

DEVELOPMENT OF A PROTOTYPE INVERTER POWERED BAKING OVEN

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ABSTRACT

Development of a prototype inverter powered baking oven was carried out and performance was evaluated to determine its efficiency. The outer and inner dimensions of a designed and fabricated oven which were made up of mild steel and stainless steel were (506 length x 506 width x 506 height) and (436 length x 436 width x 436 height) in millimeters respectively. The fiber glass was used as an insulator. The materials for fabrications were locally sourced and served as alternative for baking, roasting or boiling using electrical recharged power in case of power failure. The prototype inverter baking oven operates on the principle of electrical resistance and 0.147°C/W was obtained as the resistance of the heating element. The performance evaluation revealed the baking efficiency of the oven to be 94.29 %, 75 % and 66.7 % for bread, plantain and fish respectively, the maximum temperature of 160°C, 180°C and 200°C were recorded. Capacity of the baking oven was determined to be 6 loaves of bread per tray/batch. With practical determination and comparison made with other work, a prototype inverter powered baking oven can be adopted for domestic and industrial purpose depending on the production plans and the layout.

Keywords: Bake, Oven, Inverter, Mild Steel, Stainless Steel

1. Introduction

A thermally protected enclosure used for dry heating of a substance is known as oven, and one of the most widely used appliance in food service industry is baking oven (Genitha et al., 2014). They added that, the hot air that flows in baking oven over the baking material are either by natural convection or forced by a fan, the heat transfer from the air (i.e. convection), the heat transfer from the oven heating surfaces (i.e. radiation), and the heat transfer across contact area between product and metal surface (i.e. conduction). These are the simultaneous momentum, heat and moisture transfer mechanisms within a baking product and between the product and its environment, which theoretically are well known (Tong and Lund, 1990; Ozilgen and Heil, 1994; Carvalho and Martins, 1993). The study of electric baking oven has received a considerable attention over the decades, due to its durability, efficiency and availability. However, Adegbola et al., (2018), developed a dual powered (gas and electricity) baking oven which is efficient, cheap and cost effective both in production and operation; Mohammad and Badrul (2012), analyzed and compared the performance of a new inverter topology with two types of input sources which were solar PV source and ideal dc source (battery); Mercer (2014), designed, fabricated and evaluated the performance of domestic gas oven; while Kosemani et al., (2021) modified and optimized an existing small-scale single-powered baking oven into a dual-powered oven. Oven is a heating chamber, thermally insulated enclosure, or small furnace which is basically used for the extraction of moisture from some engineering materials to improve their mechanical properties such as hardness and ductility (Solihin and Wisnoe, 2014). It is also used for materials processing, heat treatment of engineering materials and sterilization of equipment and instruments for industrial use (Genitha et al., 2014; Adegbola et al., 2012). “Developing an efficient rotary oven that is capable of addressing the issue of long baking duration and uneven heating distribution during baking could aid in encouraging indigenous use of the oven by small and medium scale bakeries in developing countries” (Sanusi et al., 2021). Therefore, they designed the experiment using Tagushi method to investigate the influence of oven temperature and oven rack speed on the

physical properties of bread produced from the rotary oven. Morakinyo et al., (2017), developed and optimized an operational parameters of a gas-fired baking oven, they evaluated the oven characteristics in terms of the baking capacity, baking efficiency and weight loss of the baked bread while Khater and Bahnasawy (2014), developed a mathematical model of heat and mass balance of the bread baking process to predict the temperature and water content of bread at different heating temperatures and times. According to Abraham and Sparrow (2004); Edgar et al., (2017), electricity has been the part and parcel of our modern life and it is the most widely used form of energy. They added that “Man has learnt about electricity from nature as it is also a basic part of nature”. Before electricity generation began over 100 years ago, houses were lit with kerosene lamps, food was cooled in iceboxes, and rooms were warmed by wood-burning or coal-burning stoves (Banga and Alonso, 2000). Islam et al., (2016) supported the revelation of Jekayinfa (2007), that “bread-baking with wood as energy source required the highest energy (6.15 kJmin^{-1}) compared with 3.37 kJmin^{-1} and 1.5 kJmin^{-1} obtained with gas and electricity as sources of energy respectively”. Furthermore, Ogbeide et al., (2017), used locally available materials to develop a low cost cooking oven capable of using electric and solar energy; Apart from this, Olugbade and Ojo (2018), developed and carried out the performance evaluation of an improved electric baking oven. Also, Zeleke and Sameer (2018), designed, constructed and carried out the performance evaluation of a box type solar cooker with a glazing wiper mechanism. Yahuza et al., (2016) designed, constructed and tested a Parabolic Solar Oven with focused reflector. Heat from the sun was concentrated on a transparent glass located at the focal point to the black cast Aluminum plate (absorber) which was located in an enclosed insulated space (Oven). The heat absorbed by the Aluminum plate which could be utilized for baking or cooking. The sun tracking was made to be manual tilt of the parabolic reflector and a booster was mounted on top of the oven which would focus the sun rays into the enclosed oven through the top glass layer. The frame was made using 50 mm x 3 mm angle iron (Baltan et al., 2012). The holder and its support were constructed out of 3 mm x 12 mm flat bar and shaped round to accommodate the receiver holder. The principles of heat transfer were carried out to ascertain the efficiency of the oven. The system was tested in average sunny or cloudy conditions, the test results gave a higher temperature of 104°C (Udebunu and Greg, 2019). Ilo and Greg (2019), also developed a microcontroller based domestic multi-purpose solar powered electric cooker -oven -grinder. To achieve this goal, the first work done was to design a sun tracking system that followed the movement of the sun and developed an algorithm for sun tracking and energy acquisition system. Mishra, (2019) discussed a solar thermal powered bakery oven model. The proposed system integrates bakery oven with a solar parabolic trough collector. Computational fluid dynamics (CFD) analysis of the temperature and air flow distribution inside the oven was undertaken. The CFD results revealed that uniform temperature can be acquired throughout the oven by proper selection of the flow model, along with implementation of realistic boundary conditions. Akinfaloye (2018), designed, fabricated and carried out the performance evaluation of a domestic electric oven, he discovered that the bulk of the energy used for cooking and baking for most household in Nigeria is mainly derived from fossil fuel. Chukwunke et al., (2018), developed a mini dual powered oven which is mainly made up of the electric coil, the lagging material, temperature control and the gas burner. According to Mbodji and Hajji (2017), household energy need is one of the biggest issues in the daily lives of people around the world. The most important energy-consuming activities in most households are cooking, lighting and use of electrical appliances. Cooking accounts for a staggering 91 percent of household energy consumption, lighting uses up to 6 percent and the remaining 3 percent can be attributed to the use of basic electrical appliances such as televisions and pressing irons. Cooking (such as baking, frying, boiling or roasting) is an exercise that must be carried out almost on a daily basis for the sustenance of life. In case of irregular power failure, this study developed a prototype baking oven that could be used for domestic purpose powered by electrical recharged power supply (i.e. inverter). It serves as an alternative source of power for baking. In order to achieve the purpose of the work, the study considered the design and fabrication of a prototype baking oven and evaluate the performance of the fabricated baking oven with the use of food substances such as bread, plantain and fish. The rate of bread consumption increases every month. Since it's a fast food making and can also be served as snacks, the project developed a prototype baking oven for

domestic use powered by electricity supply or recharged power (inverter) as an alternative source to electricity. This work would establish a method whereby the time factor for baking will be evaluated and compare with the existing work(s) where other source of energy was used as alternative, and predict the time for subsequent baking based on the size of the loaf of bread. This would help to avoid burning of baked food or half cooked most especially when it is powered by inverter, and evaluate its efficiency. The method may also be applied in industrial settings depending on the production plans and the layout.

2. Methodology

In order to develop a prototype baking oven for domestic use, the following procedures were considered, working principles of the prototype baking oven; materials selection required for fabrication; design calculations and analysis; design of a prototype baking oven for domestic use and some other component parts and; performance evaluation of the baking oven using electrical recharged power (inverter).

2.1 Working principle of the prototype baking oven

The prototype baking oven was fabricated according to the design concept. Based on the materials selected for the oven, they are meant to withstand the required temperature for baking and the prototype was to experiment and evaluate its performance. The required temperature for baking the bread was uniform throughout the baking process, the values for the size of bread before baking was also uniform but with varying temperature. This was done to ensure the best time taken for baking the bread to avoid burning or half-baked. The most important working principle of the fabricated baking oven is the process of heat transfer using electrical recharged power (inverter) as the main source of energy. Heat is conducted whenever there is a temperature difference per unit length of heat transfer, which is known as temperature gradient. The heat flows from the hotter part to the coldest part and the greater the temperature difference, the faster the flow of heat. According to Theodore et al., 2011, the rate of heat transfer is equal to the product of driving force and conductance.

Mathematically,

$$dQ/dt = kA dT/dx \quad (1)$$

Where:

Q is the total rate of heat transfer measured in KJ/sec.

t is time in seconds.

k is the thermal conductivity measured $Wm^{-1}K$.

T is the temperature in $^{\circ}C$ or K.

x is thickness in meter m.

The heating elements were connected in series to avoid high power consumption and to prolong the time range of electrical recharged power (i.e. inverter). The heating elements were welded to the wall of the stainless steel, facing each other to ensure enough heat in the chamber and to reduce the time required for baking. The thermocouple was hanged in the oven to sense the temperature of heat produced in the oven chamber, which was displayed on the temperature controller and the temperature controller was used to regulate the temperature intended to achieve. A tray of 2 mm thickness was placed in the oven chamber, drilled all across for easy convection of heat in the baking pan placed on it.

2.2 Material selection for fabrication

The proposed materials for the development of an electrical baking oven were stated in Table 1. All the materials used were locally sourced and fabricated and the purposes of selecting these materials are due to the ability to meet functional requirements; ability to acquire quality materials with limited resources; ability of the materials to withstand corrosive attack and rust as well as high temperature; the cost of the materials and its availability.

Table 1 – Reasons for the choice of materials and their components

S/NO	Component	Material	Reasons
1	Body (outer part)	Mild steel	High resistance to breakage. Ductile and malleable.
2	Body frame	Mild steel	As above
3	Body (inner part)	Stainless steel	Retain strength at high temperature

4	Lagging material (insulator)	Fiberglass	High thermal insulation
5	Oven burner	Mild steel	High resistance to breakage
6	Perforated tray	Stainless steel	Retain strength at high temperature
7	Inverter	NIL	Rechargeable
8	Battery	NIL	High capacity to charge storage
9	Heating element	NIL	High electrical resistance
10	Pyrometer	NIL	Maintain temperature at desired range
11	Thermocouple	NIL	Sensor used to measure temperature
12	Cables	NIL	High electrical conductivity
13	Contactors	NIL	Switch for switching an electric power circuit

2.3 Design calculations and analysis

Area of Stainless steel, $A_{ss} = (436 \times 436) mm^2 = (0.436 \times 0.436) m^2$

Area of Fiber glass, $A_{fg} = (440 \times 440) mm^2 = (0.44 \times 0.44) m^2$

Area of Mild steel, $A_{ms} = (506 \times 506) mm^2 = (0.506 \times 0.506) m^2$

Since the shape of the stainless steel, fiber glass and mild steel is square and have six sides, therefore:

$$A = 6l^2 \quad (2)$$

Area of Stainless steel, $A_{ss} = 6(0.436 \times 0.436) m^2 = 1.14 m^2$

Area of Fiber glass, $A_{fg} = 6(0.44 \times 0.44) m^2 = 1.16 m^2$

Area of Mild steel, $A_{ms} = 6(0.506 \times 0.506) m^2 = 1.54 m^2$

Thickness or length of Stainless steel, $L_{ss} = 2 mm = 0.002 m$

Thickness or length of Fiber glass, $L_{fg} = 6 mm = 0.006 m$

Thickness or length of Mild steel, $L_{ms} = 2 mm = 0.002 m$

Thermal conductivity of Stainless steel, $K_{ss} = 8.09 Wm^{-1}K$

Thermal conductivity of Fiber glass, $K_{fg} = 0.036 Wm^{-1}K$

Thermal conductivity of Mild steel, $K_{ms} = 26.0 Wm^{-1}K$

h_{air} = Convection coefficient of air = $500 Wm^{-2}K^{-1}$

The required temperature from the heating element for this work was 300 °C but the maximum heat loss was 27 °C. The dimensions of the prototype baking oven for the three selected materials (Stainless steel, Fiber glass and Mild steel) and the quantity of heat flow through the materials is as shown in Figure 1 and Figure 2 respectively. The dimensions of the prototype baking oven for the three selected materials (Stainless steel, Fiber glass and Mild steel) and the quantity of heat flow through the materials is as shown in Figure 1 and Figure 2 respectively.

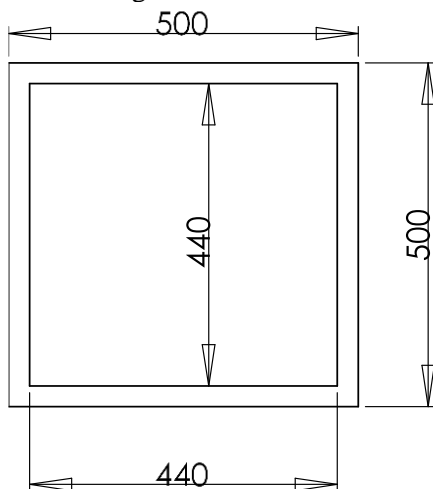


Fig. 1. Dimensions of the prototype baking oven for the three selected materials.

Since the energy can neither be created nor destroyed, therefore the quantity of heat flow through the materials is uniform.

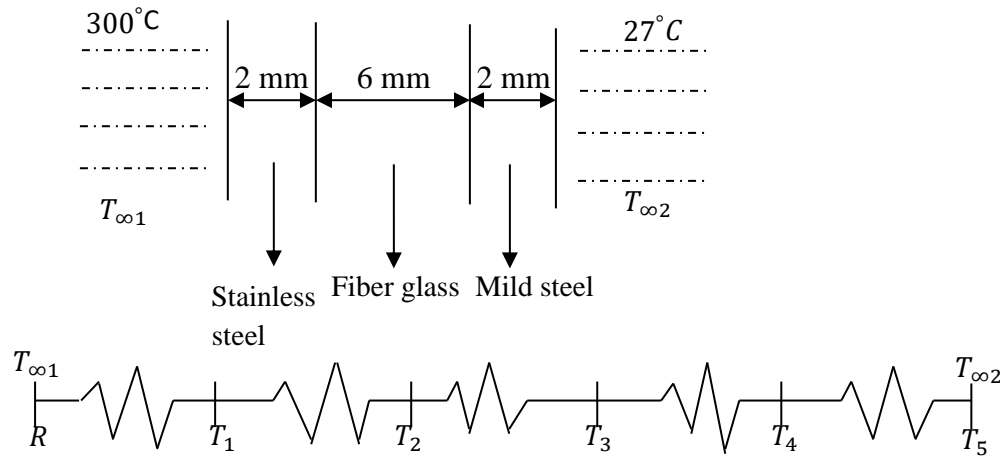


Fig. 2. Quality of heat flow through the materials

Total resistance R_T of the heating element in series:

$$R_T = \frac{1}{h_{air}A_{ss}} + \frac{L_{ss}}{K_{ss}A_{ss}} + \frac{L_{fg}}{K_{fg}A_{fg}} + \frac{L_{ms}}{K_{ms}A_{ms}} + \frac{1}{h_{air}A_{ms}} \tag{3}$$

$$R_T = \frac{1}{500 \times 1.14} + \frac{0.002}{8.09 \times 1.14} + \frac{0.006}{0.036 \times 1.16} + \frac{0.002}{26.0 \times 1.54} + \frac{1}{500 \times 1.54} = 0.147^\circ\text{C}/\text{W}$$

Quantity of heat Q required for baking is derived using the relation:

$$Q = \frac{T_{\infty 1} - T_{\infty 2}}{R_T} \tag{4}$$

Where:

$T_{\infty 1}$ is the required temperature from the heating element

$T_{\infty 2}$ is the maximum heat loss

$$Q = \frac{300 - 27}{0.147} = 1857.14\text{W}$$

For the temperature at the surface of the stainless steel, convective heat transfer is taken place at this surface which is analyzed thus:

$$Q = h_{air}A_{ss}(T_{\infty 1} - T_1) \tag{5}$$

$$1857.14 = 500 \times 1.14(300 - T_1)$$

$$T_1 = \frac{169142.86}{570} = 296.7\text{K}$$

Temperature of the stainless steel, conductive heat transfer takes place through the stainless steel.

Considering the relation:

$$Q_1 = \frac{K_{ss}A_{ss}}{L_{ss}}(T_1 - T_2) \tag{6}$$

$$1857.14 = \frac{8.09 \times 1.14}{0.002}(296.7 - T_2)$$

$$T_2 = 296.3\text{K}$$

For temperature of the fiber glass, conductive heat transfer takes place through the fiber glass and the temperature is determined using the relation:

$$Q_2 = \frac{K_{fg}A_{fg}}{L_{fg}}(T_2 - T_3) \tag{7}$$

$$1857.14 = \frac{0.036 \times 1.16}{0.006}(296.3 - T_3)$$

$$T_3 = 29.5\text{K}$$

Temperature of the external casing, convective heat transfer occurs between the external wall casing and the mild steel surface which can be expressed using the Newton's law of cooling thus:

$$Q_3 = h_{air}A_{ms}(T_3 - T_4) \tag{8}$$

$$1857.14 = 500 \times 1.54(29.5 - T_4)$$

$$T_4 = 27\text{K}$$

2.3.1 Determination of the Capacity of Electric Heating Element

Average temperature for heating element in $^\circ\text{C}$ per minute was measured to be 5°C . The total resistance of the two heating elements used and connected in series was measured as 110Ω and the required voltage was 240 volts. Therefore, the power consumed is:

$$P = \frac{V^2}{R} \tag{9}$$

Where:

P is the power measured in Watt (W)

V is the voltage measured in volts (V)

R is the resistance in (Ω)

$$P = \frac{240^2}{110} = 523.6 \text{ W}$$

Hence, the Specific heating rate of the oven, P_s , is calculated thus:

$$P_s = \frac{\text{Power rating of the heater}}{\text{average temperature of the heating element}} \tag{10}$$

$$P_s = \frac{523.6}{5} = 104.72 \text{ W min}/^\circ\text{C}$$

2.4 Design drawing of a prototype baking oven

The design drawings are illustrated in Figures 3 – 5. Figure 3 shows the isometric view of the oven, Figure 4 shows the pictorial view while Figure 5 illustrates the exploded view of the oven.

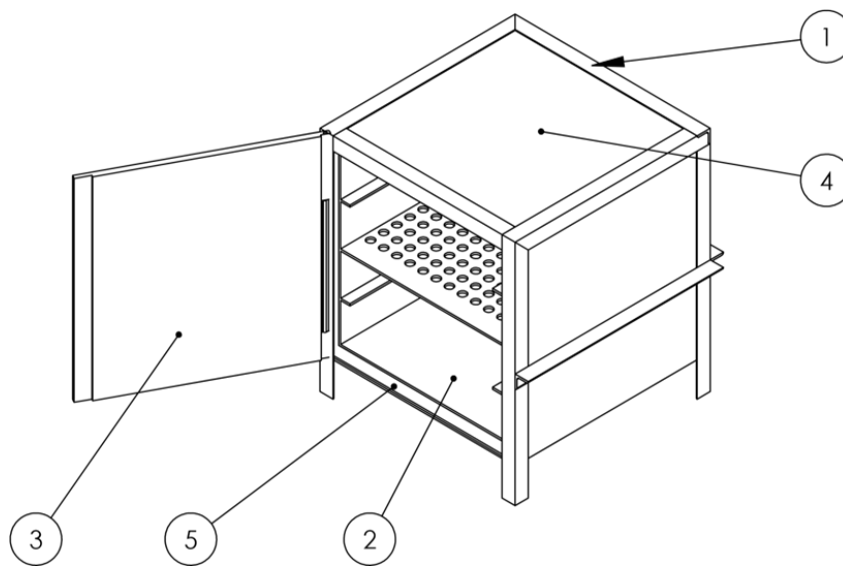


Fig. 3. Isometric View Of The Oven

Where:

1 is the Standing frame

2 is the Inner sheet metal (stainless steel)

3 is the Door (mild steel)

4 is the Outer sheet metal (mild sheet)

5 is the Lagging material (fiber glass)

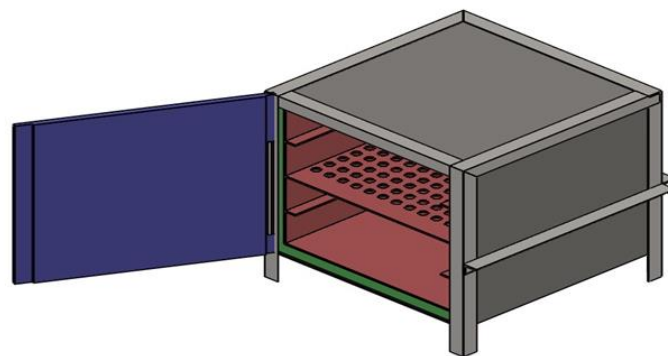


Fig. 4. Design Drawing (Pictorial) Of The Baking Oven

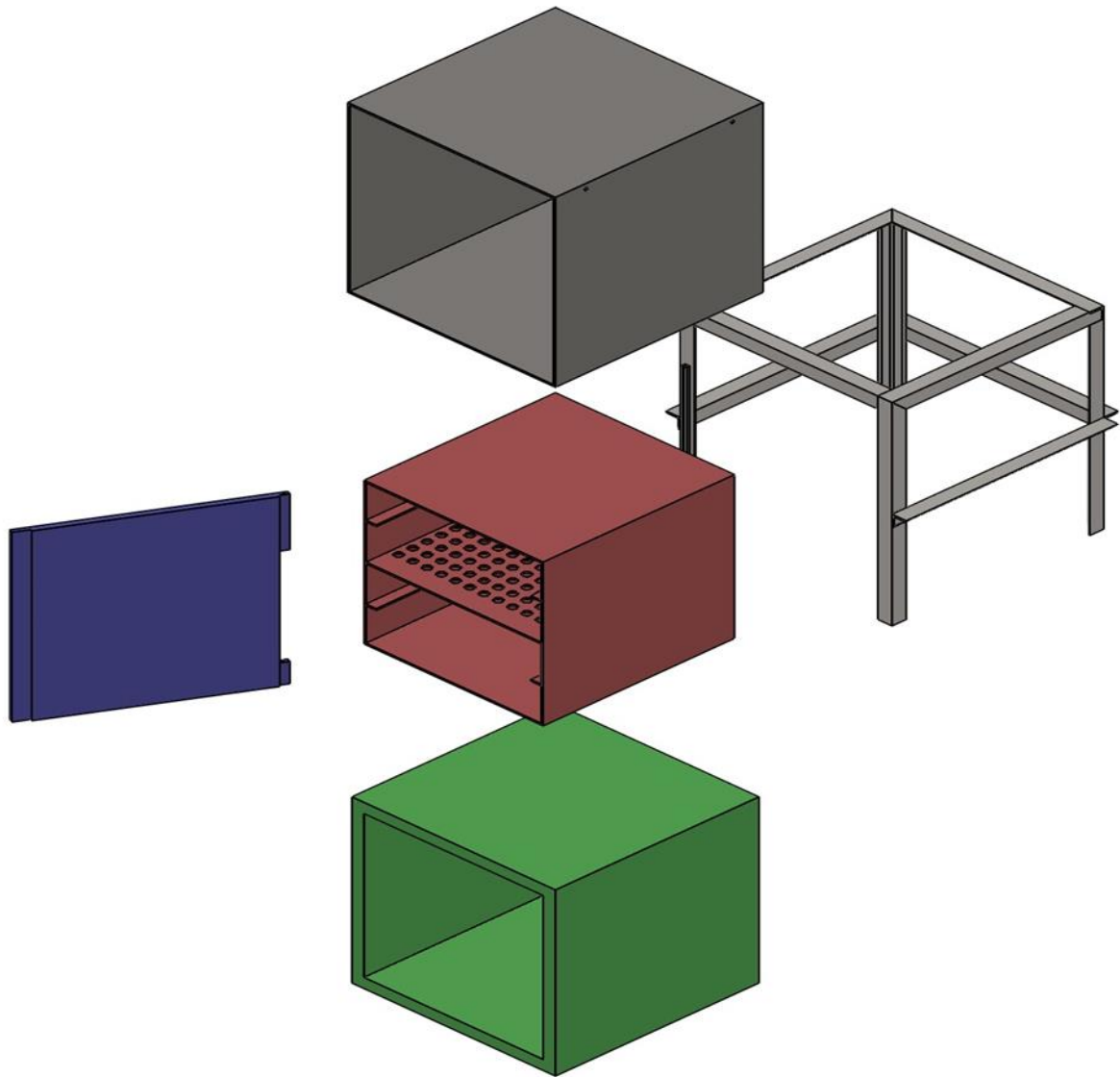


Fig. 5. Exploded view of the oven

3. Results and Discussions

3.1 Fabrication of a prototype baking oven

The stainless steel and mild steel were coupled by means of welding operation. The stainless steel was insulated by fiberglass with thickness of 0.006m and then coupled with mild steel in order to minimize the heat loss. During fabrication, the dimensions were carefully followed to avoid materials wastage and the joints parts were welded to prevent injuries during body contact. Using electrical recharged power source (i.e. inverter), the power rating were taken in order to determine the time taken for baking. Figure 6 shows the schematic diagram of the baking process of bread of same sizes; other food items were also considered to determine its effectiveness.



Fig. 6. Schematic diagram of the baking process of foods.

3.2 Performance evaluation of the baking oven

Performance of a prototype baking oven was evaluated using electrical recharged power as source of energy by considering the efficiency of the oven which can be determined as follows:

- i. Ratio of the design baking time to the actual baking time.
- ii. Capacity of the oven.
- iii. Moisture content of the food items which can be calculated as:

$$\text{Moisture content} = \frac{A-B}{A} \times 100 \text{ (on wet basis)}$$

$$\text{Moisture content} = \frac{A-B}{B} \times 100 \text{ (on dry basis)}$$

Where:

A is the weight of the wet food substance

B is the weight of the dry food substance

The electrical powered baking oven was tested to determine its efficiency and effectiveness using bread, plantain and fish. The experiment was carried out for each of them. The measurement was taken with a constant temperature and time taken at different turning level of the timer and the temperature control switch that is graduated at 160°C, 180°C and 200°C for bread, plantain and fish respectively.

3.2.1 Baking of Bread

Breads of the same sizes were baked in the prototype oven at a constant temperature of 160°C but with varying time taken to determine the appropriate time to get the best texture of the bread intended. The baking oven was powered by the inverter throughout the baking process. Table 2 summarized the sizes of the baked bread with different time interval.

Table 2 – Sizes Of Bread Baked With Different Time Interval

Baking operation	Mass of pan (kg)	Size of bread (before baking) Kg (A)	Time taken for baking (mins)	Temperature range (°C)	Size of bread (after baking) Kg (B)	Moisture content $\frac{A - B}{A}$
Pan 1	0.15	0.870	18	160	0.860	0.011
Pan 2	0.15	0.870	21	160	0.850	0.022
Pan 3	0.15	0.870	24	160	0.840	0.034
Pan 4	0.15	0.870	27	160	0.830	0.046
Pan 5	0.15	0.870	30	160	0.820	0.057
Pan 6	0.15	0.870	33	160	0.810	0.057

Figure 7 shows the relationship between the size of bread (after baking) and the moisture content in wet basis.

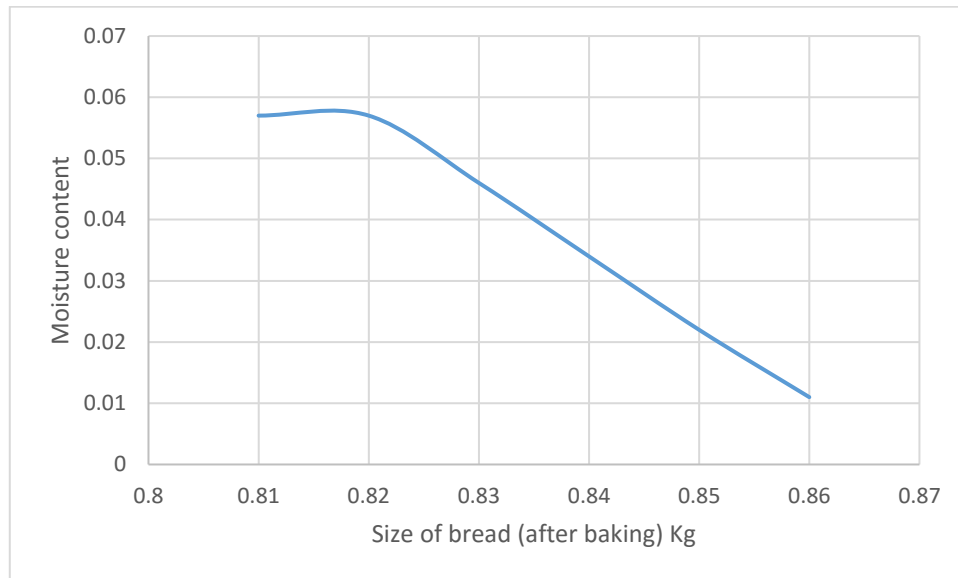


Fig. 7. Graphical Interpretation Of The Moisture Content Of Bread After Baking.

It can be deduced that, with the same size of bread before baking at constant temperature, the size of bread after baking increases with corresponding decrease in moisture content as the time taken for baking each of them reduces. The best baking time of the same size of bread was 33 minutes as it gives better texture, color and taste, and there was no drop in moisture content but there was drop in weight after baking. This shows that any further time taken for baking the same size of bread beyond 33 minutes would result to burning. In order to avoid burning or half-baked of the bread, time taken for baking the smaller, medium or bigger size according to the baking pan of the bread can be predicted with the same temperature range. Figure 8 showed the size of the baked bread of 0.82 Kg at 30 minutes with moisture content of 0.057 after undergone heating process.



Fig. 8. Baked Bread

The efficiency of a prototype oven is the time taken to bake a pan of bread to a preferred taste, texture, with no moisture content giving a brownish color on the surface of the bread. The experiment showed approximately 33 minutes to bake a pan of bread but the actual baking time was assumed to be 35 minutes.

3.2.2 Determination of the capacity of the baking oven

According to Ilesanmi and Akinnuli 2019, “the capacity of the baking oven is expressed as the number of loaves of bread the oven can process (or bake) per batch”. This is adopted in this study to determine the capacity of the fabricated prototype baking oven. Therefore:

$$\text{Size of tray} = l_{tr} \times b_{tr} \quad (11)$$

$$\text{Size of the baking pan} = l_{bp} \times b_{bp} \quad (12)$$

Where:

l_{tr} , the length of tray for baking

b_{tr} , the breadth of tray for baking

l_{bp} , the length of the baking pan

b_{bp} is the breadth of the baking pan

$$\text{Capacity of oven} = \frac{\text{size of tray}}{\text{size of the baking pan}} \quad (13)$$

$$\text{Baking efficiency} = \frac{\text{design baking time}}{\text{actual baking time}} \times 100\% \quad (14)$$

Therefore,

Desired baking time of bread = 33 minutes

Actual baking time of bread = 35 minutes

From equation 13,

$$\text{Capacity of the oven} = \frac{\text{size of tray}}{\text{size of the baking pan}} = \frac{l_{tr} \times b_{tr}}{l_{bp} \times b_{bp}} = \frac{18 \times 16}{12.5 \times 3.84} = 6 \text{ loaves of bread per}$$

tray (batch).

$$\text{Baking efficiency, } \eta = \frac{33}{35} \times 100 = 94.29\%$$

This implies that the developed prototype oven can bake six (6) loaves per tray (batch). However, the capacity of the baking oven for processing other food substances such as plantain and fish etc. varies due to different sizes of the food substance. Moisture content of the baked bread in wet basis is:

$$\text{Moisture content} = \frac{0.87 - 0.81}{0.87} \times 100 = 6.89\%$$

3.2.3 Roasting of Plantain

Plantain of different sizes were roasted at constant temperature of 180°C. The size of plantain before peeling, and after peeling but before roasting was taken. With constant temperature of 180°C, time taken for roasting the plantain was assumed to give the best look, taste and reduce the moisture content. Table 3 gives the summary of different sizes of plantain after roasting.

Table 3 – Summary of the size of plantain with constant temperature and varying time

Roasting operation (plantain)	Size of plantain (before peeling) Kg	Size of plantain (after peeling but before roasting) Kg	Time taken for roasting (s) mins	Temperature range (°c)	Size of plantain (after roasting) Kg	Moisture content $\frac{A - B}{B}$
Plantain 1	0.14	0.065	20	180	0.04	0.625
Plantain 2	0.15	0.10	25	180	0.06	0.667
Plantain 3	0.15	0.10	25	180	0.06	0.667
Plantain 4	0.16	0.11	28	180	0.07	0.571
Plantain 5	0.18	0.12	30	180	0.08	0.5

Figure 9 Shows The Relationship Between The Size Of Plantain (After Roasting) And The Moisture Content In Dry Basis.

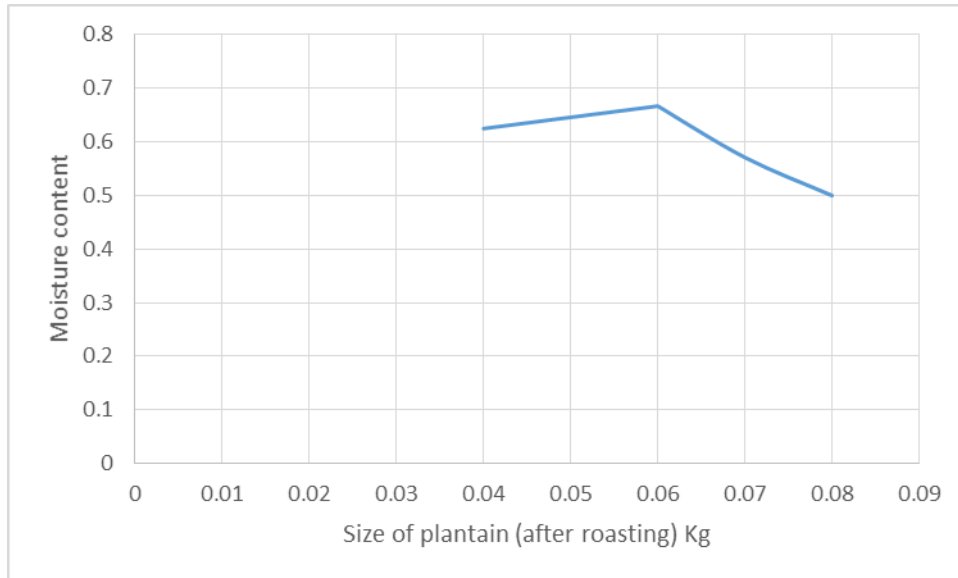


Fig. 9. Graphical Interpretation Of The Moisture Content Of Plantain After Roasting.

The size of plantain (after roasting) increases with corresponding increase in moisture content. However, the size of plantain 2 and 3 (after roasting) were uniform at 0.06 Kg since the size of plantain (after peeling but before roasting) were the same, thus leads to similar moisture content of 0.667. The moisture content of plantain 4 and 5 decreases with 0.571 and 0.5 respectively due to increase in time taken for roasting. Having considered the temperature range and the size of the plantain, it can be established that the best roasting time was 30 minutes except the size is greater or less than 0.12 Kg (after peeling but before roasting). Figure 10 shows the size of the roasted plantain after undergone heating process.



Fig. 10. Roasted Plantain

The performance test showed that the specific time for roasting the plantain cannot be determined simply because different sizes of the plantain were considered. Therefore, roasting of plantain to give the best look, color and to reduce the moisture content totally depends on the size (weight) of the plantain. However, since plantain 1 gave the largest size (i.e. before and after peeling) and the longest time taken for roasting, performance of the oven can be evaluated but the actual roasting time was assumed to be 40 minutes.

Therefore,

Actual baking time of bread = 40 minutes

Design baking time of bread = 30 minutes

From equation 14,

$$\text{Baking efficiency, } \eta = \frac{30}{40} \times 100 = 75\%$$

$$\text{Moisture content, } \frac{0.12-0.08}{0.08} \times 100 = 50\%$$

4.2.4 Roasting of Fish

In this study, fish was classified into three different sizes (i.e. small, medium and large) and roasted at constant temperature of 200°C but varying time interval. The size of fish before and after roasting were taken. Table 4 summarized the roasting process of the fish.

Table 4 – Summary Of The Roasting Process Of Fish

Roasting operation (fish)	Size of fish (before roasting) Kg	Time taken for roasting (mins)	Temperature range (°C)	Size of fish (after roasting) Kg	Moisture content $\frac{A - B}{B}$
Large	0.12	30	200	0.07	0.714
Medium	0.10	25	200	0.05	1.000
Small	0.08	20	200	0.04	1.000

Considering the sizes of fish such as large, medium and small, this implies that the bigger the fish the longer the time it takes to roast or to remove the moisture content at constant temperature of 200°C. The temperature range was considered to be constant and varying time to roast the fish of different sizes to avoid burning or half baked. Figure 11 showed the size of the roasted fish after undergone heating process. Actual roasting time was assumed to be 45 minutes.



Fig. 11. Roasted Fish

Therefore,

Actual baking time of bread = 45 minutes

Design baking time of bread = 30 minutes

From equation 14,

$$\text{Baking efficiency, } \eta = \frac{30}{45} \times 100 = 66.7\%$$

$$\text{Moisture content} = \frac{0.12-0.07}{0.07} \times 100 = 71.4\%$$

5. Conclusion

This study was able to fabricate a prototype baking oven following the design concept. The materials used for fabrication were locally sourced and served as good substitute for baking, roasting and boiling. Performance of the fabricated baking oven was evaluated using the electrical recharged power (or inverter) by considering the baking efficiency, capacity of the oven and moisture content of the bread, plantain and fish. These samples were chosen randomly since they were easily accessible and cheap to buy. From the result, baking oven has the highest percentage of baking efficiency when using bread but bread has the lowest percentage of moisture content compare to other samples used. Also, from Table 2, the study recorded the best time for baking the bread as 30 minutes as it gives the best color, texture and taste. From Table 3 and 4, plantain 1 and fish 1 were used to determine their moisture content and the baking efficiency of the oven due to their largest size among other sizes of plantain and fish considered. Since different sizes of plantain and fish were considered, it was impossible to ascertain their best cooking time unlike

bread. However, little visibility studies were made to know the average baking time of bread when the oven is powered by direct power supply, gas or charcoal, moreover this study explored more knowledge on the literature review to ascertain the average baking time of bread depending on the size of bread and it was discovered that Ilesanmi and Akinnuli (2019), baked 0.3 Kg and 0.4 Kg of bread for 30 and 37 minutes respectively at 170 – 180°C. Therefore, the model developed is efficient, faster and baked effectively as the oven was preheated to certain temperature at the same time as the dough was being prepared for baking. The developed oven is suitable for domestic and small scale enterprise as it can bake six loaves of bread per tray (batch).

References

- Abraham, J.P., & Sparrow, E.M. (2004). A Simple Model and Validating Experiments for Predicting the Heat Transfer to a Load Situated in an Electrically Heated Oven. *Journal of Food Engineering*, 62: 409 – 415.
- Ademe, Z., & Hameer, S. (2018). Design, construction and performance evaluation of aBox type solar cooker with a glazing wiper mechanism. *AIMS Energy*, 6(1), 146-169.
- Adeyinka, A., Olusegun, O., Taiye, A., Mojeed, L., & Heritage, O. (2018). Development and performance evaluation of dual powered baking oven. *Advances in Research*, 1-15.
- Adegbola, A.A., Adogbeji, O.V., Abiodun, O.I. & Olaoluwa S. (2012). Design, construction and performance evaluation of low cost electric baking oven. *Innovative Systems Design and Engineering*, 3(11) p. 38-49.
- Akinfaloye, O.A. (2018). Design, Fabrication and Performance Evaluation of a Domestic Electric Oven. *Journal of Scientific and Engineering Research*, 5(4):105-109.
- Beltran, R., Velazquez, N., Espericueta, A. C., Saucedo, D., & Perez, G. (2012). Mathematical model for the study and design of a solar dish collector with cavity receiver for its application in Stirling engines. *Journal of mechanical science and technology*, 26(10), 3311-3321.
- Bergman, T. L., Incropera, F. P., DeWitt, D. P., & Lavine, A. S. (2011). *Fundamentals of heat and mass transfer*. John Wiley & Sons.
- Carvalho, M., & Martins, N. (1993). Mathematical modelling of heat and mass transfer in a forced convection baking oven. *AIChE Symposium Series – Heat Transfer*, 88(288):205–211.
- Chukwunke, J.L., Nwuzor, I.C., Anisiji, E.O., & Digitemie, I.E. (2018). Design and Fabrication of a Dual Powered Baking Oven. *Advances in Research*, 16(4), 1-8.
- El-Adly, I. F., Bhansawi, A., Ali, S. A., & Khater, E. S. G. (2016). Bread Baking process energy requirements as affected by oven belt speed and type of breads. *Misr Journal of Agricultural Engineering*, 33(4), 1497-1514.
- Genitha, I., Lakshmana, G.B.T., & John, D.R. (2014). Design, Fabrication and performance evaluation of domestic gas oven. *IOSR Journal of Engineering (IOSRJEN)*, 4(5): 35-38.
- Ilesanmi, O.E., & Akinnuli, B.O. (2019). Design, Fabrication and Performance Evaluation of a Domestic Gas Oven. *Journal of Engineering Research and Reports*. 5(1): 1-10, 2019; Article no.JERR.48766.
- Hossain, M. A., & Bala, B. K. (2007). Drying of hot chilli using solar tunnel drier. *Solar energy*, 81(1), 85-92.
- Jekayinfa, S.O. (2007). Ergonomic Evaluation and Energy Requirements of Bread baking Operations in South Western Nigeria. *Nutrition & Food Science*.
- Khater, E.G., & Bahnasawy, A.H. (2014). Heat and Mass Balance for Baking Process. *J Bioprocess Biotech*, 4(7): 1. doi: 10.4172/2155-9821.1000190.
- Kosemani, B. S., Ilori, A. T., & Atere, A. O. (2021). Modification and Optimization of a Baking Oven for Small Scale Bread Production. *Agricultural Sciences*, 12(6), 630-644.
- Mishra, A., Powar, S., & Dhar, A. (2019). Solar Thermal Powered Bakery Oven. In: Tyagi H., Agarwal A., Chakraborty, P., Powar, S. (eds). *Advances in Solar Energy Research. Energy, Environment, and Sustainability*. Springer, Singapore. https://doi.org/10.1007/978-981-13-3302-6_19.
- Mohammad, A., & Badrul, H.K. (2012). Design and Evaluation of Solar Inverter for Different Power Factor Loads. *Energy and Power Engineering*, 4, 324-329. <http://dx.doi.org/10.4236/epe.2012.45042>.

- Morakinyo, A.T., Omidiji, B., Owolabi, H.A. (2017). Development and Optimization of Operational Parameters of a Gas-Fired Baking Oven. *Leonardo Journal of Sciences*, 31, 45-64.
- Ogbeide, O.O., Odibi, T.I., & Odude, A.O. (2017). Development of a Low Cost Dual Electric/Solar Oven from Locally Available Materials. *Nigerian Research Journal of Engineering and Environmental sciences*. 2(1): 100-107.
- Olugbade, T.O., & Ojo, O.T. (2018). Development and Performance Evaluation of an Improved Electric Baking Oven. *Leonardo Electronic Journal of Practices and Technologies*, 33 : 189-206.
- Özilgen, M., & Heil, J. R. (1994). Mathematical modeling of transient heat and mass transport in a baking biscuit. *Journal of food processing and preservation*, 18(2), 133-148.
- Ramirez-Laboreo, E., Sagues, C., & Llorente, S. (2016). Dynamic heat and mass transfer model of an electric oven for energy analysis. *Applied Thermal Engineering*, 93, 683-691..
- Sanusi, M. S., Sunmonu, M. O., Adepoju, A. L., Abodunrin, T. O., & Ajibade, H. A. (2020). Development and Evaluation of the Operational Parameters of a Rotary Oven. *Nigerian Journal of Technological Development*, 17(4), 239-249.
- Solihin, Z.H., & Wisnoe, W. (2014). An experimental metal material as heat absorbent material in the solar oven. *International Journal of Latest Research in Science and Technology*, 3(4) : 224-227.
- Sotome, I., & Isobe, S. (2011). Food processing and cooking with new heating system combining superheated steam and hot water spray. *Japan Agricultural Research Quarterly: JARQ*, 45(1), 69-76.
- Tong, C. H., & Lund, D. B. (1990). Effective moisture diffusivity in porous materials as a function of temperature and moisture content. *Biotechnology Progress*, 6(1), 67-75.
- Turabi, E., Sumnu, G., & Sahin, S. (2008). Optimization of baking of rice cakes in infrared–microwave combination oven by response surface methodology. *Food and Bioprocess Technology*, 1(1), 64-73.
- Tong, C. H., & Lund, D. B. (1990). Effective moisture diffusivity in porous materials as a function of temperature and moisture content. *Biotechnology Progress*, 6(1), 67-75.
- Yahuza, I., Rufai, Y., & Tanimu, L. (2016). Design, construction and testing of parabolic solar oven. *J Appl Mech Eng*, 5(4), 212-216.