powered Fish Roasting Machine

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Abstract- ***Traditional charcoal-based fish smoking kilns are associated with long processing times, low energy efficiency, product contamination, and health hazards arising from smoke exposure. To address these limitations, an electrically powered fish roasting machine was designed and fabricated using locally available materials. The machine employs controlled electric heating elements and a thermostatic regulator to achieve uniform heat distribution within an enclosed roasting chamber. Engineering design calculations were carried out to determine the structural strength, thermal performance, and suitability of the selected materials. The developed system was evaluated experimentally using catfish and tilapia samples to determine roasting time, moisture reduction, roasting rate, efficiency, sensory quality, and shelf-life stability. Results showed that initial fish masses of 7.00 kg (catfish) and 2.00 kg (tilapia) were reduced to 2.30 kg and 0.65 kg, respectively, with final moisture contents of 8.88% and 11.11%. Roasting efficiencies of 91.11% for catfish and 88.88% for tilapia were achieved within 45 to 60 minutes, representing a significant reduction in processing time compared with traditional kilns. Sensory evaluation indicated good consumer acceptability, and shelf-life assessment confirmed product stability for up to five weeks. The study demonstrates that electrically powered fish roasting offers a hygienic, efficient, and practical solution for small- and medium-scale fish processing applications.***

Keywords: ***Fish preservation, Roasting, Electric kiln, Drying***

1. INTRODUCTION

Fish is a widely consumed, nutrient-dense protein source, rich in omega-3 and omega-6 fatty acids as well as B-vitamins, while being comparatively lower in calories, saturated fats, and cholesterol [1]. Regular consumption of fish has been associated with reduced risk of coronary heart disease and improved cognitive and sensory function. Despite these benefits, fresh fish is highly perishable, making rapid processing and preservation essential to maintain quality, safety, and market value [2]. In industrial supply chains, freezing whether conventional or flash-freezing is a common method of preservation. However, in many developing regions, preservation continues to rely heavily on thermal processes such as smoking, roasting, and drying due to high costs, limited infrastructure, and restricted access to cold storage facilities [3,4].

Early attempts at improving fish smoking technology relied largely on firewood or charcoal. Charcoal smoking kilns have been developed to optimize fish drying processes. For instance, a kiln designed with a capacity of 7.2 kg achieved effective moisture reduction in fish within 120 to 160 minutes at varying temperatures and air v671elocities [5]. Adamu et al. [6] designed and constructed a smoking kiln that reduced the moisture content of African mud fish to 11.46% within five hours, with dried fish retaining acceptable quality for up to two months before spoilage. Michael [7] developed a motorized kiln using locally available materials that relied on natural convection of heated air at temperatures between 60 and 110 °C. The kiln, with a capacity of 120 kg, reduced fish moisture from 80% to 30% in about one hour, achieving weight losses of 36% for *Etholmosa fimbriata*, 37% for *Scombridae mackerel*, and 45% for *Clarias gariepinus* (catfish). Olayemi et al. [8] assessed the microbial quality of catfish smoked with the Nigerian Stored Products Research Institute (NSPRI) kiln and found bacterial counts of 2.0×10^4 cfu/g and mould/yeast counts of 0.7×10^4 cfu/g, with no detection of *Pseudomonas*, *Escherichia coli*, or *Salmonella*. Sensory evaluation confirmed the smoked fish to be acceptable in taste and flavor, establishing the NSPRI kiln as capable of producing fish of high microbiological quality. However, while these improvements have addressed some challenges, traditional biomass-based kilns still suffer from smoke emissions, uneven heating, and limited safety controls. A dual-powered (gas and electric) automated kiln was developed in Minna, Nigeria, using locally sourced composite insulating materials, with the capacity to process up to 90 kg of fish per batch at a drying efficiency of 98%. The system incorporated automated temperature control (0-150 °C), blower regulation, and solar energy integration, which collectively addressed common challenges in traditional smoking methods such as heat loss, uneven drying, and the presence of harmful polycyclic aromatic hydrocarbons (PAHs) in smoked fish [2].

Recent work has therefore shifted toward electric-powered solutions that combine efficiency with better control. Taduran [9] developed a microcontroller-based smoked fish machine equipped with a proportional integral derivative temperature controller to automate cooking, smoking, and drying stages. The system, with a 5 kg batch capacity, completed full cycles in about 60 minutes, demonstrating the role of automation in ensuring process consistency and product uniformity. In Nigeria, Ogundana et al. [10] fabricated a low-cost electric kiln from locally sourced composite materials, integrating thermostatic controls, electrical heating elements, and clay insulation to improve hygiene and reduce energy loss. Complementary to this, Isinkaye et al. [11] reported on a forced-convection electric dryer that used blowers and heating coils to enhance heat distribution, making it suitable for small- and medium-scale processors in rural and urban settings. Photovoltaic (PV) systems have been utilized to power fish drying machines, demonstrating significant energy generation that exceeds operational needs, thus supporting sustainable practices for fishermen [12]. A forced convection electric fish dryer was developed, capable of drying 126 kg of fish efficiently, achieving a mean moisture reduction of 60% in one hour [13].

Hybrid systems have also emerged, addressing the challenge of unreliable power supply. Ansori et al. [14] designed a solar-electric dryer where electric heaters ensured stable drying during periods of low solar irradiance, thereby improving reliability and uniformity. At a larger scale, Adegbola et al. [15] fabricated a 300 kg capacity oven that could run on either electricity or gas, reporting thermal efficiencies of 79% for electric mode and 84% under dual operation. Alongside efficiency, safety remains a central concern. Uiuiu et al. [16] showed that poorly designed portable smoking ovens can generate harmful levels of PAHs, recommending cleaner electric heating or indirect smoke delivery to reduce contamination risks. Tahir et al. [17] demonstrated the effectiveness of smoke filtration using a furnace-heat exchanger–cyclone system, which could be adapted for electric heating designs. Modibbo et al. [18] further emphasized that controlled, improved kilns consistently produced fish of better color, appearance, and uniformity compared to traditional open-fire methods.

In this study, an electrically powered fish roasting machine was designed, fabricated, and experimentally evaluated to address the limitations associated with traditional charcoal-based fish smoking kilns, including long processing time, product contamination, low efficiency, and health risks from smoke exposure. The machine was developed using locally available mild steel materials and electric heating elements, with design considerations based on the physico-mechanical properties of fish, structural stability, and heat transfer principles. Controlled electric heating elements positioned within the roasting chamber provided uniform heat distribution, eliminating the need for manual turning of fish during roasting. Performance evaluation was conducted using catfish and tilapia samples to assess moisture reduction, roasting rate, efficiency, sensory quality, and shelf life. The results demonstrated that the developed machine achieved moisture contents of 8.88% and 11.11% for catfish and tilapia, respectively, with roasting efficiencies exceeding 88% and significantly reduced roasting times compared to conventional kilns.

II. METHODOLOGY

2.1 Material Selection

Choosing the right material for engineering applications is often one of the most challenging tasks for designers. The ideal material is one that meets the required objectives at the lowest possible cost. In material selection, factors such as its suitability for the intended working conditions and its overall cost are carefully considered. The material selected for the construction of the machine is mild steel having the following properties such as weldability, machinability, malleability, high strength, nice finish and polish-ability. The mild steel was cut to size using a cutter, hacksaw, and hand shearing machine, then assembled by welding. An additional key component was the electric heating element, whose capacity depends on the electrical circuit regulator. The heating elements supply the heat energy required to roast the fish, ensuring the production of high-quality preserved dry fish.

2.2 Material for Construction

The materials selected for the development of the machine are as follows; mild square pipe (25.4 mm), sheet metal plate of gauge 2 mm, electrodes of gauge 12 and sauna heating elements.

2.3 Machine Components

The components of the machine include frame, roasting chamber, hinges, stand, sauna heater element, rack, cover, control circuit box, personal digital scale. Figure 1 represents the exploded view and parts list of the electrically powered fish roasting machine.

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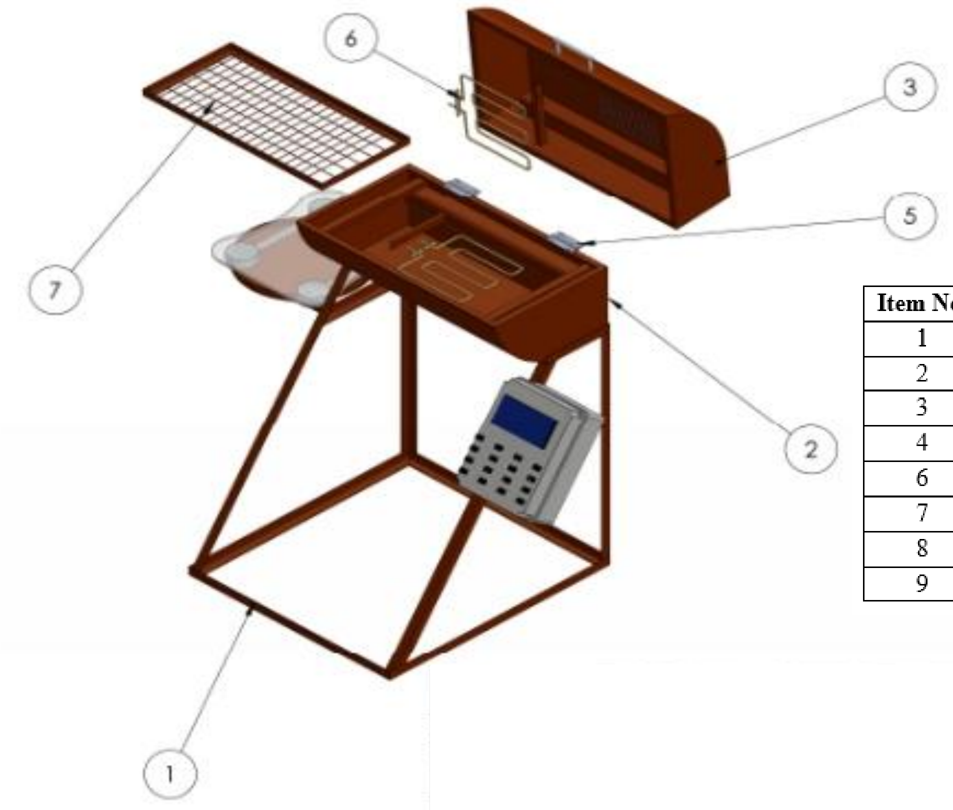

Item No.	Part Number	Qty.
1	Stand	1
2	Bottom Compartment	1
3	Cover	1
4	Hinge	2
6	Element	2
7	Rack	1
8	Control Circuit Box	1
9	Personal Digital Scale	1

Figure 1: Exploded view and bill of materials of the electrically powered fish roasting machine

2.3.1 Frame

Figure 2 represents the frame which is mainly made with the mild steel of square pipe. Mild steel is used to make the frame rigid. This is used to secure the roasting chamber firmly in position on all sides, upon which the roasting chamber seats.

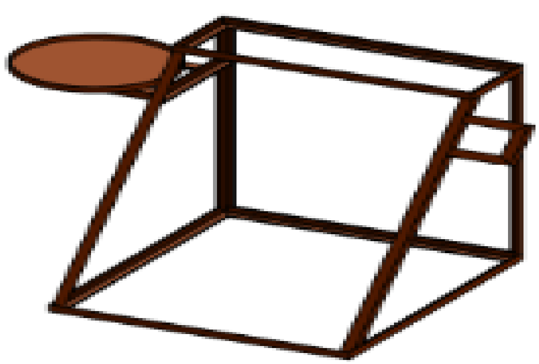

Figure 2: Frame

2.3.2 Roasting Chamber

The roasting chamber is an enclosed compartment used for baking, heating, or roasting food, as shown in Figure 3. It is the section where the fish samples are placed and exposed to controlled heat for uniform roasting and moisture reduction.

Figure 3: Roasting chamber

2.3.3 Hinge

A hinge as shown in Figure 4 is a mechanical joint that permits rotational motion between two connected components. It enables the door of the roasting chamber to swing open and shut, providing access while maintaining structural alignment.

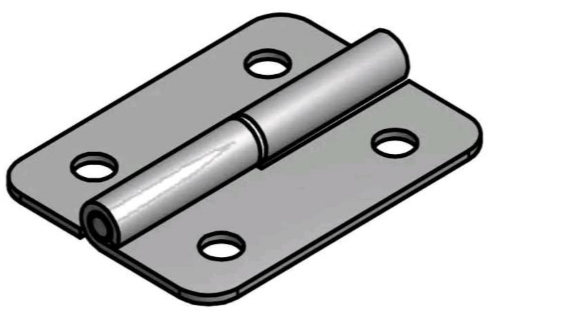

Figure 4: Hinge

2.3.4 Rack

A rack (Figure 5) is a framework or stand used to hold, store, or display things. It serves as support for the fish samples and allows adequate spacing for uniform heat circulation during roasting.

Figure 5: Rack

2.3.5 Heating Element

A heating element shown in Figure 6 converts electrical energy into heat through the process of joule heating. The heat generated is transferred to the roasting chamber to provide the thermal energy required for roasting and drying the fish.

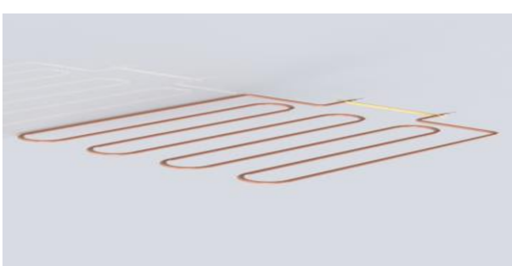

Figure 6: Heating Element

2.3.6 Digital Scale

The digital scale shown in Figure 7 measures and displays the weight of an object electronically using internal sensors that detect the applied load. It is used to measure the mass of fish samples during performance evaluation.

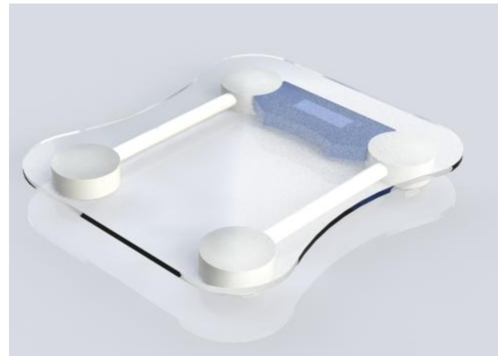

Figure 7: Digital scale

2.3.7 Control Circuit

Control power (Figure 8) is supplied by an AC source and then rectified to DC. The control circuit regulates and supplies the required electrical power to the heating elements, allowing controlled temperature operation during fish roasting.

Figure 8: Control circuit

2.4 Materials Consumption

I. Mild steel plate: A steel plate of 2 mm thickness was selected, with one purchase piece measuring $8\,ft \times 4\,ft$.

II. Round pipe: A round pipe of size $1\,in \times 1\,in$ with extra-thick walls was used, requiring 2.5 standard lengths.

III. Square pipe: A square pipe of $2\,in \times 2\,in$, of thick quality, was purchased in two standard lengths.

IV. Bolt and nut: Bolts and nuts with a threading diameter of 10 mm were chosen for coupling the cut-out components.
V. Cutting and grinding discs: These discs were attached to the angle grinder, where the cutting disc was used for shaping the plate metal to the required geometry, and the grinding disc was used to smooth rough edges.
VI. Welding electrode: Welding electrodes of the required specification were employed to join parts permanently through welding.
VII. Non-polar solvent: A petroleum-based solvent such as petrol or kerosene was used to clean dust and debris from the packed metal surfaces.
VIII. Iron wire brush: The wire brush was used to remove corrosion from surfaces and prepare them for painting.
IX. Paint: Silver-colored paint was selected to coat and protect the extractor, while also providing lustre.
X. Painting brush: The painting brush was used to apply the paint uniformly across the machine surfaces.

2.5 Operational Procedure

The smoking oven works by powering the heating elements in the roasting chamber with electricity, causing them to generate heat. These elements are positioned above and below the fish tray. The fish to be roasted are placed on the tray and left to smoke. A switch regulates the temperature inside the chamber. As the elements produce heat, the fish are dried while the smoke (oil) surrounds them, acting as a preservative. Once roasting is complete, the fish are removed by sliding out the tray onto a support. The weight of the fish is typically measured every hour of smoking until the final weight is reached.

The procedures of operations of the fish roasting machine are summarized as follows:

1. Position the machine so that you can easily open the gate completely and have access to every side of the machine (both inside and outside of the machine).
2. Connect the roasting machine electric plug to the source of electricity (socket).
3. Switch on the machine.
4. Close the gate and any other places where heat can escape to preheat for approximately five minutes.
5. Put the fish samples on the cooking grate and close the gate to start the grilling process.
6. Grasp the temperature control valve and turn it clockwise or anticlockwise to control, regulate or quench the amount of heat.

III. DESIGN ANALYSIS

The electrically powered roasting machine was designed using formulas sourced from engineering textbooks, standards, and journals. The roasting chamber assembly, the supporting frame, and the heating element are regarded as essential components for effective roasting. The roasting chamber subassembly includes the chamber itself, which is fitted with a vent to discharge moisture released from the fish during roasting. The frame is designed as a welded triangular structure, and its load-bearing capacity was further evaluated through simulation. The device is a forced-convective, electrically powered fish roaster designed for roasting fish and similar foods. Both the external and internal parts (roasting chamber) are made of mild steel due to their resistance to rust and corrosion, ensuring the fish remains uncontaminated during processing. Sauna-type electric heating elements are installed at the top and bottom of the chamber, while a thermostat regulates the temperature. Heat is evenly circulated within the chamber to achieve uniform roasting. The machine is designed to roast up to ten fish per batch.

3.1 Design Requirements and Calculations

Design calculations were carried out for each component of the machine, and based on the results, suitable materials were selected for construction. The calculations covered elements such as the roasting chamber, digital scale support, control board seat, frame/stand, heat flow analysis, and others.

3.1.1 Roasting Chamber

The roasting chamber volume, V was determined according to Equation (1):

$$V = \frac{\pi r^2 h}{4} + l.b.h \tag{1}$$

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where r is the radius, l is the length, b is the width, h is the height and V is the volume of the chamber. For this design, the dimensions provided are:

$$r = 0.19m$$
$$l = 0.19m$$
$$b = 0.17m$$
$$h = 0.64m$$
$$V = \frac{3.142 \times 0.19^2 \times 0.64}{4} + (0.19 \times 0.17 \times 0.64)$$
$$V = 0.0388m^3$$

The mass of the chamber was then estimated using the density relation in Equation (2):

$$m = \rho V \quad (2)$$

where m is the mass of the chamber (kg), ρ is the density of the material (kg/m³), and V is the volume of the chamber (m³).

For mild steel, the density is taken as $\rho = 7850kg/m^3$. Thus,

$$m = 7850 \times 0.0388 = 304.52kg$$

The weight is computed according to Equation (3):

$$W = mg \quad (3)$$

where W is the weight of the chamber (N), m is the mass of the chamber (kg), and g is the acceleration due to gravity, taken as 9.81 m/s^2.

$$W = 304.52 \times 9.81 = 2987.34N$$

3.1.2 Roasting Chamber Seat

The applied load on the chamber seat is obtained from Equation (3). Substituting $m = 304.52$ kg, the load is calculated as:

$$W = 304.52 \times 9.81 = 2987.34 \text{ N}$$

Equation (4) expresses the total volume of the platform, V_T, as the sum of the side volume, V_1, and the front–back volume, V_2.

$$V_T = V_1 + V_2 \quad (4)$$

The side volume is expressed in Equation (5):

$$V_1 = 2(lbt) \quad (5)$$

where l, b, and t are the length, width, and thickness of the plate, respectively. With $l = 0.17$ m, $b = 0.0254$ m, and $t = 0.0254$ m, the side volume becomes:

$$V_1 = 2(0.17 \times 0.0254 \times 0.0254) = 2.194 \times 10^{-4} \text{ m}^3$$

The front–back volume is shown in Equation (6):

$$V_2 = 2(lbt) \quad (6)$$

Substituting $l = 0.64$ m, $b = 0.0254$ m, and $t = 0.0254$ m, gives:

$$V_2 = 2(0.64 \times 0.0254 \times 0.0254) = 8.258 \times 10^{-4} \text{ m}^3$$

Thus, the total volume is:

$$V_T = 2.194 \times 10^{-4} + 8.258 \times 10^{-4} = 1.0452 \times 10^{-3} \text{ m}^3$$

The mass (m) of the platform is obtained from Equation (7):

$$m = \rho V_T \quad (7)$$

where ρ is the density of mild steel (7850 kg/m^3). Substituting values gives:

$$m = 7850 \times 1.0452 \times 10^{-3} = 8.204 \text{ kg}$$

The corresponding weight (W) of the platform using Equation (3) is calculated as:

$$\text{W} = 8.204 \times 9.81 = 80.5 \text{ N}$$

3.1.3 Digital Scale Support

The volume of the support, V is given by Equation (8):

$$V = \pi r^2 h + 2(lbh) \quad (8)$$

where r is the radius of the circular base, $l$is the length, b is the width, and h is the height of the support. Substituting $r = 0.165$ m, $l = 0.195$ m, $b = 0.05$ m, and $h = 0.02$ m, the volume becomes:

$$V = (3.142 \times 0.165^2 \times 0.02) + (2 \times 0.195 \times 0.05 \times 0.02)$$
$$V = 2.101 \times 10^{-3} \text{ m}^3$$

The mass of the support, m is determined from Equation (9):

$$m = \rho V \quad (9)$$

where $\rho = 7850$ kg/m^{3}is the density of mild steel. Substituting values gives:

$$m = 7850 \times 2.101 \times 10^{-3} \approx 16.5 \text{ kg}$$

The weight, W of the support is obtained using Equation (3) as:

$$W = 16.5 \times 9.81 = 161.8 \text{ N}$$

3.1.4 Control Board Support (2 Pairs Square Pipe)

The volume of the control board support, V is expressed as seen in Equation (10):

$$V = 4lbt \quad (10)$$

where l is the length, b is the width, and t is the thickness of the square pipe. Substituting $l = 0.135$ m, $b = 0.0254$ m, and $t = 0.0254$ m, the volume becomes:

$$V = 4 \times 0.135 \times 0.0254 \times 0.0254$$
$$V = 3.484 \times 10^{-4} \text{ m}^3$$

where $\rho = 7850\,\text{kg/m}^3$is the density of mild steel. The mass of the support is calculated using Equation (9):

$$m = 7850 \times 3.484 \times 10^{-4} = 2.735\,\text{kg}$$

The corresponding weight of the support according to Equation (3):

$$W = 2.735 \times 9.81 = 26.8\,\text{N}$$

3.1.5 Stand

For the front side, the length, L, is obtained from the Pythagorean relation in Equation (11):

$$L = \sqrt{a^2 + b^2} \quad (11)$$

where a and b represent the perpendicular side dimensions of the front face.

Substituting $a = 0.7$ m and $b = 0.53$ m

$$L = \sqrt{(0.7)^2 + (0.53)^2} = \sqrt{0.7709} = 0.878\,\text{m}$$

The volume of the front side, V_f, is given by Equation (12):

$$V_f = 2lbt \quad (12)$$

substituting $l = 0.878$ m, $b = 0.0254$ m, and $t = 0.0254$ m, yields:

$$V_f = 2 \times 0.878 \times 0.0254 \times 0.0254$$
$$= 1.133 \times 10^{-3}\,\text{m}^3$$

For the back side (one pair), the volume (V_b) is calculated using Equation (13):

$$V_b = 2lbt \quad (13)$$

with $l = 0.7$ m, $b = 0.0254$ m, and $t = 0.0254$ m. Substituting gives:

$$V_b = 2 \times 0.7 \times 0.0254 \times 0.0254$$
$$= 9.032 \times 10^{-4}\,\text{m}^3$$

The total volume, V of the stand is therefore:

$$V = V_f + V_b = (1.133 \times 10^{-3} + 9.032 \times 10^{-4})$$
$$= 2.04 \times 10^{-3}\,\text{m}^3$$

The mass (m) of the stand is obtained using Equation (9):

$$m = 7850 \times 2.04 \times 10^{-3} = 15.98\,\text{kg}$$

The corresponding weight (W) is obtained using Equation (3).

$$W = 15.98 \times 9.81 = 156.81\,\text{N}$$

3.1.6 Stand Base Platform

For the front and back members (one pair), the volume, V_{fb}, is obtained using Equation (14).

$$V_{fb} = 2lbt \quad (14)$$

where $l = 0.64$ m, $b = 0.0254$ m, and $t = 0.0254$ m. Substituting gives:

$$V_{fb} = 2 \times 0.64 \times 0.0254 \times 0.0254$$
$$= 8.26 \times 10^{-4}\,\text{m}^3$$

For the right and left members (one pair), the volume, V_{rl}, is obtained using Equation (15).

$$V_{rl} = 2lbt \quad (15)$$

with $l = 0.7$ m, $b = 0.0254$ m, and $t = 0.0254$ m. Substituting values gives:

$$V_{rl} = 2 \times 0.7 \times 0.0254 \times 0.0254$$
$$= 9.032 \times 10^{-4}\,\text{m}^3$$

The total volume of the stand base platform (V) is therefore:

$$V = V_{fb} + V_{rl} = (8.26 \times 10^{-4} + 9.032 \times 10^{-4})$$
$$= 1.73 \times 10^{-3}\,\text{m}^3$$

The corresponding mass (m) is obtained using Equation (9).

$$m = 7850 \times 1.73 \times 10^{-3} = 13.57\,\text{kg}$$

The weight (W) of the base platform is obtained using Equation (3).

$$W = 13.57 \times 9.81 = 133.2\,\text{N}$$

3.1.7 Heat Flow Analysis

Heat transfer through the cooking grid occurs primarily by radiation. Unlike conduction and convection, radiation heat transfer is governed not simply by a temperature difference, but by the absolute temperature raised to the fourth power. Moreover, radiation can occur without any intervening medium between surfaces.

Let a heat flow at a rate Q be applied at a surface temperature T across a total surface area $A$of the cooking grid. The rate of radiant heat flow is given by Equation (16):

$$Q = \varepsilon\sigma A T^4 \quad (16)$$

where Q is heat flux (energy per unit time), A is surface area through which heat is radiated, σ is Stefan–Boltzmann constant ($5.67 \times 10^{-8}\,\text{W/m}^2\text{K}^4$), ε is emissivity of the cooking surface (0.21), and T is the absolute temperature of the radiating surface (in kelvin).

3.1.8 Heat Analysis

The heat generated by the electric heating element is obtained from the relationship between electrical parameters and thermal energy shown in Equation (17):

$$H = IVT \quad (17)$$

where H is heat energy generated (J), I is electric current (A), V is voltage (V), and T is time (s).

Also, the heat quantity per unit time is given in Equation (18):

$$Q = \frac{H}{T} = IV \quad (18)$$

where Q is the heat transfer rate or power (W).

For the electric heating element used in this study, the heat output (Q) was specified as 1000 W. According to Fourier's law of one-dimensional steady-state heat conduction, the rate of heat transfer through the wall is given by Equation (19):

$$Q = \frac{KA\,\Delta T}{\Delta x} \quad (19)$$

where K is thermal conductivity of mild steel, A is heat transfer cross-sectional area, ΔT is temperature difference, and Δx is material thickness.

The area of heat transfer is given in Equation (20):

$$A = \mathrm{L} \times \mathrm{B} \quad (20)$$

where L is the length of the chamber wall (m) and B is the breadth of the chamber wall (m)

Substituting the known values:

$$A = 0.633 \times 0.390 = 2.469 \times 10^{-1}\ \mathrm{m}^2$$

Also, $\Delta x = 0.015$ m and $K = 50$ W/mK.

Rearranging Equation (19):

$$\Delta T = \frac{Q\,\Delta x}{K\,A}$$

$$\Delta T = \frac{1000 \times 0.015}{50 \times 0.2469} = \frac{15}{12.345} = 1.2151^{\circ}\mathrm{C}$$

$$\Delta T = 274.22\ \mathrm{K}$$

IV. RESULTS AND DISCUSSION

4.1 Machine Assembly

Figure 9 shows the developed electrically powered fish roasting machine. Appropriate bolts and nuts were used for tight construction. In the development of the electrically powered fish roasting machine. The height of the electrically powered fish roasting machine (frame) was 878 mm, the length was 25.4 mm and width 156.8 mm. The metal sheets were measured using measuring tape and cut to desired size and length to construct the machine. The fish tray of length 520 mm, width 310 mm and height of 200 mm was constructed and put into the roasting chamber; the heating elements were also fitted into the roasting chamber.

Figure 9: Assembled machine in operation

4.2 Care and Maintenance

The machine is made up of metallic materials; corrosion is apparent therefore subsequent repainting with oil paint is necessary. The fish tray should be removed, cleaned and oiled after using. Heating elements should be cleaned after using. For long periods of non-usage, the machine should be kept under dry shed or inside store for storing.

4.3 Performance Evaluation

Two sets of fish samples (catfish and tilapia) were procured from Ago Main Market, Nigeria. The samples were thoroughly washed, lightly salted, and allowed to drain to remove excess water. The fish were then sun-dried for 30 minutes prior to roasting. The heating elements of the developed roasting machine were powered electrically and preheated for 5–10 minutes to ensure uniform temperature distribution. After draining, the initial mass of each catfish and tilapia sample was measured using a digital weighing scale. The fish samples were then arranged on the trays of the developed machine. During roasting, constant heat was supplied by the electrically heated elements, with heat circulation occurring both above and below the fish samples. Consequently, turning of the fish was unnecessary, unlike in conventional charcoal smoking kilns where periodic turning is required to achieve uniform heating. The total roasting time was recorded as the duration from the start of heating to completion of roasting. After roasting, the fish samples were allowed to cool to ambient temperature and subsequently stored in polythene bags for shelf-life evaluation. Storage was conducted over a period of five weeks. The final mass of each fish sample was measured after roasting, and the percentage moisture loss was calculated using Equation (21):

$$M_w = \frac{m_2 - m_1}{m_2} \times 100\% \qquad (21)$$

where M_w is percentage moisture loss (%), m_2 is initial mass of fish before roasting (g) and m_1 is final mass of fish after roasting (g).

4.4 The Efficiency of the Roasting Machine

Roasting efficiency based on percentage moisture evaporated from roasted food was verified using Equation 22. The efficiency of the roaster is considered at optical roasting parameters for each fish. The fish roasting machine can roast over ten (10) fish at a time within ten (30) minutes. The roasting efficiency was calculated based on the percentage moisture evaporated from roasted fish.

$$E_r = \frac{M_w - L}{E_{hc} \times E_f} \qquad (22)$$

Where E_r is efficiency of the roasting machine, M_w represents percentage moisture loss (%), L is latent heat of vaporization of water (kJ/kg), E_{hc} is heat capacity of the heating element (kJ), E_f denotes energy factor accounting for system heat losses.

4.5 Determination of Shelf Life

The shelf life of the roasted fish was evaluated by packaging samples from the two fish species in polythene bags and storing them for at least five (5) weeks. Attributes such as color, texture, flavor, and overall condition were monitored weekly. A panel of 10 members experienced in fish scoring assessed the products each week. After cooking, the two fish samples were served to the panelists, who were asked to taste and rate them using a score sheet. The scoring was based on a 5-point scale: 5 – very good, 4 – good, 3 – average, 2 – fair, and 1 – poor.

4.6 Design Results

Based on the preliminary investigation of the physio-mechanical properties of the fish samples, the design and fabrication of the various components of the roasting machine were carried out. Fish roasting was performed using the developed roasting machine incorporated with electric heating elements. The machine was tested using two fish species (catfish and tilapia). The temperature of the heating elements was regulated using a temperature control regulator, and an increase in temperature was observed up to the maximum set level. Table 4.1 presents the raw performance evaluation results for catfish roasted using the developed machine, while Table 4.2 shows the corresponding results for tilapia. A total fresh weight of 7.00 kg of catfish and 2.00 kg of tilapia was reduced to 2.30 kg and 0.65 kg of dried products, respectively, after 1 hour and 30 minutes of roasting. The moisture content of the roasted catfish and tilapia was 8.88% and 11.11%, respectively. The roasting rates were determined as 0.51 kg/hr for catfish and 0.19 kg/hr for tilapia, while the roasting efficiencies were 91.11% and 88.88%, respectively.

Table 4.1: *Summary result of the performance evaluation of catfish and Tilapia fish roasted using the developed machine.*

S/N	Initial weight(kg)	Final Weight(kg)	Time (Hr/Min)	Moisture Content (%)	Roasting rate (kg/h)	Smoking Efficiency (%)
Catfish	7.00	2.30	3.55	8.88	0.51	91.11
Tilapia	2.00	0.65	2.56	11.11	0.19	88.88

4.6.1 Mean Sensory Evaluation Using Developed Roasting Machine

The results were presented as mean values, and differences between the means were analyzed using a paired *t*-test. Statistical significance was considered at $P < 0.005$.

Table 4.2: *Mean sensory evaluation using developed roasting machine*

Evaluations	Developed roasted catfish	Developed roasted Tilapia fish
Colour	4.10	2.90
Texture	4.10	4.10
Flavour	4.10	3.70
Overall acceptability	4.00	3.70

V. CONCLUSION

The development of the electrically powered fish roasting machine was aimed at increasing the processing capacity of traditional kilns, reducing product contamination from ash and smoke associated with charcoal-based skewers that pose health risks, and minimizing roasting time. The design and construction were based on the physico-mechanical properties of fish, and performance evaluation showed mean moisture contents of 8.88% and 11.11% (dry basis), mean smoking efficiencies of 91.11% and 88.88%, and mean roasting rates of 0.51 kg/hr and 0.19 kg/hr for catfish and tilapia, respectively. Compared with labor-intensive and time-consuming traditional smoking kilns, the electrically powered oven efficiently dried fish to safe moisture levels within 45 minutes for catfish and 60 minutes for tilapia, whereas the traditional method required approximately 5 hours and 3 hours, respectively, with the roasted fish remaining storable for up to five weeks. These results demonstrate that electrical fish roasting is a viable and efficient processing method for extending fish shelf life, particularly in developing countries where access to advanced processing equipment is limited, thereby confirming that the project objectives were successfully achieved. Based on these findings, the machine is recommended for home, roadside barbecue, party, anniversary, and camping use due to its safe operating conditions; future designs may incorporate automated or programmable multipurpose features to accommodate various roastable items such as fish, meat, maize, and other aquatic animals to enhance versatility and user acceptance; larger oven capacities can be developed to handle greater quantities per cycle; repeated protective painting over time will further improve resistance to rust; and alternative renewable energy sources may be explored to reduce reliance on conventional electricity.

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