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Design, Fabrication and Performance Evaluation of a Domestic Gas Oven

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Authors' contributions

This work was carried out in collaboration between both authors. Authors OEI and BOA designed the study, performed the statistical analysis, wrote the protocol and first draft of the manuscript. Authors OEI and BOA managed the analyses of the study. Author OEI managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

This study reports on the design, construction and performance evaluation of a domestic gas oven. The oven was designed and was fabricated with an outer dimension of 860 mm length × 660 mm width × 1150 mm height made up of mild steel and the inner dimension of 759 mm length × 559 mm width × 835 mm height made up of mild steel and fiber glass of 40 mm thickness was used as an insulator to reduce cost to a minimal level. The aim of this research work is to improve on the already existing gas baking oven through the incorporation of a vent/chimney for removal of humid air and roller (wheels) for easy movement. Cooking gas is supplied to the burner located in the lower chamber of the oven via a pipe connection to the gas cylinder. Perforations allow for heat dissipation within the lower chamber. Capacity of the baking oven is 12 loaves of bread of 0.5 kg per bread per tray (batch). Using a temperature regulator and from practical determination, the maximum temperature of 210°C was recorded. The performance test on the oven showed that the efficiency of the oven is of 90.7 percent. The oven can be adapted for both domestic and industrial

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purposes and have been found very useful in bakery industries. The oven was constructed with locally available materials. Estimated production cost is N56, 470 which is $156.86 at the exchange rate of 360 Naira to a US Dollar as at the time of this design. This can be seen in the Bill of Engineering Measurement and Evaluation (BEME) shown in the report.

Keywords: Domestic gas oven; design; fabrication; material selection; production cost estimates and performance evaluation; bread; temperature.

1. INTRODUCTION

Baking is the oldest and most popular food processing techniques that uses the prolonged dry heat by convection rather that the thermal radiation normally in an oven, but also in ashes or on hot stones. It is a complex simultaneous heat and mass transfer process commonly applied in food industries [1].

A baking oven is the most widely used appliance in food service industry. An oven can be simply described as a fully enclosed thermally insulated chamber used for the heating, baking or drying of a substance [2]. In a baking oven, the hot air flows over the baking material either by natural convection or forced convection by a fan, by the convection heat transfer from the air, by the radiation heat transfer from the oven heating surfaces, and by the conduction heat transfer across contact area between product and metal surface. The moisture in the food material simultaneously diffuses towards the surfaces, then, it transfers from the surface by convection, and the product loses moisture with continuous movement of the oven ambient air. These are the simultaneous momentum, heat and moisture transfer mechanisms within a baking product [3,4] and between the product and its environment [5], which theoretically are well known. Commercially, ovens are available in various configurations like electric ovens, micro oven and wood oven etc.

Electric ovens are the direct fired ovens, which effectively distribute heat while being powered by electricity, although this can often result in a higher heating cost for the consumer.

Gas oven; one of the first recorded uses of a gas stove and oven referenced a dinner party in 1802 hosted by Zachaus Winzler, where all the food was prepared either on a gas stove or in its oven compartment. In 1834, British inventor James Sharp began to commercially produce gas ovens after installing one in his own house [6,7].

Convection is the transfer of energy from one place to another by the motion of a mass of materials between the two points. In a natural convection, the motion of the fluid is entirely as a result of differences in density resulting from temperature differences [7,8]. Study of baking oven is important because it could lead to a more efficient process of baking favorable to energy efficiency and better product quality [9,10]. The baking process usually requires significant energy consumption as relatively high temperature is applied in order to remove moisture in bakery products and create desired texture.

Analysis and optimization of baking process and equipment have been conducted for minimizing energy consumption [11].

In developing countries like Nigeria, the electric oven users are facing a problem due to the erratic power cuts in the middle of the operations, these causes the loss of the quality of the end product and the loss of the capital and the electric oven consumes more energy. The use of gas as the energy source for baking oven is commercially necessary in most of the regions because the electricity by comparison is prohibitively expensive. Therefore, the need arises more than ever before to develop a portable gas baking oven, easy to transfer heating and drying system of acceptable standard that will meet certain essential requirements such as portability and cost effectiveness. This paper reports the design, the production, the cost estimate and the performance evaluation of the portable multipurpose gas baking oven.

2. METHODOLOGY

The method used here involves the engineering drawing of the oven, the principle of operation, the design calculation, the material selection and the cost estimate for the developed oven.

2.1 Design Concept (Engineering Drawing of the Oven)

The gas oven was fabricated with the use of indigenous material according to the conceptual design. The oven consists of a housing unit (frame), a thermometer, a gas regulator, a tray, an oven door and an oven firing door, a perforated plate, a heating gas burner, a chimney or vent, rollers. The housing unit which is the frame represents the entire outlook of the baking oven. The housing unit of the gas oven was made up of three layers, the body (outer layer) is made of well coated mild steel of thickness 1mm with the dimension 860×660×1150 (Length × Width × Height respectively) in mm, inner layer is made of mild steel of thickness 1mm with the dimension from the end of the perforated sheet 759×559×835 (Length × width × height respectively) in mm. Fiber glass of thickness 40 mm is the lagging material (insulator) which is stuffed in-between the outer layer and inner layer and which acts as a thermal insulating material to prevent loss of heat (insulation), from the inner baking chamber to the outside and also ensure even baking of the product in the baking chamber, and this fiber glass makes up the middle layer of the gas oven. Fiber glass is known to have light weight, high strength and high thermal shock resistance characteristics.

The oven has two door chambers. The upper door chamber of the gas oven made up of mild steel and fiber glass of thickness 40 mm was placed in between the steel plate to avoid the loss of heat through the door and in front of the door was provided with a heat treated (resistive) glass which can withstand very high temperatures to monitor the baking product inside the oven without opening the door. And the lower door chamber also known as oven firing door houses the burner compartment. Inside the oven firing door is an oven burner stand on which the burner is welded to, the stand is kept at a height of 190 mm from the ground level so that an opening is created under the body in the same direction with the burner to enable the entrance of required amount of air (oxygen) for easy and neat burning/combustion of the gas flame. The opening of about 200 mm by 200 mm length by width respectively is created through which the burner head is connected to the gas pipeline / hose i.e. gas inlet. It is regulated with gas knobs.

Table 1. Component parts of the oven

Item no.	Component	Quantity
1	Tray	3
2	Gas valve or regulator	1
3	Handle	2
4	Frame	1
5	Burner	1
6	Perforated plate	1
7	Oven door	1
8	Oven firing door	1
9	Chimney or vent	1
10	Caster wheel or rollers	4
11	Thermometer	1

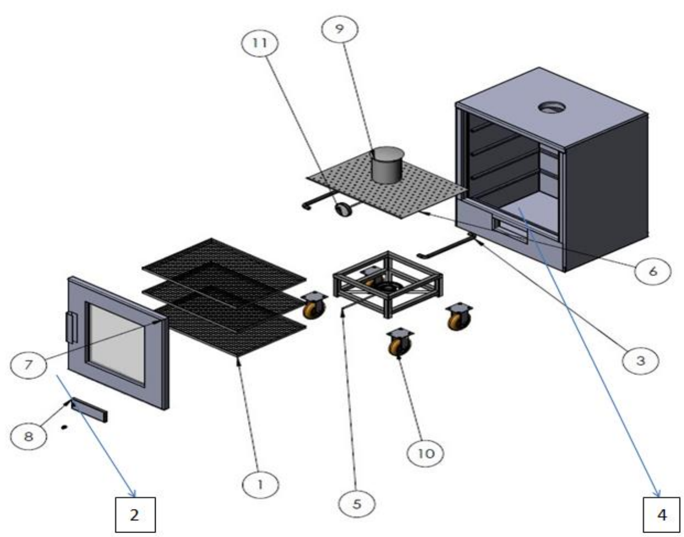

Fig. 1. Exploded view of the gas oven

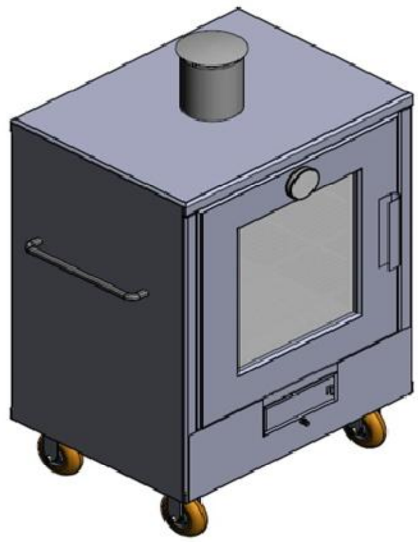

Fig. 2. Assembled view of the oven

The oven burner is an O shaped pipe drilled/perforated with small opening at intervals. It is mounted inside the oven lower chamber and tightened with nuts and bolts. Perforations are created just below the burner to allow for heat dissipation. Heat energy is caused to escape through holes created just below the burner and circulates round the oven chamber. The base of the inner baking chamber was provided with a deflector plate of the thickness of 1 mm with dimension of 800×580 (length × width) mm placed at a height of 280 mm from the base of the oven to avoid the direct flame coming from the burner to the baking chamber and to provide even distribution of the heat throughout the baking chamber.

The thermometer was attached to a drilled surface on top of the oven. The thermometer sensor was placed in the center portion of the baking chamber to ensure that the thermometer should detect the temperature of the both the lower and the upper layer of the baking oven. The oven is also provided with a vent/chimney at the top of the baking oven connected from the inner baking chamber for the continuous removal of hot and humid air from the inner baking chamber. The baking oven was provided with the handles in both the sides for mobility, easy carriage and to prevent the rollers (wheels) from wearing out due to bad terrain. The oven supports have rollers for easy movement and to absorb shock as well as sustain the weight of the oven.

Three trays were provided in the baking chamber of the oven, each having the dimensions of 770×570 (length × width respectively) in mm, galvanized wire mesh was welded to provide base or support for the baking trays and the oven works by natural convection; it helps for the movement of hot air from the lower tray to the upper tray of the oven. The distance between the top of the oven and the upper tray was kept at 230 mm, also the distance from the upper tray to the middle tray was also kept at 230 mm and also the same distance (230 mm) was kept between the middle tray and lower tray, while the distance between the lower tray and the base of the oven was kept at a height of 410 mm.

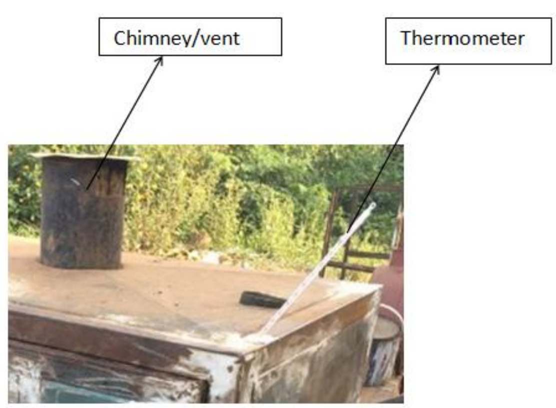

Fig. 3. Fabricated gas oven

2.2 Principle of Operation

The major operational principle of the fabricated gas oven is the process of heat transfer. Heat transfer tends to occur whenever there is a temperature difference, and the ways in which heat may be transferred in the gas oven that is convection.

Convection is the transfer of energy from one place to another by the motion of a mass of fluids between the two points. Convection occurs when particles with a lot of heat energy in a liquid or gas move and take the place of particles with less heat energy. Heat energy is transferred from hot places to cooler places by convection. Naturally, convection occurs when a solid surface is in contact with a fluid of different temperature from a surface. Density differences provide the force required to move the fluid (moisture) in the food. In the oven, the fluid involved is the enclosed air and the burner surface, which provides the solid surface, while the oven walls serve as the solid surfaces.

Usually this equipment has a gas inlet through which it is connected to a medium size gas cylinder via a regulator with low pressure flexible hose. The regulator of gas flow rate into the pipeline from the gas cylinder is turned open.

With gas in the pipeline, the gas burner is activated by turning on the temperature knob after being turned on from the gas cylinder. This creates a gap through which the gas rushes to the nozzle. The gas then passes through the nozzle after which the pressure drops with increased velocity. The low pressure high velocity gas then flows into the burner gas compartment together with the air (oxygen) from the opening created below the oven stand into a channel where it spreads out through the holes around the burner to glow in flame when lighted up by a lighter. The intensity of the heat generated from the flames depends on the amount of gas that is being burnt. The gas flow rate is altered or controlled by the continuous adjustment of the valve (gas knob).

2.3 Design Analysis of the Gas Oven

In the construction of this baking oven equipment, emphasis was laid on its functional aspects as well as on the structural appearance of the formal design and construction work.

The functional aspects of the construction include the capability of the equipment to perform reliably most in the combustion of the gas and quantity of heat produced. Such a combustion is required to produce smokeless bluish flame which is effective, much better and non-luminous. The flame is obtained by creating an air space or air hole to allow a limit amount of air to mix with the burning gas.

The capacity of the gas baking oven is expressed in terms of the number of loaves of bread. The oven can process per batch.

Average mass of a loaf of bread = 0.5kg (1)

Size of tray = $l_t \times b_t$ (2)

Size of loaf of bread considered = $l_b \times b_b$ (3)

where: l_t is the length of tray; b_t is the breadth of tray; l_b is the length of bread; b_b is the breadth of bread

Size of tray = 770 mm (length) x 570 mm (breadth) = 438,900 mm^2 (4)

Size of loaf of bread = 280 mm (length) x 130 mm (breadth) = 36,400 mm^2 (5)

Capacity of Oven = Size of tray / Size of bread = 438,900 / 36,400 = 12 Loaves of bread per tray (batch). (6)

However the capacity of the oven might vary for other food items such as fish, meat, plantain, etc.

2.4 Energy Requirement of the Gas Oven

The oven uses methane as cooking gas. Methane is a chemical compound with the chemical formula CH_4 (one atom of carbon and four atoms of hydrogen). It is the simplest alkane, and it is the main constituent of natural gas. Compared to other hydrocarbon fuels, methane produces less carbon dioxide for each unit of heat released.

The combustion reaction of methane is given by:

$$CH_{4(g)} + 2(O_{2(g)} + 3.76N_{2(g)}) \longrightarrow CO_{2(g)} + 2H_2O_{(g)} + 7.5N_{2(g)} + Heat\ (KJ) \quad (7)$$

In which heat of formation of water vapor is:

The constituent elements are Hydrogen and Oxygen. The chemical equation for the reaction is shown below:

$$H_{2(g)} + \tfrac{1}{2}O_{2(g)} \longrightarrow H_2O_{(g)} ------241.8KJ \quad (8)$$

The enthalpy of formation of water vapor ($\Delta H°_f$) is -241.8KJ/mol, which is an exothermic reaction. This value is negative because heat is released to the environment [12].

Heat of formation of Carbon IV oxide;

The constituent elements are Oxygen and Carbon (graphite) which is a solid. The chemical equation for the reaction is shown below:

$$O_{2(g)} + C_{(solid)} \longrightarrow CO_{2(g)} -------393.5KJ \quad (9)$$

The enthalpy of formation of Carbon dioxide at 298.15k ($\Delta H°_f$) is -393.5KJ/mol

Also, heat of formation of methane (CH_4) at standard conditions (298.15k, 1 atm) is -74.8KJ.

From equation (7), we can calculate the total heat of combustion for methane. Thus, Total Heat involved in the combustion reaction of methane is:

[Heat of formation of $CO_{2(g)}$ + 2 × Heat of formation of $H_2O_{(g)}$+ 7.5 × Heat of formation of $N_{2(g)}$] minus [Heat of formation of $CH_{4(g)}$ + 2 × Heat of formation of $O_{2(g)}$+ 7.5 × Heat of formation of $N_{2(g)}$]

Total heat of combustion = [-393.5KJ + 2 × (-241.8KJ) + 7.5 × (0KJ)] minus [-74.8KJ + 2 × (0KJ) + 7.5 × (0KJ)]

Total heat of combustion = (-877.1 + 74.8) KJ mol^{-1} (10)

Total heat of combustion = **-802.3 KJ mol^{-1}** (11)

Thus, total heat involved in the combustion reaction of methane in the oven is **-802.3 kJ mol^{-1}** (note that the negative sign indicates that the reaction emits (gives off) heat to the environment as expected for a combustion reaction, i.e. exothermic reaction) [13].

2.5 Material Selection

In selecting the materials for the fabrication of the gas baking oven, the following points were put into consideration; the ability of the material to meet the functional requirement as having reasonable tool life and durability; the ability of the material to be rolled, folded without breakage, welded and drilled. Also, the material must possess the ability to withstand considerable high temperature as well as corrosive attack and rust. Other factors include the cost of the material and its availability. The affordable machines and tools were also put into consideration.

Table 2. Components, selection of materials and reasons for their selection

S/NO	Component	Material	Reasons
1	Body	Mild steel	Most available and cheap. Tough and ductile
2	Cover plate	Mild steel	As above
3	Body frame	Mild steel square pipe.	Most available and cheap.
4	Oven burner	Mild steel	Availability. High corrosion and heat resistance
5	Lagging material (insulator)	Fiberglass	High thermal endurance
6	Handle	Mild steel	Most available and cheap.
7	Gas pipe/channel		Easy and fast flow of gas.
8	Thermometer/sensor	Glass	Availability
9	Gas knob or valve	Brass	Good Strength.
10	Deflector (perforated) plate	Mild steel	Most available and cheap.

2.6 Bill of Engineering Measurement and Evaluation (BEME)

This bill constitute: material cost, labour cost, design cost, machine cost, cost of study's report.

Table 3. Material cost

S/N	Quantity	Material description	Unit cost	Total cost
1	3	Mild steel sheet metal (1mm)	₦2, 000.00	₦ 6,000.00
2	1	Roll of fibre glass	₦ 3, 500.00	₦ 3, 500.00
3	1	Temperature sensor / thermometer	₦ 2, 500.00	₦ 2, 500
4	1	Gas burner	₦2, 800.00	₦ 2, 800
5	4	Length 40 x 40 square pipe	₦ 450.00	₦ 1800.00
6	2	Angle iron	₦ 875.00	₦ 1750.00
7	4	Lock bolt (10mm)	₦ 30.00	₦ 120.00
8	1	Handle	₦ 250.00	₦ 250.00
9	1	Filler	₦ 1500.00	₦ 1500.00
10	2	Sand paper	₦ 125.00	₦ 250.00
11	2	Yards gas hose	₦ 200.00	₦ 400.00
12	2	Clips	₦ 50.00	₦ 100.00
13	1	Gas regulator	₦ 1, 000.00	₦ 1, 000.00
14	1	Gas cylinder (3kg)	₦ 4, 500.00	₦ 4, 500
15		Gas	₦ 500.00	₦ 500.00
16	1 (240 pieces in a pack)	Electrode (gauge 12)	₦ 1, 500.00	₦ 1, 500.00
17	3	Drill bit (5m)	₦ 150.00	₦ 450.00
				₦28, 420.00

Total Engineering Evaluation of the Gas Baking Oven: Material Cost(₦ 28, 420.00), Labour Cost (₦ 9, 000.00), Design Cost(₦ 13, 000.00), Machine Cost (₦ 1, 050.00), Typing and binding (₦ 5, 000.00), **TOTAL COST = ₦ 56, 470.00 ($156.86) at exchange rate of ₦ 360 to a Dollar as at the time of this study.**

3. RESULTS AND DISCUSSION

The gas baking oven was put to test in order to determine its functionality and the effectiveness through baking some food items like bread, meat and fish. The oven works majorly by convection mode of heat transfer. The experiment was performed for each of them while measurement was taken with respect to the corresponding time taken for the baking of the particular food items. A timer was used to measure the time taken for each of the food items.

3.1 Baking of Bread

Breads of different sizes were baked in the gas oven at a temperature range of the 170-180°C. The time taken by the gas oven for the baking of the breads is shown in Table 4, from this it can be seen that, as the size of the bread increases the time required for the baking also increases. The quality parameters like the volume, weight, color and the texture of the bread was well developed and was acceptable. The bread also had a very good taste.

- Volume of Bread: A part volume of the loaf is determined for each measured distance from the reference point to the surface of the loaf, and the total volume of the loaf is then determined by adding up all the part volumes.
- Weight of Bread: The loaf weight for the bread samples was determined by weighing directly on a weighing balance.
- Color of Bread: Bread comes in dozens of shades ranging from pale cream to a brown so dark that it is almost black. Average consumer prefers golden or brownish color. This depends on ingredient color like the flour or residual sugar.
- Texture of Bread: When gently pressed with fingertips, a soft sensation was produced. The bread was silky and smooth. Density of the bread depended on the amount of flour.

Table 4. Baking time of the bread

Product	Size	Time taken for baking at 170-180°C
Bread dough (small size)	300 grams (0.3 kilograms)	30 minutes
Bread dough (medium size)	400 grams (0.4 kilograms)	37 minutes

3.2 Performance Test

The efficiency of an oven may be defined in terms of the time taken to bake a batch of dough to the desired taste, color, texture and moisture content. The performance test shows that it took approximately 43 minutes to bake a batch of dough to the desired quality.

Design baking time of dough = 39 minutes (12)

Actual baking time of dough = 43 minutes (13)

Baking efficiency, η = (39/43) x 100 = 90.7% (14)
From Equation 6, Capacity of Oven = Size of tray / Size of bread = 438,900 / 36,400 = 12 Loaves of bread per tray (batch).

The following results were obtained during the various experiments carried out. The following graphs were also obtained and can be seen below:

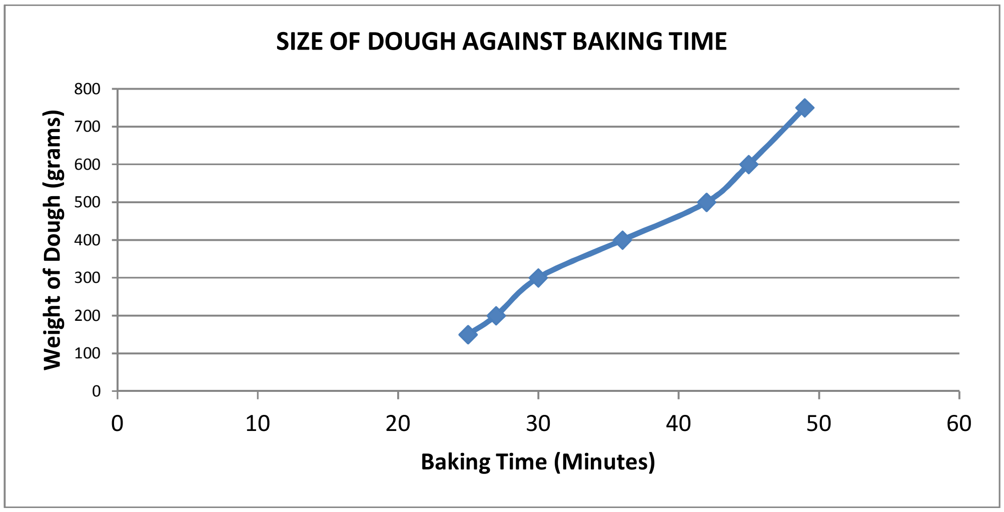

Fig. 4. Variation of size of dough against baking time

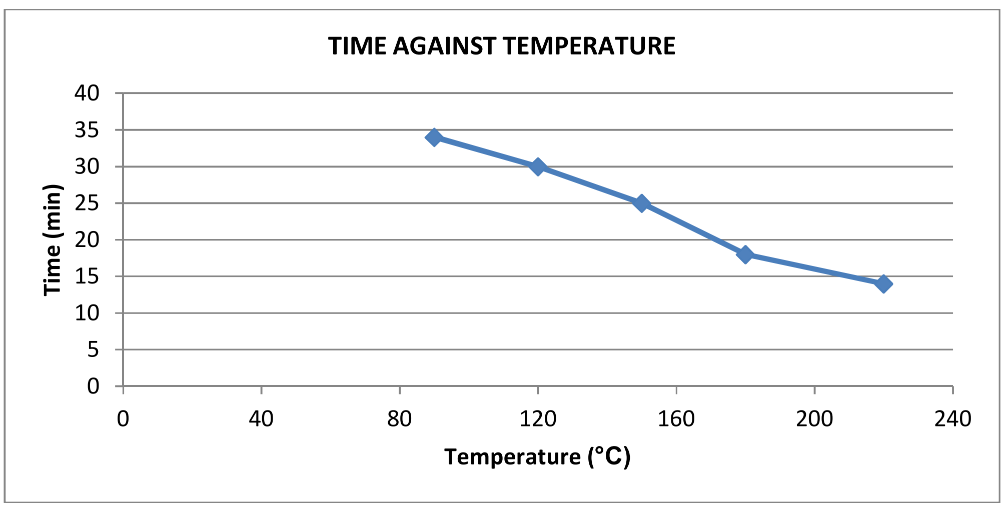

Fig. 5. Variation of time against temperature

Fig. 4 shows the variation of dough size against time which reveals a proportionate increase in the weight of dough followed by a respective increase in the time required to bake. Therefore as the size of dough increases, baking time also augments.

Fig. 5 shows the relationship between temperature and time which reveals that foods are baked within lesser time with an increase in temperature. It can be concluded that as the temperature rises, the time required to bake the food reduces. It can therefore be deduced that the designed project is faster and also baked efficiently when compared with an existing one.

4. CONCLUSION

The design and fabrication of the gas baking oven has been achieved successfully as well as the performance evaluation of the oven.

The materials were carefully selected to meet the needs for their respective parts. The gas baking oven design was made as simple as possible and it had to be operated manually by a spark lighter to provide flames from the burner to the oven chamber.

From this study it is evidently clear that the designed gas oven can be better used for the baking of cakes, cookies and all bakery products with good quality parameters like color, texture and taste with good volume for the fermented products and also with reduced preheating time of the gas oven. This in turn consumes much less energy and shortens the baking time, which reduces the overall working cost. This can be used for small entrepreneurs and can be popularized in areas where power cuts are more frequent and power is available only for limited hours. The design and construction of this project has been satisfactorily completed with the capability of providing high performance heat energy for effective baking. The design of the gas baking oven was produced with locally soured raw materials in its totality, with the exception of bimetallic thermometer, sensor and knobs due to their scarcity.

Nevertheless, we cannot claim that the gas baking oven is hundred percent efficient, since from the knowledge of thermodynamics, it is impossible for any heat transferring device to deliver heat with a 100% efficiency due to some heat losses. But the designers ensured that a good finish was given to the design and development of the equipment. We recommend that further and adequate research should be made on the availability and incorporation of a bimetallic temperature sensor.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Genitha I, Gowda BT, John Diamond R. Design, fabrication and performance evaluation of domestic gas oven. Journal of Engineering. 2014;4(5):35-38.
2. Merriam-Webster Dictionary. Available:https://www.merriam-webster.com (Retrieved November 23, 2011)
3. Tong CH, Lund DB. Effective moisture diffusivity in porous materials as a function of temperature and moisture content. Biotechnology Progress. 1990;6:67–75.
4. Ozilgen M, Heil JR. Mathematical modeling of transient heat and mass transport in a baking process. Journal of Food Processing and Preservation. 1994;18: 133–148.
5. Carvalho M, Martins N. Mathematical modeling of heat and mass transfer in a forced convection baking oven. AICHE Symposium Series – Heat Transfer. 1993;88(288):205–211.
6. Mary B. History of the oven from cast iron to electric; 2017. (Updated April 30, 2017)
7. Klass DL. Biomass for renewable energy, fuels and chemicals. Academic Press; 1998. Available:https://www.smartech.gatech.edu
8. Islam MR, Nabi MN, Islam MN. Characterization of biomass solid waste for liquid fuel production. Int. Conf. on Mechanical Engineering (ICME2001), Bangladesh. 2001;77-82.
9. Fellows PJ. Food processing technology-principles and practice. Wood Head Publishing Limited, Cambridge; 2000.
10. Community Research and Development Centre (CRDE). Nation Dialogue to Promote Renewable Energy and Energy Efficiency in Nigeria; 2008.
11. Therdthai Nantawan, Zhou Weibiao, Thomas Adamczak. Three-dimensional CFD modeling and simulation of the

temperature profiles and airflow patterns during a continuous industrial baking process. Journal of Food Engineering. 2003;65:599–608.
12. Vogel AI. Textbook of practical organic chemistry. 3rd Edition; 2005. Available:www.bookboon.com/en/chemistry-ebooks
13. Okafor BE. Simple design of a dual-powered domestic oven. International Journal of Engineering and Technology. 2014;4(5):313-317.

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