DESIGN AND CONSTRUCTION OF AN ELECTRIC-GAS OVEN FOR SMALL SCALE BAKING AND MOISTURE MANAGEMENT

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Abstract
The research was conducted to develop, design and construct an electric gas oven at the Electrical/Electronic Engineering laboratory of Rufus Giwa Polytechnic Owo, Ondo State, Nigeria. Radiation and convection are the primary heat transfer methods used to deliver heat to the materials. The electric gas oven primarily consists of an electric coil, a gas burner and lagging material. It features an external surface area of 1420 cm^2, a double tray for baking and oven chamber capacity of 0.140 m^3. The oven's functionality and effectiveness was tested using baking cake, cookies, and muffins. Depending on the size of the cake, the results showed that the cake took 27 minutes to bake at 180°C, cookies took 9 minutes at 150°C, and muffins took 12 minutes at highest temperature of 180°C. Subsequently, compared with the traditional charcoal oven, electric-gas oven was found suitable for baking and drying at higher energy efficiency by reducing the energy, cost, and baking time.
Keywords: Electric-gas, Heat, Layer, Radiation, Steel

1.0 Introduction

An oven is a heat-isolated enclosure used to heat, bake, or dry an item; it is most frequently employed for the preservation of food (Genitha, Lakshmana and John, 2014). Baking is a sophisticated technology for simultaneous heat and mass transfer that is frequently used in the food industry. A simple definition of an oven is a completely enclosed, thermally insulated space used for heating, baking, or drying a product.

The objective of designing and building an electric gas oven was to provide an alternate method of baking and roasting meals for domestic or commercial usage. This makes a significant contribution to reducing the issue of spoilt food, which is commonly encountered and brought on by insufficient boiling and roasting of food. Due to its dependability, effectiveness, and accessibility, electric gas oven innovation has attracted a lot of interest throughout the years. It is one that uses both electricity and gas to heat and preserve food.

Two separate heating elements, one powered by electric power and the other by gas, are included in an electric-gas oven. The convection heat transfer from the air, the radiation heat transfer from the oven heating surfaces, and the forced airflow from a fan all work together to move hot air over the baking material in an oven. It should be stated, nevertheless, that the single use of a gas or electric oven requires a lot of time because consumers have to wait a long time for their meals to be done. Additionally, the efficiency of this so-called single oven is awfully poor and inadequate. Ovens are available widely in a variety of formats, including electric, micro, and wood ovens, among others. Electric ovens in this case operate by electricity (Mohammed, Olugbade and Odesanmi, 2015) direct fired electric ovens efficiently transmit heat (Abraham and Sparrow, 2004), but the user is frequently faced with greater heating costs as a result. This kind of oven is popular because it frequently uses dry heat, which reduces the chance of rust accumulation.

A thermostat that electrically regulates the oven's temperature is another feature of this oven, and many incorporate top, bottom, or rear grill elements (Akinnuli and Olugbade, 2014). Compared to other types of ovens, electric ovens are very affordable but might take longer to heat. Subsequently, fired ovens that cook with wood fuel are known as wood-fired ovens. Ovens like this can be made out of cob or iron in addition to the typical wood-fired oven (Adegbola *et al*., 2012), which is similar to a mud oven. Unlike wood-fired stoves, which offer a heated cooking surface for pots and pans like an electric stove, wood-fired ovens do not (Genitha *et al*., 2004).

An oven separated from the fire chamber is another option for a wood stove. They all feature an oven chamber made up of a floor, a dome, and an entrance, regardless of the material. The

wood-fired oven has the advantages of spending less capital and being simple to construct, but it also has the drawbacks of requiring more time to bake products, causing them to bake unevenly, and losing their original flavour.

Liquefied petroleum gas is used in gas ovens to bake goods including bread, cakes and biscuits (Mohammed *et al*.,2016; Plateau and Nicolas, 2012). The heat transmission mechanism serves as the gas oven's main operating component. When there is friction, heat transfer frequently happens. Convection is the movement of a mass of materials between two places (Dales and George, 2015), which transfers energy from one location to another. Natural convection occurs when temperature changes cause differences in density, which in turn cause movement of the fluid.

Convection naturally happens when a solid surface is in contact with a fluid with differing surface temperatures. The force needed to move the moisture in the meal is provided by variances in densities. Studying electric gas oven is crucial since it could result in a more effective baking procedure that is good for both energy efficiency and product quality (Ogedengbe *et al.*, 2015 and Khatir*et al.*, 2012)

Since very high temperatures are used to eliminate moisture from baked goods and achieve the correct texture, baking often uses a lot of energy. The irregular power outages that occur in the middle of operations have recently been an issue for users of electric ovens, as they reduce the quality of what is produced, cost money, and increase energy use. In most areas, it is commercially important to utilise gas as the energy source for oven due to the excessively high cost of electricity. The electric gas oven allows moisture in the food material simultaneously diffuses toward 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 (Fellows, 2000) and between the product and its environment (Akinnuli and Olugbade, 2014).

2.0 Materials and Methods

2.1 Materials

Before the electric-gas oven was constructed, a number of factors were taken into consideration. The size of the oven and the easy assembly of the oven parts. An electric gas oven was designed and fabricated to consist of a housing unit, power switch, thermostat, light indicator, temperature controller and timer, and heating element.

2.1.1 Housing unit

The parts that make up the overall system or mechanism of the electric-gas oven are included in its body as shown in Figure 1.

2.1.2 Locking device

This safety mechanism serves as a lock against heat leakage or other hazards.

2.1.3 Temperature controller

This regulates the amount of heat delivered to the food items inside the oven chamber; for the electric control system, we have a thermostat, and for the gas supply, we have a control nozzle.

2.1.4 Gas cylinder

This acts as the gas supply reservoir for the gas hob. Depending on the cost and size of the oven, gas cylinder is produced in a variety of sizes, including 3kg, 4kg, 6kg, 7.5kg, 12.5kg, 25kg, and so forth.

2.1.5 Pipe line/hose

This line supplies gas to the gas hob in the oven. It is built of reinforced rubber and fibre to ensure that there are no leaks at all, and the reinforcement gives it extra strength to endure very high gas pressures without bursting.

2.1.6 Powered fan

This is air-blowing mechanism to ensure an appropriate supply of heat that is evenly distributed throughout the oven chamber. To feed the oven chamber with the most heated air possible, uniformly, it has an a.c powered fan.

2.2 Description of the Oven

The housing component for the baking ingredients is an insulating material box. In order to prevent the transmission of too much heat and prevent over-roasting or burning, the heating element is fitted with a thermostat to control the rate of the generated heat in the system. The control or cables regulate the current flow to the heating element.

ISSN: 2714-3643
October, 2023

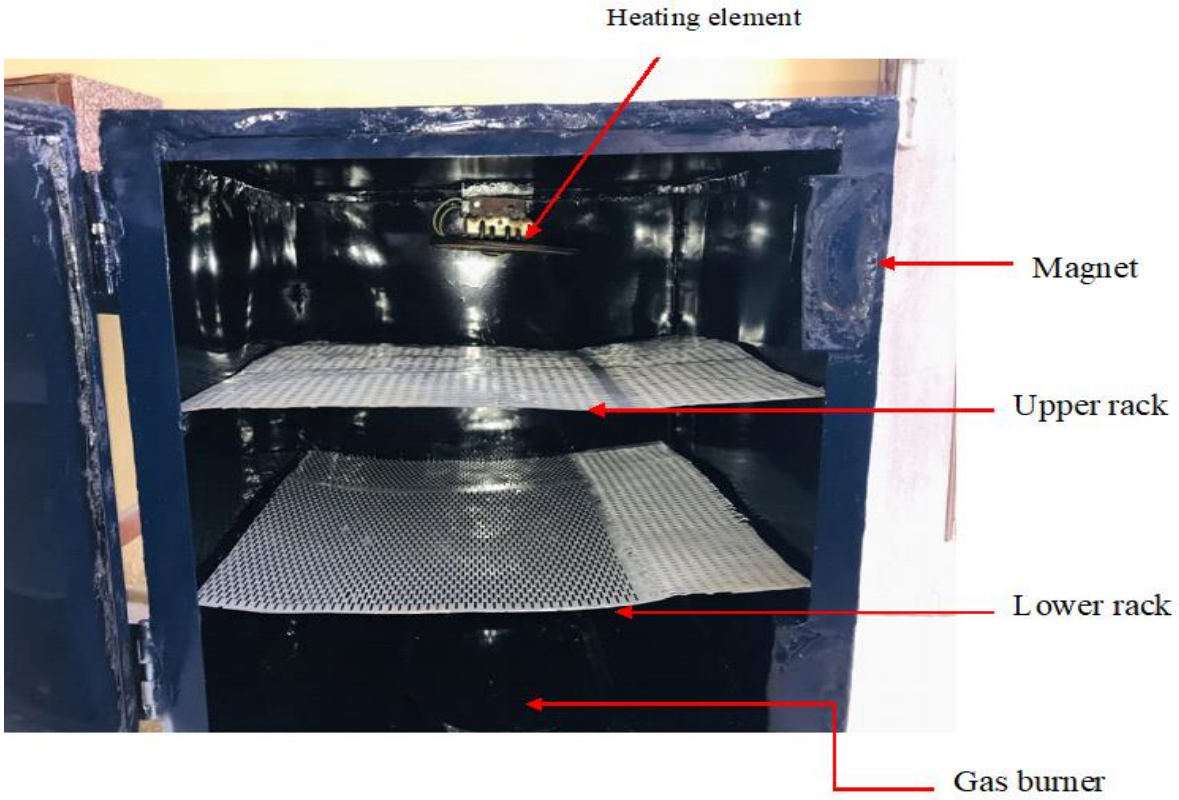

Figure 1: A full view of the Project

The process of heat transmission serves as the electric oven's fundamental operating principle after firmly welding of the parts (Abioye*et al*., 2017). The application of a relatively high temperature during baking removes moisture from baked goods and creates the desired texture, which typically consumes a lot of energy. Generally speaking, the temperature of the oven changes depending on the ingredients used to manufacture the food substance. Electric resistance is the basis for how the electric oven works. The heating element heated up as a result of the resistance to current flow, and a green light on the voltage indicator indicating current flow is evidenced. When the switch is turned on, the indicator turns red to indicate that the oven is functioning. In order to prevent heat loss to the body, the galvanized steel sheets were joined together by welding and then insulated with rock wool. The performance of an electric oven was thoroughly assessed, and the operating elements that must be taken into account when designing one were determined.



Figure 2: Power Side of the Oven

3.0 DESIGN ANALYSIS

A design of the electric-gas oven has been fabricated with the use of galvanized steel material using the following equations:

3.1 Size of Tray,

$$T_s = l_t * b_t \quad (1)$$

where:

T_s, l_t and b_t are the tray size, length of tray and breath of tray respectively.

Electric-oven capacity = n = size of tray/size of items in the oven (2)

Since the oven has a double tray;

Therefore, 2 * n = N number of items in the oven

3.2 Heating Operation of the Oven

$$Q = M_t * C_t(\mathrm{T} - T_0) \quad (3)$$

where:

M_t, C_t, T and T_0 are total mass of the items in the oven, total specific heat of the items in the oven, average oven temperature and oven room temperature respectively.

3.3 Power Dissipated in the Oven

$$P = VI \quad (4)$$

and

$$P = I^2R \quad (5)$$

$$P = \frac{V^2}{R} \quad (6)$$

Power of electric heating element,

$$P = \frac{Energy}{Time} \quad (7)$$

where:

P, V, I and R are the Rate of expenditure of Energy, Voltage in v, Current in A and Resistance in Ω

If the average processing time per batch is within 60 minutes, the quantity of heat supplied to the oven chamber is 1,498 kJ, considering 80% heat transfer to the painted metal (Heat = 1.2 x 1,498KJ =1,797.6KJ) This indicates that the heating element must provide the oven chamber with a minimum of 1,797.6 KJ of heat energy in 60 minutes.

Work done, $W = I \times V \times t$

Where: t = time in s, V =voltage in V and I = current in A

3.4 Heat by Conduction

Due to the interaction of nearby molecules that cause internal radiation to vibrate, food substances conduct heat. Using Fourier's law of conduction in a one-dimensional condition, which is mathematically stated as Eq. (8), the following is determined:

$$Q = \frac{KADT}{DX} \quad (8)$$

Where: Q is the rate of heat flow in Kw (KJ/secs), K is the material's thermal conductivity (W/mk), DT is the temperature differential between metal surfaces, DX is the material's thickness (m), and A is the area of the right-angled section (m2).

3.5 Heat by Convection

Conventionally, a mass of materials is moved between two places to transmit energy from one to the other. Eq. (9) is one way to write it out mathematically.

$$Q = LA\,[T2 - T1] \quad (9)$$

Where: [T2 T1] - thermal temperature, A - area of surfaces not perpendicular to direction of heat flow, L - coefficient of corrective heat transfer.

3.6 Heat by Radiation

The Stefan-Boltzman law determines the total radioactive flux over the hemisphere from the black surface of area "A" and absolute temperature T. It can be formulated mathematically as Eq. (10).

$$Q = A\sigma T^4 \quad (10)$$

Where: Q - heat flux, energy per second, A stands for area of heat flux intensity, for Stefan Boltzman constant (5.67 x 10 -8) 10/m 2 (K4), and T for absolute temperature.

4.0 Methodology

The electric-oven, which is composed of aluminium sheets, silicon rubber, and asbestos for insulation was built in a way that the electric coil heater is fitted to the first chamber while the gas burner is in the base chamber. The thermometer sensor was placed in the center portion of the upper chamber to detect the temperature of both the lower and the upper layer of the electric gas oven. The oven is provided with a vent at the top of the oven connected to the upper chamber for the continuous removal of the hot and humid air from the chambers.

The oven was provided with a handle attached to the door. The two trays provided in the oven were made of a perforated aluminium mesh of thickness 0.32 cm. The distance between the lower and upper trays of the oven was kept at 15 cm. The base of the inner baking chamber was provided with a deflector plate of a

ISSN: 2714-3643
October, 2023

thickness of 0.3.5 cm with a dimension of 24.4×20.22 (length × breath) cm placed at a height of 5 cm from the base of the oven to avoid the direct flame from the burner to the lower chamber and to the even distribution of the heat throughout the baking chamber as shown in Figure 1. To avoid injury from a body touching against the oven, the welded parts were made very smooth with ash colour paint.

The heat produced by the heating element is dissipated inside the oven chamber. It is transferred to the metal pans that are set on the wire mesh via convection. Due to its close proximity to the pans, the mixture is more prone to heat transfer by conduction. In order to avoid overheating, over-roasting, or burning, the thermostat controls the current flow to the heating element. The technique of heat transmission serves as the fundamental operating tenet of an electric oven. Every time there is a temperature differential, heat transfer by conduction, convection, and radiation tends to take place.

5.0 Testing Procedure

The electric gas oven was put to test in order to determine its functionality and effectiveness by baking some food items like cakes, cookies, and muffins. 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.

5.1 Results and Discussion

Cakes, cookies, and muffins were used as test items to assess how well the created system performed. The experiment was carried out with similar measurements and equal monitoring time. Figure 3 clearly show a relationship between cake size and baking time.

Baking of Cake

The system was set to a temperature range of 175-180^{0}C, and cakes of various sizes were baked there.

Bread Loaf, Muffins, and Cookies

The bread loaf is set at a temperature of 225^{0}C while the muffins are baked in an electric oven at 195^{0}C. The cookies were prepared using an electric oven, and the time taken for baking was shown in the table at the baking temperature of 166^0 C. The texture and color of the cookies and the bread loaf are great and acceptable, and the bread loaf, muffins, and cookies are all prepared in an even manner.

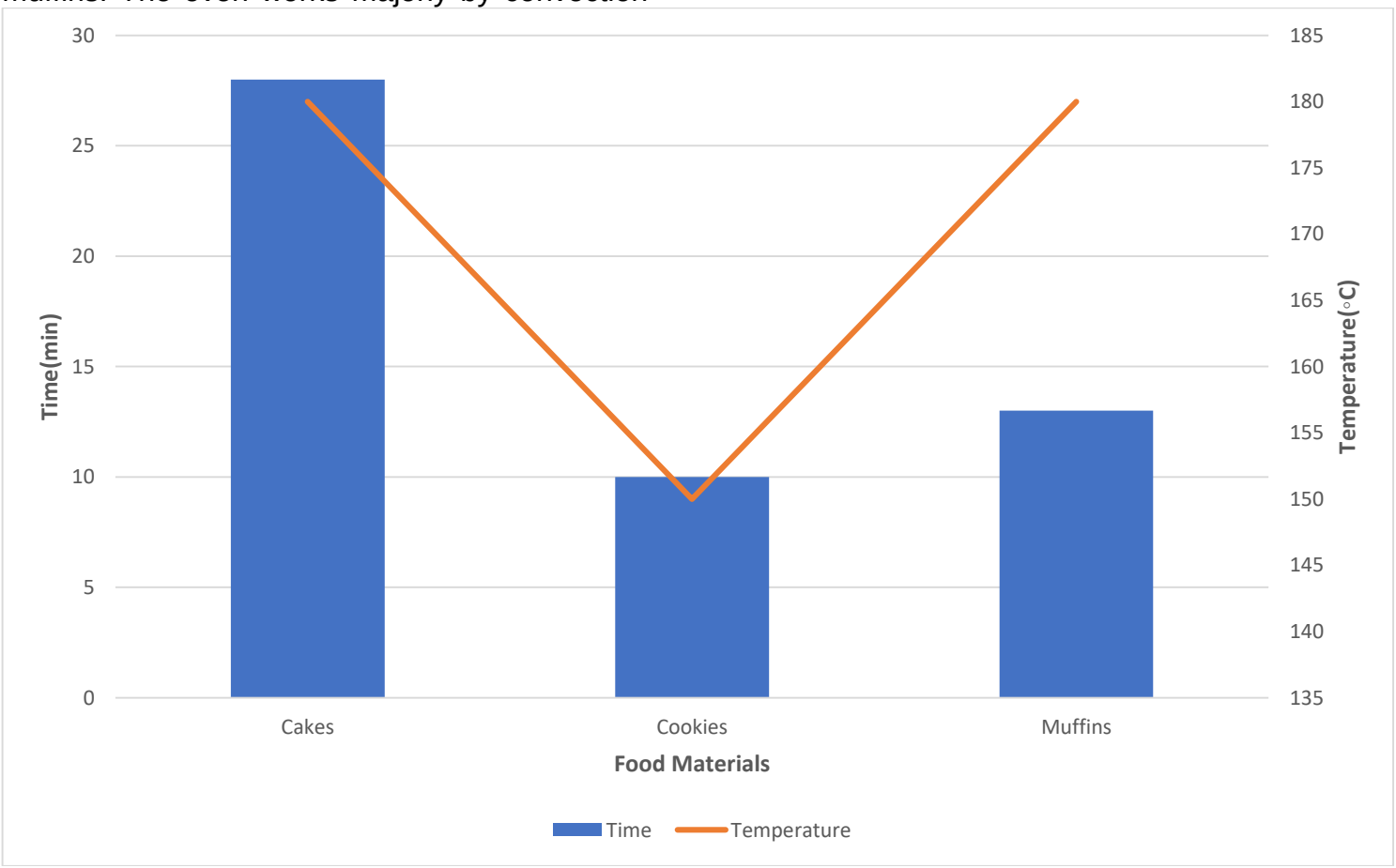

Figure 3: Temperature Ranges of the Items in the Oven

The results showed that the cake took 27 minutes to bake at 180°C, cookies took 9 minutes at 150°C, and muffins took 12 minutes at 180°C, demonstrating higher energy efficiency by reducing the energy, cost, and baking time.The drying process in the electric gas oven was observed to heat up to 250^0C, and the air around it heated to 200^0C.

6.0 Conclusion

An electric-gas oven was designed, constructed and tested at the Electrical/Electronic Engineering laboratory in Rufus Giwa Polytechnic Owo, Nigeria. The oven is suitable for domestic, and commercial baking and drying of food materials at 90 %. From the results, it is concluded that the oven will always be useful with very less energy and the overall working cost is reduced. The oven is simple to operate, portable and affordable. For the dual source of power, the oven is more reliable, serviceable and repairable than the available imported type. It is therefore recommended for both domestic and commercial use.

In summary, the temperature of the oven changes depending on the ingredients used to manufacture the substance. However, the amount of time needed to bake something varies on its size, shape, and oven temperature.

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