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Design and Construction of A Small Scale Charcoal Baking Oven

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Abstract- **The need for baked food has become a necessity in disgust. Bread and cakes has become part of our lives, as such an oven for baking of bread/cake become important. The production of different types of oven has grown rapidly over the years particularly baking oven for domestic use. But in our society today these ovens have been crippled by electricity power instability in the urban settlement and lack of electricity in the rural settlement because they largely depend on electricity. Therefore the need for baking oven not depending on electricity arises. Charcoal oven which is one of such oven, is cheap and efficient and can be used both in the rural and urban settlement for domestic consumption and small-scale business this oven uses little quantity of charcoal to bake at a short time.**

Keywords-- **baking, charcoal ,oven, Temperature, Time**

I. INTRODUCTION

Baking refers to a process "to cook by dry heat"and is therefore next to cooking another essential way of preparing food from raw staple crops. During the baking process the dough is transformed into eatable food (nutritional improvements) and at the same time, microorganisms causing spoilage are destroyed prolonging keeping time of the product (food preservation). Unlike other cooking methods, baking does not alter the nutritional value of the food item, e.g. the fat and calorie content of the food [1, 3, 4]. Usually, baking takes place in an oven or on a hotplate, but also in hot ashes or on hot stones. During baking, the heating process is done by a combination of three forms of heat: by infra-red energy that is radiated from oven walls, by circulating hot air; and by conduction through the baking pan or tray [3]. That means the efficiency of the baking process depends on the optimal use of three different parts of the device: the walls, the tray and the ventilation system [2, 10].

The dry heat of baking changes the structures of starches in the food and gives its outer surface a brown colour, giving it an attractive appearance and taste, while partially sealing in the food's moisture. The browning is caused by caramelization of sugars and the Maillard reaction. Moisture is never really entirely "sealed in", however over time an item being baked will become dry. This is often an advantage, especially in situations where drying is the desired outcome, for example in drying herbs or in roasting certain types of vegetables [5, 12].

II. BAKING USING CHARCOAL

Charcoal is a black substance that resembles coal and is used as a source of fuel. Charcoal is generally made from wood that has been burnt, or charred, while being deprived of oxygen so that what's left is an impure carbon residue. While charcoal is used in the manufacture of various objects from crayons to filters, its most common use is as a fuel [7]. One of charcoal's most common fuel uses is for cooking. Charcoal produces a heat that is hotter and burns cleaner than wood, making it ideal for cooking. Though charcoal as a heat source has been around for centuries, Henry Ford is credited with cornering the U.S market for mass produced charcoal for backyard grilling.The charcoal burns (oxidizes) provided there is sufficient oxygen at the fire-bed. At temperatures around 800 C, the carbon monoxide produced reacts with oxygen (again provided oxygen is available) just above the fire bed to give carbon dioxide. The charcoal will usually continue to burn long after the volatiles have been used up. A charcoal fire requires oxygen both at the fire bed (primary air) and just above the coals (secondary air). If there is insufficient secondary air, the fire will give off carbon monoxide, which can be dangerous to the stove user especially in enclosed spaces[8].

Charcoal oven has proven to be more efficient and effective than expected. Baking with charcoal gives you a lot of advantages, particularly in this part of the world where electricity power supply is a problem. The baking oven could be used both in the rural and urban settlement for small-scale business and also for domestic use. To solve our domestic need, a small-scale oven, which can be used at home, is needed and to a large extent a small-scale business can actually emerge and help in providing extra money for the family.

III. METHODOLOGY

3.1 Theory of Heat

Heat is energy in transit under the motive force of a temperature difference. Any theory should be able to explain the facts below;

i. Whenever there is an exchange of heat is consumed (heat lost by the hot body always equal to heat gained by the cold body
ii. The heat flow takes place from higher to lower temperature.

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iii. The substances expand on heating.
iv. In order to change the state of a body from solid to liquid or liquid to gas without rise in temperature, certain amount of heat is required.
v. When a body is heated or cooled its weight does not change.

According to the modern or dynamical theory of heat, Heat is a form of energy. The mean kinetic energy per molecule of the substance is proportional to its absolutes temperature [9].

3.2 Heat Transfer

Heat transfer many be defined as the transmission of energy from one region to another as a result of temperature gradient.

Heat transfer is as a result of temperature gradient. It takes place by the following three modes: (i) Conduction (ii) Convection (iii) Radiation.

Heat transmission in majority of real situations occurs as a result of combustion of the modes of heat transfer in a baking, heat transfer from the charcoal to the baking space and heat conduction through the oven walls. Heat always flows in the direct of lower temperature.

3.2.1 Conduction

Conduction is the transfer of heat from one part of a substance to another part of the same substance, or from one substance to another in physical contact without appreciable displacement of molecules forming the substance.

In solid, the heat is conducted by the following two mechanisms:

i. By lattice Vibration (the faster moving molecules or atoms in the hottest part of a body transfer heat by impacts some of their energy to adjacent molecules.
ii. By transfer of free electrons (free electrons provide an energy flux in the direction of decreasing temperature for the major portion of the heat flux except at low temperature.

In case of gases, the mechanism of heat conduction is simple. The kinetic energy of a molecule is a function of temperature. These are in continuous random motion exchanging energy and momentum. When a molecule from the high temperature region collides with a molecule from the low temperature region, its looses energy by collisions.

3.2.1.1 Fouriers Laws Of Heat Conduction

Fourier's laws of heat conduction are an empirical law base on observation and state as follows:

The rate of flow of heat through a simple homogeneous solid is directly proportional to the area of the section at right angles to the direction of heat flow and to changes of temperature with respect to the length of the path of the heat flow.

Mathematically, it can be represented by the equation [9]

$$Q = A \times \frac{dt}{dx} \quad (3.1)$$

Where Q = heat flow through a body per unit time (watt)

A = surface area of heat flow (perpendicular to the direction of flow) m2

dt = temperature difference of the face of block (homogeneous solid) of thickness dx through which heat flows °C or °K

dx = thickness of body in the direction of flow, m.

Thus $Q = A\frac{dt}{dx}$, where K = constant of proportionality and is known as thermal conductivity of the body.

For composite materials:

Total heat flow is given by [9]

$$Q = \frac{dT}{\sum R} = \frac{T_1 - T_2}{\sum R} \quad (3.2)$$

Where

$$\sum R = \frac{1}{h_i A} + \frac{1}{h_o A} + \frac{L_a}{k_a A} + \frac{L_b}{k_o A} + \frac{L_c}{k_c A} \quad (3.3)$$

Where:
R=resistance to heat flow
Hi and ho = inner and outer convective heat transfer co-efficient
A= cross sectional area
la, lb and lc= thickness of materials a, b, c
Ka, kb and kc =conductive heat transfer co-efficient for materials a, b, c

3.2.2 Convection

Convection is the transfer of heat with a fluid by mixing of one portion of the fluid with another. Convection constitutes the macro form of the heat transfer since macroscopic particles of a fluid moving in space cause the heat exchange.

The effectiveness of heat transfer by convection depends largely upon the mixing motion of the fluid.

This mode of heat transfer is met within situation where energy is transferred as hear to flowing fluid at any surface over which fluid occurs. This mode is basically conduction in a thin fluid layer at the surface and them mixing caused by the flow. The heat flow depends on the properties of the fluid and is independent of the properties of the material of the surface.

However, the shape of the surface will influence the flow and hence the heats transfer.

1. Free or natural convection -: free or natural convection occurs when the fluid calculates by virtue of the natural differences in densities of hot and cold fluid; the denser portions of the fluid move downward because of the greater force of gravity, as compared with the force on the less dense.

2. Forced convection:- When the work is done to blow or pump the fluid, it is said to be forced convection.

3 Newton law of cooling: states that the heat transfer from a solid surface of area A at a temperature t_w, to a fluid of temperature t, is given by

$Q = hA (t_w - t)$ -(3.4)

Where h is called the heat transfer co-efficient. It is used for heat transfer from a solid to a liquid and vice-versa.

3.2.3 Radiation

Radiation is the transfer of heart through space or matter by means other than conduction or convection.

Radiation heat is thought of as electromagnetic waves or quanta; an emanation of the same nature as light and radio waves. All bodies radiate heat so a transfer of heat by radiation occurs because hot body emits more heat than it receives and a cold body receives more heat than it emits. Radiant heat energy (being electromagnetic radiation) requires no medium for propagations and will pass through vacuum.

The properties radiant heat in general is similar to those of light.

Some of its properties are:

1. It does not require the presence of a material medium for its transmission.
2. Radiant heat can be reflected from the surface and obey the ordinary laws of reflection.
3. It travels with velocity of light.
4. Like light, it shows, interference, diffraction and polarisation
5. It follows the inverse square laws. The wavelength of heat radiations is longer than that of light waves; hence they are invisible to the eye.

3.2.3.1 Laws of Radiation

1. *Wien's law:* - it states that the wavelength ^m corresponding to the maximum energy is inversely proportional to the absolute temperature T of the hot body
2. *Kirchoffs law:* - it states that the emissivity of the body at a particular temperature is numerically equal to its absorptivity for radiant energy from body at the same temperature.
3. *The Stefan Boltzmann law:* – states that the emissive power of a black body is proportional to fourth power of its absolute temperature. I.e. $Q \propto T^4$

$Q = F\sigma A (T_1^4 - T_2^4)$ - (3.5)

F= a factor depending on geometry and surface properties

$\sigma =$ Stefan - Boltzmann constant = $5.67\times 10^{-8} w/m^2k^4$

A = area, m^2

T_1, T_2= Temperature degree Kelvin (K)

This equation can also be re-written as;

$$Q = \frac{T1 - T_2}{T1 +_1 T_2} \quad - \; - \; (3.6)$$

Where denominator is radiation thermal resistance

(R_{Th}) rad = F $\sigma A (T_1 + T_2)(T^2_1 + T_2^2)$ - - (3.7)

F =1 for simple cases of black enclosed by other surface

F = emissivity ε - for non−black surface enclosed by other surface.

Emissivity (ε) is defined as the ration of heat radiated by a surface to that of an ideal surface.

3.3 Calculations

3.3.1 Heat Emitted by Charcoal: The heat emitted by charcoal of recommended mass of 0.5kg was 17,220 kJ.

3.3.2 Heat Loss to Baking Space. The heat loss to baking space as calculated was found to be 9, 284 kJ.

3.3.3 Thickness of Insulation: The thickness of the insulation was calculated to be approximately 25 mm.

3.4 Construction

The materials used in the fabrication of the oven are: mild steel, angle iron, flat bars and square pipes. Aluminum foil was also used. The choice of these materials was based on their availability and affordability. Aluminium foil is also widely used for thermal insulation (barrier and reflectivity), heat exchangers (heat conduction) and cable liners (barrier and electrical conductivity). The oven was constructed in the Departmental workshop of Mechanical Engineering, Ahmadu Bello University Zaria using standard fabrication tools. Plate 1 to Plate 3 shows the views of the oven.

3.4.1 Oven Box: The oven box was made from one-millimetre (1mm) mild steel. Basically cutting and joining the metals together to make the box. The method of joining is Lapp joint. This method involves the bending and hammering the joint together. The choice of this metal sheet is because it is relatively light so that the box becomes easy to carry. The dimensions of the box are 80 x 50 x50 cm.

3.4.2 Charcoal Tray: The tray is also made from 1mm sheet of mild steel. It is formed by Lapp joint. The base of the tray is perforated using a drilling machine. Its dimensions are 80 x 40 x 20 cm.

3.4.3 Slide Door: The slide door is made from 1mm sheet of mild steel. It is simply cut and curved at one end to the handle. Its dimensions are 30 x 20 cm.

3.4.4 Asbestos: The inside of the oven box is lined with double of asbestos board to provide the necessary insulation for the oven.

3.4.5 Aluminium Foil: Aluminium foil is used to reduce heat loss through the oven wall by reflecting the heat back to the baking space.

3.4.6 Angle Iron: Angle iron is used to hold the aluminium foil and asbestos firm to the oven wall. Holes are drilled through the angle iron and oven wall. Screws are used to hold it firm. The angle iron provides a means of supporting the flat bars.

3.4.7 Flat Bars: The flat bar is used to support the baking pan. It is placed on the angle iron.

3.4.8 Cost of Production: The total production cost of the prototype oven was ₦5,200 ($30) only. However, with mass production the unit production cost will be less. This is because the material purchase will be in bulk and there will be minimal waste.

IV. Testing Result And Discussions

0.2kg of charcoal was used for the baking of bread. It took 25 minutes to bake at 140 ^{o}C . The initial temperature of the oven was 33 ^{o}C. The baking of the bread took place after baking of the cake. The cake was baked at a Teperature of 120 ^{o}C and the time taken was 28 minutes. The maximum temperature of the oven was 220 ^{o}C The outer oven temperature was 63 ^{o}C. Mercury in glass thermometer was used to determine the temperatures of the oven (thermometer of range 0-110 ^{o}C and of range 140-300 ^{o}C). Plate 4 to Plate 7 shows the stages of the baking processes and the baked items. From the test results, the charcoal oven prototype can be used for baking both in rural and urban settlements especially in the Northern part of Nigeria. The results also agree with [2, 6, 10, 11] recommendations respectively.

V. Conclusion

It was amazing to discover such an efficient and highly economical oven. With a very small quantity of charcoal, bread can be baked in a short time. What is even more interesting is that it does not depend on electricity for heat supply. The charcoal provides the heat supply and it is readily available at a cheap rate.

VI. Recommendation

This oven is a wonderful piece for small-scale business. You have a combination of efficiency and availability of raw materials. The oven can be used both in rural and urban settlements. The oven is an advantage largely because of electricity power instability. The Federal and State Government should assist in the mass production of this oven to the end users.

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Figure 1: Baking Oven in Construction
Figure 2: Baking Oven after Construction

Figure 3: Ignited Charcoal before baking
Figure 4: Dough before baking

Figure 5: Dough in oven before baking
Figure 6: Cake in oven just after baking

Figure 7: Cake after removal from oven
Figure 8: Cake served and ready for eating