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Design and Fabrication and Evaluation of a Dual Powered Baking Oven for Smoking Fishes at CEDAP Village (A 2021/2022 TETFUND IBR PROJECT)

ADEBAYO ADEDEJI
(PRINCIPAL RESEARCHER)
Auchi Polytechnic, Auchi, Edo State, Department Of Computer Science
adedejibayoadedeji@gmail.com

ENGR. DR. ALIEMEKE, BLESSING NGOZI GOODLUCK
Department of Mechanical Engineering, Auchi Polytechnic, Auchi, Edo State.
E-MAIL:aliemeka@yahoo.com
(CO-RESEARCHER)

SADO EMMANUEL
Auchi Polytechnic, Auchi, Edo State, Department Of Computer Science
E-MAIL:sadosky4u@gmail.com
(CO-RESEARCHER)

Abstract
This work develops a mini dual powered oven which is mainly made up of the electric coil, the lagging material, temperature control and the gas burner. It has an internal volume of 0.140m3, with a double tray for baking and drying of food items and outside surface area of 0.142 m2. The oven will be constructed in such a way that the electric coil heater and the gas burner are in one chamber. Using the electrical coil heater and a temperature regulator, the maximum temperature of 220˚C was recorded. The oven was insulated with a material (slag wool) that has a thermal conductivity of 0.042 w/moC. The oven can bake maximum of 12 loaves of bread (area of 0.022 m2per loaf), smoke 100pieces of 1kg fishes and it will be constructed with locally available materials.

This project will cost N1,980,000:00 which is to be sponsored by Tertiary Education Trust Fund (TETFUND) grants. The aforementioned amount (N1,980,000:00) will be invested on the entire research work and handled prudently despite the country's economic downturn.

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1.1 INTRODUCTION

Roasting and baking are universal cooking methods consisting in heating the food inside an oven at a uniform temperature. In these processes, heat is transferred to the load mainly by means of radiation and convection. Although these are widely-known phenomena, complex and combined thermal, chemical and mass transfer processes occur within the product and change its properties during the cooking. By considering their energy source, ovens can be broadly classified into two groups, fuel–based and electric ovens. Electric resistance heating has various advantages over systems based on fuel combustion, such as increased control accuracy and heating rate. Thus, electrical heating constitutes a suitable choice for developing laboratory instruments, especially those demanding small heating volumes and precise temperature control. Researchers have analysed diverse types of ovens; Mirade et al., predicted the air temperature in an industrial biscuit baking oven while Ploteau et al., and Khatir et al., worked on bread baking. Some research works achieved valuable outcomes for transient responses but the high computational necessities of the numerical approaches make them unrealistic for processes involving a high number of simulations.

1.2 PROBLEM STATEMENT/JUSTIFICATION

Some earlier works were focused on developing simple thermal models for ovens, primarily to use them in the design of temperature regulators such as where elementary principles were applied to build models that describe the temperature dynamics of an oven cavern. While these models showed their helpfulness, they did not consider the complete thermal behaviour of the system because they were wholly interested in the cavern temperature. Other research groups oriented their studies to the cooking load itself, obtaining precise models for specific combinations of cooking load and heating method. Abraham & Sparrow, predicted a model of heat transferred to a metallic load while the models presented by included both thermal diffusivity and mass transfer phenomenon in cake baking or meat roasting processes.

It is a general belief in a country like Nigeria that finishing what one starts with an electrical appliance or machine is nearly impossible due to the epileptic nature of power supply which is a major problem facing the country, and oven is not excluded from those appliances. Considering the frequent power outage especially at the middle of operation normally experienced by bakers and other oven users, and the damaging effect on the final product like reduction in quality which also results in loss of capital, there was a need for the development of dual–heating source for an oven to help solve this problem. In this paper, a design, fabricated and tested dual powered oven is presented using locally sourced materials.

1.3 OBJECTIVE(S) OF THE STUDY

This project is constructed to achieve the following purposes:
1.To design and construct a portable gas/charcoal baking oven equipment with temperature regulator / sensor.
2. To design and construct a drying system with a high performance.
3. To design a drying system that will be economical and low cost effective.
4. To design and construct a drying system that is efficient and with little or no complication in maintenance.
5. To design and construct a drying equipment that could improve on existing design taking into cognizance area of need.

2. LITERATURE REVIEW

2.1 Oven

This is a thermally insulated compartment where food and other materials can be cooked, baked, fried, and heated. It works on the basis of heat and mass transfer, with the three modes of heat transfer (convection, radiation, and conduction) taking place simultaneously withing this enclosure to bring about the desired effect to the materials. Although the different heat transfer modes take place but are of different degree. In baking operation, oven is responsible for bringing the dough pieces to the desired temperature. Since heating primarily causes moisture evaporation, this initiates a series of physical and chemical changes in the baked product. (Kreith, 1999) To produce and transfer heat, ovens require one or a combination of energy sources. These are:

- Electricity
- Fuels (natural gas, liquefied petroleum gas)
- Steam (generated in a boiler)

2.2 Types of Ovens

Ovens can be classified based on their mode of operation and heat transfer mechanisms as either a batch or continuous equipment and as using either direct or indirect heat exchange.

The type of an oven that suits a particular operation is a function of production capacity, product specification, floor space, energy source available, construction materials, maintenance needs. (V, 2008)

2.2.1 Direct-fired oven (DFO)

DFOs place combusting gas inside the baking chamber to heat the air and the products. The heat transferred to the product is mainly by radiation from the gas flames, top, base and walls of the baking chamber. They are very efficient because they convert most of the fuel to heat and process the products. (V, 2008)

2.2.2 Indirect-fired oven (IFO)

IFOs heat the baking chamber by using heat exchangers. They are suitable for sensitive bakery products like cakes, pastries etc. since the product do not have a direct contact with the heat source, it eliminates contamination. It has less heat transfer capacity and hence not widely used.

2.2.3 Electric oven

They are similar to direct fired oven but instead of using gas fuel, electrical resistance heating element is the heat source. (Kreith, 1999)

2.2.4 Peel brick oven

This is one of the earliest constructed ovens. It consists of a massive brick material chamber while coal and wood are used as the combustion fuel. (Kreith, 1999)

2.2.5 Tunnel oven

These are continuous mode operation baking units commonly used in large-scale bakeries. They fuel is mainly natural gas as heat source while electricity is used for air circulation. (V, 2008)

2.2.6 Hybrid oven

This combines the three modes of heat transfer effectively and takes advantage of their synergistic effect on products. (Kreith, 1999)

2.3 Heat transfer

There are three modes of heat transfer in nature. These are:

- Conduction
- Convection
- Radiation.

2.3.1 Conduction heat transfer

This refers to the transfer of heat through a stationary medium which is as a result of the vibration of the molecule of the medium in question. It is governed by The Fourier law.

$$dQ = -kA \frac{dT}{dx} \quad (W) \qquad 2.1$$

Where dQ is the rate at which heat is being transferred
K is the thermal conductivity of the material A is the area of the surface
dT is the temperature difference between the two ends dx is the distance.
The minus sign denotes that heat flows in the direction of decreasing temperature. (Cengel, june, 2019)

2.3.2 Convection heat transfer

This is the mechanism of heat transfer through a fluid in the presence of bulk fluid motion. Convection can be either natural or forced. Convection greatly depends on the fluid properties such as the density, the specific heat capacity, the dynamic viscosity, velocity, geometry of the surface, solid surface roughness, among others. The convection heat transfer is governed by the Newton's law of cooling as:

Qconvection= $hA(Ts - T\alpha)$ 2.2

Here, Qconvection is the convective heat transfer in watt
h is the convective heat transfer coefficient A is the area of the surface
Ts is the surface temperature
Tα is the lower body temperature

Convection can be forced or natural depending on how the air circulation is being initiated. This project intends to employ the use of natural convection heat transfer. Reasons for this are: to reduce the cost of material in the form of a blower and also to reduce the cost of energy consumption by the machine.

In natural convection, buoyancy effect, a natural means is the cause of fluid (hot air) motion. It is the rise of hotter fluid (low density air around the heating element) and a fall of colder fluid (air of high density surrounding the dough) due to temperature difference.

The convection heat transfer coefficient is a strong function of the velocity. The higher the velocity, the higher the convective heat transferred from the heating element to the dough placed in the mould. This velocity is compensated for by the use of a small enclosure to reduce the distance travelled by the hot air and hence, effective baking of the dough.

The convective heat transfer over a surface also greatly depends on the geometry and orientation of the surface. It also is a function of temperature difference as was seen from the Newton's law of cooling and the thermophysical properties of the fluid. In using the convection equation, it is best to evaluate the fluid properties at the film temperature, which is an average of the higher and lower temperature. (Cengel, june, 2019)

2.4 Radiation heat transfer

This mode of heat transfer is different from the other two in that it does not require a material medium to occur. It can perfectly take place in a vacuum. The heat of the sun reaches us by this mode of heat transfer. It is governed by the Stefan-Boltzmann law. (Kreith, 1999) The radiation heat transfer between two bodies of different temperature is given by:

Qradiation= $\varepsilon\sigma A(Ts4 - T\alpha4)$ where: 2.3

ε is the emissivity of the surface

o is the Stefan-Boltzmann constant and other parameters are as defined earlier.

2.5 Safety aspect of oven design

In every engineering work, it is sufficed to say that safety is paramount. A surface that is too hot poses a danger to people who are working in that area of accidentally touching the hot surface and burning themselves. To prevent this danger, The Occupational Safety and Health administration (OSHA) has stipulated that temperature of hot surfaces should be reduced to below 60°C, (140°F). Also, excessive heat coming off hot surfaces creates an unpleasant environment to work in. These are among the chief reasons as engineers, when designing an oven, effort must be put in to ensure that the walls are well insulated to limit the amount of heat transferred to the outermost walls. (TechTarget Contributor, 1970)

2.6 Edible cutlery

Cutlery has been one of the simplest but very useful devices that has been created and used over the world for food consumption. It includes any hand implement used in preparing, serving, and especially eating food in western culture. Edible cutlery is any tableware like spoon, plates, fork that can be eaten rather than disposed like plastics. (Zeki Berk, 2009) They can be homemade and can be mass produced.

The process below shows how one can transform a dough into an edible cutlery: Step 1: create dough with rice and sorghum flours in 50:50 ratio (30g each)

Step 2: add about 1 percent sorbic acid.

Step 3: soak 2g of gum in 30ml of Palak extract for about 2 hours.

Step 4: mix the soaked gum in the flour

Step 5: press the dough so formed into a desired mould

Step 6: bake the material in an oven at 80 0C for 50 minutes

Step 7: allow to cool and pack in an airtight material and store in a cool dry place.

2.7 Problems with plastics

Plastic is an invention that has seen more than half a century of innovation, provided smart practical solutions that paved way for an industry, which has made since 1950, a total of 9.2 billion tonnes till date.

In December 2018, Great Britain's Royal Statistical Society gave a shocking revelation to the world: a meagre 9 percent of the plastic ever produced has been recycled while the remaining 91 percent found itself in landfills. These plastics eventually found their ways into human body and because of their carcinogenic nature, they are harmful to us. (Zeki Berk, 2009)

2.8 The automatic control system

The control system regulates the temperature within the oven chamber. This is done to ensure that the material being baked does not get burnt as a result of excessive heat due to high temperature.

2.9 Review of related works

Temitope Olumide Olugbade and Oluwole Timothy Ojo (2018) in their research "Development and performance evaluation of an improved electric baking oven" designed and evaluated the performance of an electrically powered oven that takes about eighty minutes (80-minutes) to get food baked. A performance evaluation showed a moisture reduction of 67.7% within this time. (Temitope Olumide OLUGBADE, December, 2018.)

Mette Stenby Andresen, Jorgen Risum and Jens Adler-Nissen (2013) in their research "Design and construction of a batch oven for investigation of industrial continuous baking process" constructed a batch oven to mimic industrial convection tunnel oven. They were able to control the process parameters (airflow, air temperature, humidity, velocity) over a wide range of settings. Their results after evaluation showed that the oven is able to heat and bake uniformly across the baking area. (Mette Stenby Andresen, 2012)

J.L Chukwuneke, I.C Nwuzor, E.O Anisiji and I.E Digitemi (2018) in their research paper "Design and fabrication of a dual powered baking oven" developed a mini dual powered oven which is capable of baking a maximum of twelve (12) loaves of bread per batch. Their materials were locally sourced, and use was made of gas burner in the absence of electricity. (J. L. Chukwuneke, 30 september, 2018)

Adegbola A.A, Adogbeji O.V, Abiodun O.I and S. Olaoluwa (2012) in their paper "Design, construction and performance evaluation of low-cost electric baking oven" reported on the construction and construction of domestic baking oven. The major focus of the research was to incorporate a blower which is for improved and speedy heat transfer within the oven compartment. This is a form of forced convection and it is effective in that the heat transfer becomes rapid and evenly distributed. The extra power required by the blower might have to be looked into if it was justified or not. (Adegbola A.A., November, 2012)

Genitha I, Lakshmana Gowda BT and John Diamond Raj (2014) in their work "Design, fabrication and performance evaluation of domestic gas oven" wrote on how they were able to use SolidWorks software, a Computer Aided Design tool to design such an equipment. The time taken for dough to bake was great but still employed the use of fossil fuel as a source of energy and hence contributing to more global warming. To drift to a carbon neutral environment, this project would not help. (Immanuel, may, 2014)

Ilesanmi O.E and Akinnuli B.O (2019) carried out a fabrication work on gas oven with an estimated cost of Fifty-six Thousand, Four Hundred and Seventy Naira ((₦56,470) at an exchange rate of ((₦156.86/$1). In today's Nigerian economy, this cost is equivalent to One Hundred and Sixty-two Thousand Naira ((₦162,000). This shows that such products are not feasible now price competitive in today's economy, hence a cheaper and more efficient solution. (O. E. Ilesanmi, may, 2019)

Muhammad Azmeer Bin Rozman (2012) carried out a design analysis work on domestic gas oven using ANSYSS simulation software for the heat transfer and CATIA design software for the structural modelling. His focus was on getting the right thickness of insulation to greatly reduce the heat loss and hence more heat retention in the oven chamber. He recommended the use of Alumina ceramics, Al2O3 of 30mm thickness as the most suitable insulator. The shortcoming of this project was that no prototype was constructed to verify the reality of this result. (Rozman, september, 2012)

TN Malafia, MA Devine and LL Lesher in their research paper (1994) "A user evaluation of biodegradable cutlery journal of environment" is a study on the evaluation of acceptance and performance of disposable cutlery made from biodegradable polystyrene cutlery. The US sailors who used the cutlery at the launching rated the performance as very acceptable. (Barrett, 2019)

Richard A. Gross and Bhanu Kalra (2002) in their research "Biodegradable polymers for the environment" studied on biodegradable polymers designed to degrade upon disposable by the action of living organisms. The need to create alternate biodegradable water soluble water polymers is extremely important. (Barrett, 2019)

M Flieger M., Kantorova A. Prell T., Rezanka J. Votruba (2003) in their research paper "Biodegradable plastics from renewable resources authors and affiliations" says that plastic waste disposal is an eco-technological problem and to solve this problem is a development of biodegradable plastic. (M Flieger, 2003)

Having reviewed some of the past works on the three facets of this thesis, it will be good to let the readers in on the intent of this research.

The problem statement has clearly shown that this research and design is broad. To make it easier and well-focused, our target is to design the oven powered by a single source, electricity and evaluate how long it takes to bake compared to the available ones in the market to determine its efficiency. We will also try to design in such a way as to determine among the three faces of the oven enclosure; the top, bottom and vertical walls which will be most suitable and efficient in the heat transfer as it has been discovered in the course of my research that most designers do not consider this in their approach to placing their heat source which can greatly affect the amount of the overall heat

3. METHODOLOGY

3.1 Design Concept

The oven is designed such that the electrical source (heating element) and the gas source (gas burner) are incorporated into one chamber to minimize wastage of material which would have been used to construct two different chambers for the two sources. The gas burner is located at the base of the baking chamber beneath the deflector plate while the heating element is attached to the side of the baking chamber close to the inside base of the oven.

In Fig. 1, the outside of the oven is made up of galvanized steel sheet coated with emulsion paint, while the inside is made up of aluminum sheet. Between the inside and outside is a slag fibre, an insulating material used for lagging. Slag fibre is a form of mineral fibre known to have lightweight, high strength and high thermal shock resistance characteristics. The oven design (see Fig. 1) has a general outlook dimension of 460 mm x 400 mm x

750 mm (length x width x height). A vent of 20mm is provided at the top of the oven which is connected to the inner baking chamber for the continuous removal of the hot and humid air from the inner baking chamber during baking.

3.2 Design Consideration

A variety of factors were put into consideration before the design of the mini dual powered oven was done. The factors considered include ease of assembly of the oven parts; size of the oven; size and geometry of bread loaves; bread baking temperature; and time is taken to bake the bread loaves.

3.3 Design Analysis

The baking oven is rectangular in cross-section, and a vent is provided at the top of the oven which is connected from the inner baking Where: lt is the length of tray; but is the breath of chamber for the continuous removal of the hot and humid air from the baking process.

Oven capacity in number of loaves of bread it can process per batch using the dimension as shown in Fig. 2: tray; average mass of a loaf of bread = m

Capacity of oven = size of tray⁄size of bread = n

But because the oven has double tray; 2 ∗ = size of tray = l ∗ b

Therefore, the oven will contain loaves of size of loaf of bread considered = l ∗ b (2) bread per batch.

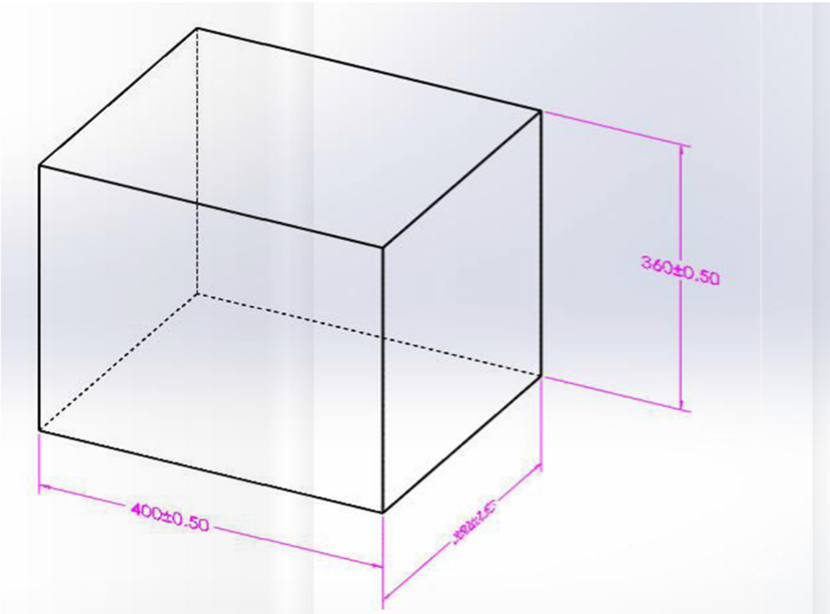

Fig. 1. Oven parts

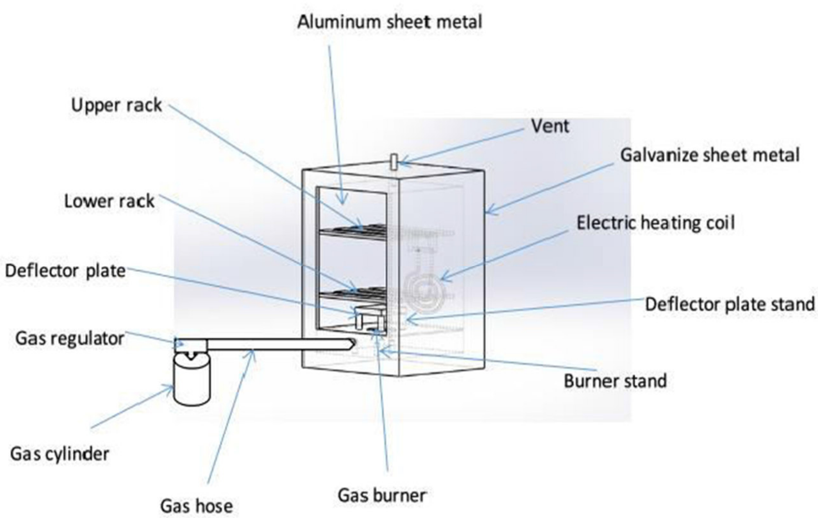

Fig. 2. Oven schematic volume

3.4 Electric Energy Requirement

Heat required to bake loaves per batch, Q = m ∗
c ∗ (T − T) P = . ∗ Also,
Where average baking (oven) temperature = T;
average mass of a loaf of bread = m ; P = IV and ,
specific heat capacity of bread = c ; and P = I R =
oven room temperature = T . Heating Element Rating
Power of electric heating element, P = Average processing time per batch = T

Where: I is current; V is voltage; and R is resistance.

3.5 Material Selection

Material selected for the fabrication of the baking oven is tabulated as shown in Table 1. The materials were selected in view to avoid contamination with the food material, the At 85% heat transfer, H to the loaves; H = 0.85 ∗ Q
Functionality of the material and cost- effectiveness of production of the oven.

Table 1. Component Description

SN	Oven component	Functions	Reason for selection
1	Galvanized steel	For the outer casing of the oven	Suitability, low cost
2	Aluminum sheet (Gauge 450)	For the inner casing of the oven	Suitability, not easily damaged and available
3	Rheostat	For the regulation of current inflow to the heating element	Availability
4	Power switch	For the completion of the electrical circuit	Availability
5	Heating element	Converts electrical energy to heat energy needed for baking	Availability, suitability
6	Gas burner	For burning the hydrocarbon gas inheating of the baking chamber	Suitability
7	Gas hose	Connects the burner to the external gas cylinder	Suitability
8	Tray	For suspension of the substance being baked	Suitability and availability
9	Deflector plate	Protects the direct contact of the flame with the food	Low cost and availability
10	Slag wool	Prevents heat transfer from the oven chamber to the outside.	Low cost and availability
11	Door handle	For opening of the oven chamber	Suitability, durability
12	Locking device	for locking of the oven chamber	suitability
13	Stand (2mm angular steel iron)	For rigid support and suspension of the oven for good supply of oxygen	Durability and High strength
14	Indicator light	It indicates when the oven is in operation	Suitability

3.6 Characteristics of the Baking Oven

The electric baking oven was put to test in order to determine the maximum heat of the oven and for the calibration of the thermostat. After the assembling of the oven, the first experiment that was done with it is to use a thermometer and a timer to discover the effective heating of the oven. The oven heating coil reached its maximum heating temperature in 30 minutes and the maximum heating temperature is 220°C. The maximum temperature of the oven was divided into 5 in order to get the calibrated mark for the thermostat and it was calibrated in degrees but before the calibrations were made, it was discovered that the external body of the oven was about 68°C when the internal oven was 220°C. Therefore, efforts were made in order to minimize the external body heating of the oven while maximizing the internal body heating of the oven. We have to disassemble the oven and we discovered that the internal body of the oven has connections with the external body of the oven. Since we were able to discover the problem, it was easier for us to solve it by separating the internal connection with the external through the use of wood which is not a good thermal conductor. We assembled the oven again and another experiment was performed for each of the calibrated thermostats while measurements were taken with respect to the corresponding temperature and time-taken for particular turning level of the thermostat knob.

3.7 Baking Oven Performance Analysis

The following results were obtained during the various experiments conducted. Time-taken and temperature attained by the electric baking oven for the calibration of the thermostat.

The following chart for the calibration of the thermostat was obtained for analysis:

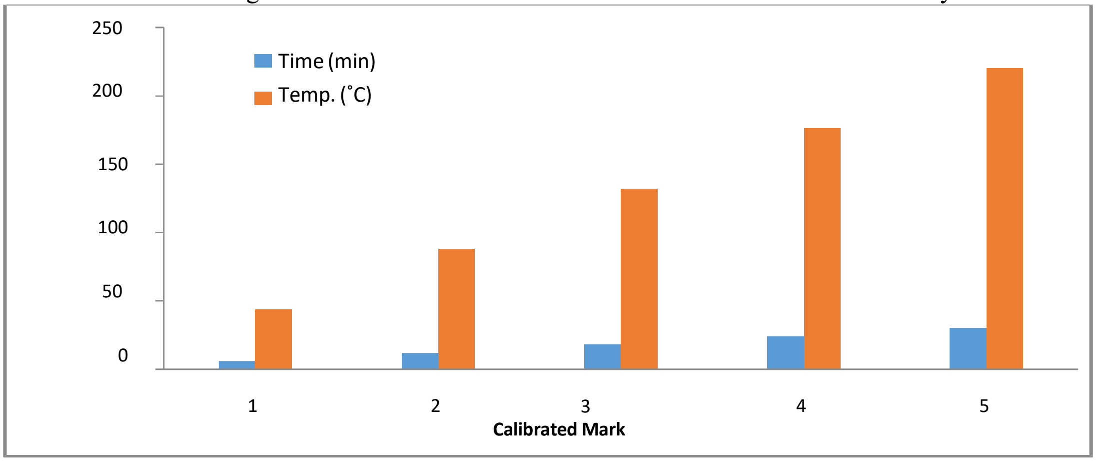

Fig. 3. Variation of time and temperature against calibrated mark

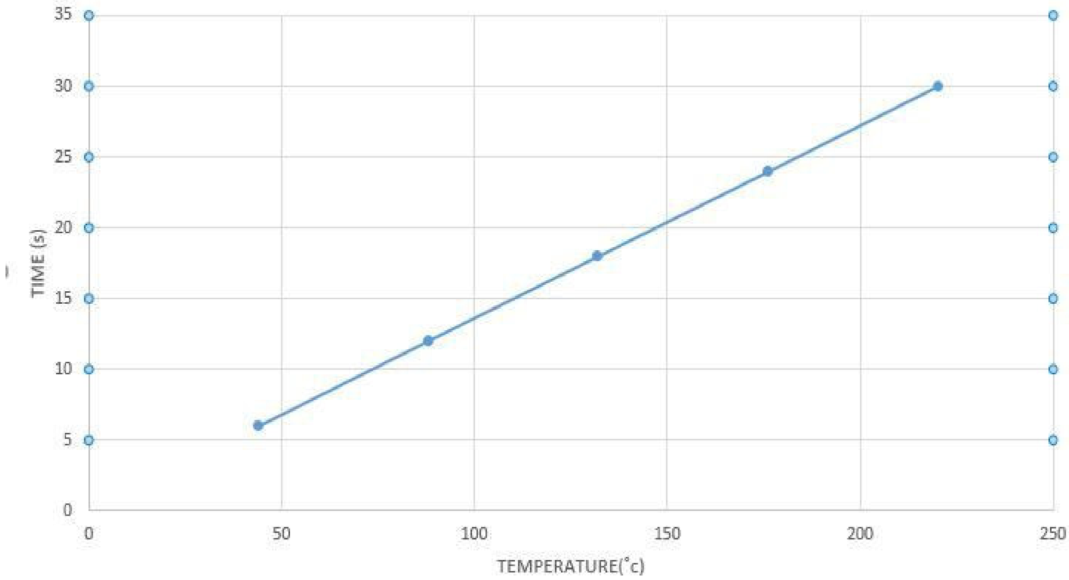

Fig. 4. Variation of time against temperature

Fig. 3 show the calibrated mark against concluded that as the temperature increases, the temperature and time which reveals an increase time required to cook the food reduces. That is, in temperature with increase in degrees of temperature is inversely proportional to time turning of the thermostat knob. Fig. 4 shows the relationship between time and temperature which while baking. Therefore, it can be deduced that the designed project is faster and thus baked reveals that foods are bake within shorter time effectively when compared with the existing with an increase in temperature. The graph also one. Hence

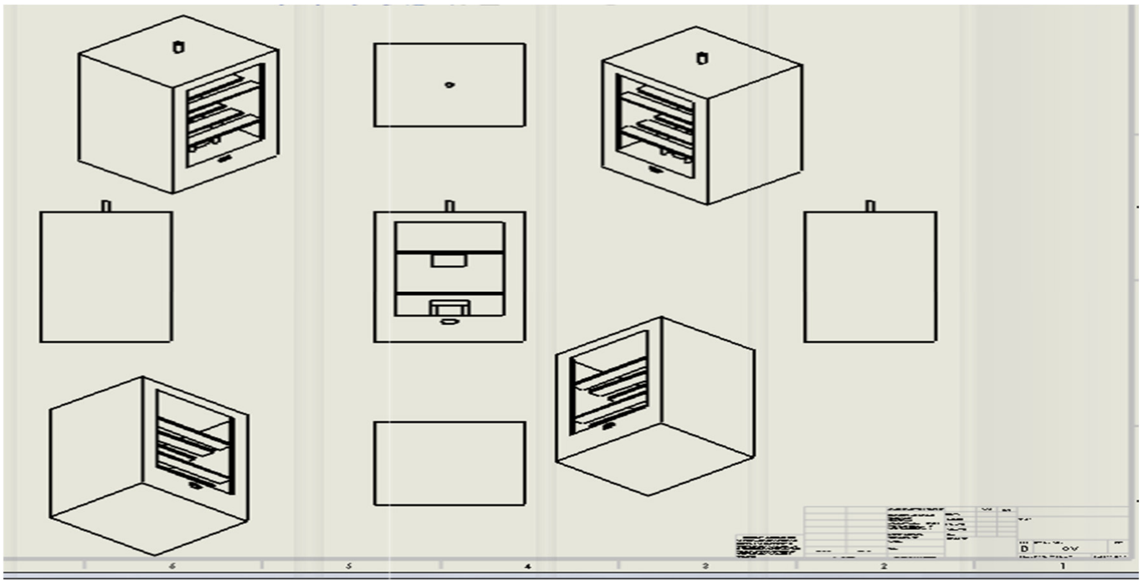

Fig. 5. Different views of the oven

after the oven had been tested, it reveals that the higher the temperature, the lesser the time-taken for food to bake. It can be was realized that it is efficient baking.
andfaster.

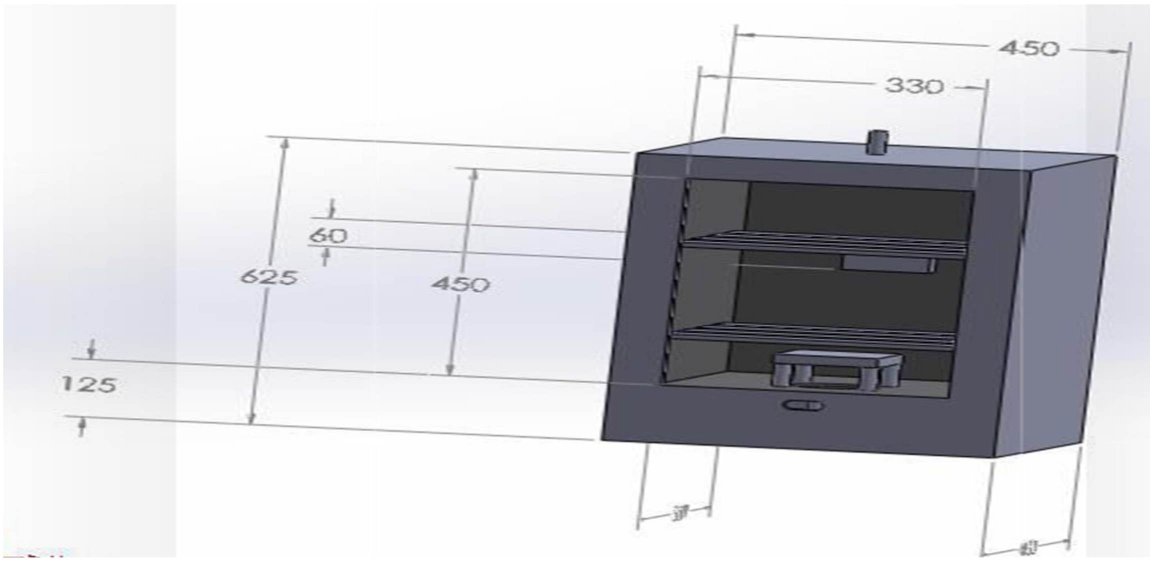

Fig. 6. A fully defined view of the project using solid works

Fig. 7. The assembled oven design with solid works

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

3.8 COST OF PRODUCTION

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

Bill of Engineering Measurement and Evaluation BUDGET ESTIMATE

S/N	**MATERIAL DESCRIPTION**	QTY	UNIT PRICE	TOTAL
1	Mild steel sheet metal(1mm)	6	30,000	180,000
2	Roll of fibre glass	4	25,000	100,000
3	Temperature sensor/thermometer	2	30,000	60,000
4	Gas burner	1	10,000	10,000
5	Length40x40squarepipe	4	5,000	20,000
6	Angle iron	2	5,000	10,000
7	Lock bolt(10mm)	4	2,500	10,000
8	Handle	4	2,000	8,000
9	Filler	1	20,000	20,000
10	Sandpaper	2	1,000	2,000
11	Yards gas hose (pipe)	2	2,000	4,000
12	Clips	2	500	1,000
13	Gas regulator	1	10,000	10,000
14	Gas cylinder(25kg)	1	40,000	40,000
15	Gas	10kg	1,000	10,000
16	Electrode(gauge12)	4packs	5,000	20,000
17	Drill bit(5m)	5	4,000	20,000
18	Tray	5	20,000	100,000
19	Gas valve or regulator	1	10,000	10,000
20	Handle	2	2,500	5,000

21	Frame	5	4,000	20,000
22	Burner	2	5,000	10,000
23	Perforated plate	10	10,000	100,000
24	Oven door	2	25,000	50,000
25	Oven firing door	2	5,000	10,000
26	Chimney or vent	2	5,000	10,000
27	Caster wheel or rollers	4	5,000	20,000
28	Miscellaneous Expenses			10,000
			TOTAL	₦900,000

4.1 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.

4.2 CONCLUSION

The design, fabrication and performance analysis of the automated domestic oven has been achieved successfully.

i. All the two (2) mode of heat transfer were analysed and calculated for optimum operation of the oven, convection and radiation for the oven chamber and conduction for the insulation

ii. A galvanized sheet metal was used for both the outside and inside body of the oven. A mineral wool of 0.042 (W/M°C) will be used as the insulating material. A 4000watt heating element was used which shows clearly that the automated oven can be suitable for baking doughs and all bakery product with good quality parameters like colours, texture, and good volume for fermented products.

iii. A thermocouple with a timer is also used to ensure that the oven temperature regulates properly

iv. The design also shows bakery product can be baked at lesser time due to high energy of the heating element compared to other oven design like gas ovens, hence reduce energy consumption and overall working cost

From the thermodynamics study, heat transferring device cannot deliver heat with a 100% efficiency due to some heat losses, but I ensure that a good finishing was giving to the design and materials were selected very carefully to suit the design parameters.

4.3 Recommendations:

i. I recommend further research on materials to be selected while dealing with heat as the widely used once are mainly aluminium, galvanized and mild steel.

ii. I also recommend that adequate and further research should be made on the heating element as heat is key factor in this thesis. The higher the temperature the lesser the time but not too high as it may result to burnt products.

iii. I wish to recommend and encourage the use of more advance timer that can show real timing digitally.

4.4 Acknowledgment

We are using this medium to say a very big thank you **Tertiary Education Trust Fund, (TETFUND)** and **Auchi Polytechnic Management** for the sponsorship and support granted us in the course of this Project

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