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Design and Construction of an Electric Oven

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--**ABSTRACT**--

An oven is an enclosed compartment for heating, backing and drying. It is commonly used in cooking and pottery. The electric oven requires heat for specific period of time for sterilization to be achieved. This oven like any other is designed and constructed to bake bread and meat pie, dry fish, meat and other food items to preserve them. This work involves the design and construction of a closed system with inner and outer casting of 1.5mm mild steel plate. Material selected for the project includes mild steel sheets, square pipes, heating element, thermostat, and rolling wheels which are all cut and joined together using the welding process. The main source of power for the oven is electricity. This will enable good maintenance, and less cost compared to other source such as gas. It is easier to operate. The oven does not contaminate the food baked or cooked. The significance of this work is based on the fact that today, ovens are in wide use domestically, it is necessary to therefore reduce the time required for cooking food and as well minimize the energy use. The approach used in this study was first sourcing for materials and investigating into what the project mainly entails. These were gotten as explained in the parts that follow below.

Key words; *Heat, Design, Construction, Electricity, Materials, Volume, Power, Current, Voltage.*

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I. INTRODUCTION

An Oven is a thermally insulated chamber used for heating, baking, or drying of substances. It is commonly used for cooking, kilns and furnaces. Baking oven is a complex simultaneous heat and mass transfer process equipment commonly applied in food industries. An oven can be simply described as a thermal insulated chamber used for the heating, baking, cooking, or drying of food substances, Afolabi T.M et al(2017). An oven is a heated enclosure for baking and roasting food by dry heat at temperatures usually not greater than 45^0 degrees Fahrenheit (23^0 degrees Celsius). The study on electric baking oven has received a considerable attention over the decades, due to its durability, efficiency and availability, Temitope O.O et al(2018). Ovens may have a separate broiler compartment used primarily to broil foods. In a standard domestic oven, food is heated mainly by radiation from the hot walls and partly by convection of hot air. The radiant heat is absorbed in a very thin surface layer of the solid food, whose interior then slowly heats by conduction. The improvement of an existing product usually requires a lot of effort, time and resources for the preparation of prototypes and measurement of different solutions, Uros K et al (2017). The earliest ovens were found in central Europe, and dated to 29,000 BC. It was used to cook Mammoth . In Ukraine, from 20,000 BC, they used pits with hot coal, covered in ashes. The food was wrapped in leaves and set on top, then covered with earth.Electric ranges have heating units that use an electric current to produce heat. Most electric ranges have four circular heating units on a cook top and one or two rectangular units in each oven. Typically, one of the circular units will have an expandable electric element, with two or three size settings. These heating units have an exterior shell in the form of a metal tube in two parts. Each section is shaped like a spiral and encases a coil of wire. Electricity travels through the coil, thereby heating the coil and the metal tube. The heat generated by a cook top unit can be regulated in several ways. Controls can determine which one of two possible electric voltages passes through the coil. The higher the voltage the hotter the coil. Other controls offer the choice of heating one or two coils. Another type of control varies the heat supplied to the cook top unit by turning the current on and off at intervals. The heat increases with the length of time that the current flows through the unit. Thermostats, usually regulate the oven heating units in electric ranges, as well as in some cook top units. Ovens vary in the way they are controlled. The simplest types, may not have any control at all, but simply runs continuously at various temperatures. More conventional ovens have thermostats; this both turns the oven “on” and “off” and selects temperatures at which it will operate. Setting to the highest setting may also enable the broiler element. A timer may also allow the oven to be turned “on” and “off” automatically at pre-set times. Types of electric oven include; Traditional ovens, steam ovens, convectional ovens, trivection ovens, refrigerated ovens and speed-cook ovens. This project study was as a result of the need to develop an electric oven at a relatively low cost, maximum performance and minimum maintenance with the application of engineering techniques and materials. The oven is also designed to limit human exposure to heat and smoke unlike ancient ovens. The project involves the design and construction of a closed system with an inner and outer casing of mild steel plate with lagging material in between, to give insulation. The machine is easy to maintain and has high durability. It is highly preferred to all other types of oven due to the availability of electricity over a wide range of places throughout the countries, Adegbola A.A et al (2012) Having considered the advantages that can be derived from the use of electric oven, it is relatively cheap when compared with other means of baking.This work includes planning, design, material selection, construction analysis, calculations, and assembly of parts.

II. MATERIALS AND METHOD

To understand the concept behind the operation of an electric oven, one must first understand heat, its principle and its properties.

HEAT: Heat is defined as the form of energy that is transferred between two systems (or a system and its surroundings) by virtue of a temperature difference. (Majid,2005)

That is, an energy interaction is heat only if it takes place because of a temperature difference. Then, it follows that there cannot be any heat transfer between two systems that are at the same temperature. Heat can be transferred by any of the following modes; Conduction, Convection, Radiation.

2.1 Heat Supplied By Electricity

From ohm's law, power is given by; $P = IV$

Where;

P = Power in watts (of heating element)
I = Current in Ampere
V = Voltage in Volts (220V)
Therefore;

I = —— (current flowing through heating element)…………… (1)

Also, $P = I^2R =$ —

Therefore;

R = —— (resistance of heating element)………………………. (2)

2.2 Work Done Or The Electrical Energy Expended

$W = IV\,t$ ……………………………………………….(3)

Where t = time taken (in minutes)

The entire oven design is made up of the internal and external body, which is of mild steel material, both separated with lagging material, and the whole assembly made rigid by a rectangular framework.

The detailed step by step construction, assembly and installation of the parts are drafted below, involving the following steps;

1. The main framing
2. The body
3. Interior assembly and installation
4. Insulation/lagging
5. Exterior assembly and installation

2.3 Design analysis and calculations

Below are various oven sizes;

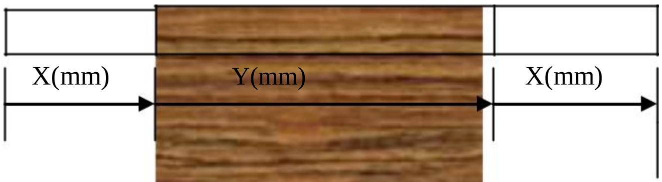
Area = Length (L) x Width (W)

Volume = Length (L) x Width (W) x Height (H)

2.4 Internal Size

This refers to the interior space of the oven and can be gotten by subtracting the thickness of the wall from the external size.

The thickness of the wall comprises of the mild steel sheet thickness And the insulator thickness.



Where;
X = thickness of mild steel (millimetres)
Y = thickness of Lagging material (millimetres)

❖ Therefore ;

Total thickness (T) = X + Y + X (millimeters)……………………...(4)
Length = L – 2(T) …………………….……..………………. .(5)
Width = W – 2(T) ……………………………………………. .(6)
Height = H – 2(T) ……..………………………….……………(7)
Internal Area = L x W ……………………………………………(8)
Internal Volume = L x W x H ……………………………………(9)

2.5 Material Selection; involves the choice of materials used in the construction of the project. Material selection is also based on some factors of material selection criteria which includes;

2.5.1 Operating Temperature

Temperature is often the first—and sometimes the only—data point given upon which one is supposed to base material selection. However, one cannot successfully choose material based on temperature alone. Nevertheless, one simple guide to material selection is an estimate of the maximum temperature at which a given material might have useful long-term engineering properties. (Kelly, 2004)

1. **Thermal Stability**
2. **Suitability of material for the intended purpose**
3. **Strength**.
4. **Cost and availability of materials**
5. **Oxidation**
6. **Weld-ability of the material**

- The materials selected and their respective properties are below;

2.5.2 Mild Steel

This is an alloy of carbon with carbon content ranging from 0.1%-0.3%. The square metal bar for oven body frame work and angular bar used for supporting the wire mesh are all made of mild steel material.

2.5.3 Physical Properties

Mild steel is a good conductor of heat. It has a melting point of 1650^0 C. The maximum temperature the oven produces is 300^0 C - 350^0 C, which is far below the melting point of the mild steel.

It has a density of $7900kg/m^3$, and due to its light weight, it can be carried from one place to another when needed.

It has a low specific capacity. Its expansion with respect to increase in temperature is very small.

2.5.4 Mechanical Properties

These are properties determined by the application of force. They include; ultimate strength, yield strength, hardness and ductility.

Mild steel is hard, cannot be easily damaged. Mild steel possesses good weld-ability. This plays a great role in the joint formation and strength of the compartment in withstanding load or applied force.

2.5.5 Heating Element

This material possess features such as

a) Ability to resist oxidation at high temperature
b) Very high melting point and high electrical resistivity
c) Has high resistance to corrosion

The heating elements for this project is made of tungsten material

2.5.6 Lagging Material

These are placed between the internal and external walls of the oven, and are used for proper insulation and its bonding process is well adapted to the function of the laminates and panel. The lagging material used for this project is fibre glass.

TABLE1; Material selection table

COMPONENTS	ATERIAL SELECTED	CRITERIA FOR SELECTION
Frames	Mild steel	It is Malleable, ductile, available, low cost, it gives good rigidity to the frame structure.
Heating element	Tungsten	Capable of generating the required heating for the oven, available, high heat conductivity.

III. RESULTS AND DISCUSSION

Design Calculations

Internal Size

Considering the cross-section of the oven wall shown below;

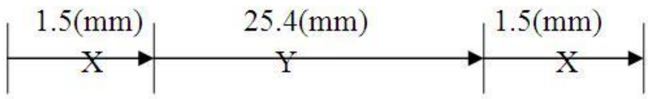


Fig4.1

Where;
X = thickness of mild steel (millimetres)
Y = thickness of Lagging material (millimetres)
Therefore;

- Total thickness (T) = (1.5 + 25.4 + 1.5) = 28.4mm ………..(10)

For internal size, with L= 508mm, W= 508mm, H= 457.2mm;

- Length = L – 2(T) = 0.508 – 2(0.0284) = 0.4512m
- Width = W – 2(T)= 0.508 – 2(0.0284) = 0.4512m
- Height = H – 2(T)= 0.4572 – 2(0.0284) = 0.4004m
- Internal Area = L x W= 0.2036m^2
- Internal Volume = L x W x H= 0.0815m^3

3.1 Computing For Current And Resistance Of Heating Element; From ohm's law, power is given by; P = IV

Where;

P = Power in watts (of heating element)
I = Current in Ampere
V = Voltage in Volts (220V)

Therefore;
I = P/220V (current flowing through heating element)
Where P = 1800watt
I = 1800/220 = 8.18 amps

Also, $P=I^2R=$ —

Therefore;

R = —— (resistance of heating element) = 27 ohms

3.2 Work done or the electrical energy expended

W = IV t = 8.18 x 220 x 60 = 107,976joules
Where t = time taken (say 1minute)

3.3 Stress Analysis;
Considering the cross sectional view of the oven wall below;

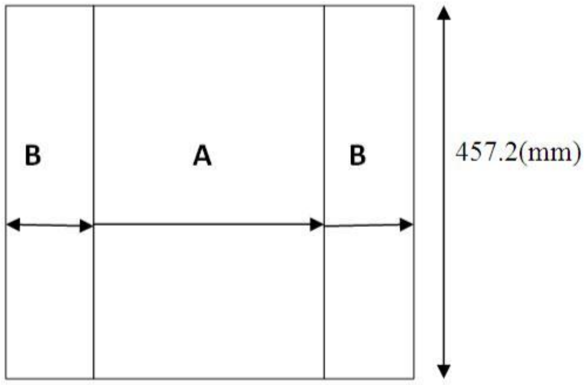


Fig 4.2

Where A = Mild steel
B = Lagging material
In this setting, as the internal temperature increases, the materials undergo thermal stress and since the coefficient of linear expansion for mild steel is greater than that of the Lagging material (fibre glass), it expands more.

❖ coefficient of linear expansivity; α_A= 13.0 x 10^{-6} / k
α_B= 39.4 x 10^{-6}/ k
❖ Young modulus;

❖ Cross sectional area

❖ We know the induced stresses in a compound/composite wall; ε_A + ε_B = (α_A - α_B)t= (39.4 x 10^{-6}- 13.0 x 10^{-6})20 = 5.28 x 10^{-4}…… (11)
❖ Force on body A is same as force on body B

= 0.0394 ……………...…………………………………….. (12) ε_A = and ε_B =

+ = 5.28 x 10^{-4} ……………………………………………….. (13)
+ ~~= 5.28 x 10~~$^{-4}$ x 1.28486 x 10^{-11}= 5.28 x 10^{-4} =
41.09MN/m^2 (stress experienced by the mild steel)

And from equation 12;
= 0.0394 x 41.09 = 1.62MN/m^2 ……..stress experienced by lagging material.

3.4 Design And Calculation Of Heating Element
Given;
Length of coil (L) = 0.45m
Diameter of coil (D) = 0.012m
T1 = Temperature of heating element, designed for = 350^{o}C = 623K T2 = Temperature of charge (say room temperature) = 41^{o}C = 314K e = emissivity = 0.9
k = radiating efficiency (of Tungsten element) = 13.8
❖ From Stephan's equation, H = 5.2ek

H = 5.2 x 0.9 x 13.8

H = 64.58 = 64.58 x 1,498.2 = 96,752.6 Watts/M^2

❖

We know that total power emitted by heating coil (P)

$P = \prod \times D \times L \times H = 3.142 \times 0.012 \times 0.45 \times 96{,}752.6 = 1{,}641.4$ Watts

Say 1,800 Watts

IV. PROCEDURES OF OPERATION, RECOMMENDATIONS AND CONCLUSION,

4.1 Operational Procedures

The electric oven is moved close to the main supply with the help of the movable legs/rollers, and is then connected to a main supply at 220V.

The switch of the oven is put on, therefore making the electric circuit complete, and current flows round the system. This electrical energy is then converted to heat energy by the heating element.

The greater part of heat in the chamber flows by radiation from the heating element, and the entire volume space is heated up until the needed temperature is reached.

4.2 Safety Precautions

Some precautions were ensured during the process of construction to enhance safety, and for long service of the oven, some maintenance precautions should be also be ensured. Viz;

1. The walls of the oven were properly lagged to avoid excessive heat losss.
2. The use of personal protective equipments, eg eye goggles,welding gloves, coveralls etc was ensured during the fabricating process.
3. Water and corrosive fluids should be kept away from the heating element to ensure its durability.
4. The maximum load capacity of each tray is 15kg, and should not be exceeded.
5. When not in use, oven plug should be disconnected from power source.
6. The unit should not be operated by those who have no knowledge about its use.
7. Before doing any work or repairs on an electric oven, make sure it is unplugged and disconnected from power source.

4.3 Maintenance and repair

Electric ovens are easy to repair. Most repairs are actually replacement, an act of disconnecting the old part, and fixing a new one.

Most of the malfunctions that affect electric ovens involve faulty heating elements.

4.4 Conclusion

The principle and technoligy behind the design and construction of the electric oven is not too complex, but practically took a lot of manpower and financial resources because it was not produced on a large scale. Its numerous importance calls for improved methods of producing it locally, instead of developing the idea of importing, as this will always retard technological growth. Therefore the electric oven design is a viable one that will withstand the test of time with its simple design, easy operation and proper browness.

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