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Development and Evaluation of Charcoal-Powered Bread Baking Oven

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Charcoal-powered bread baking oven was developed and evaluated with functional efficiencies of 91.2% and 92.1% for baking dough of mass 0.5kg and 1.5 kg to bread at BP of 27.7minutes, 35.9 minutes with the baking temperature (BT) of 153.8^{o}C and 165.9^{o}C respectively. Baking temperature-heating interval of the oven as computed at 100^{o}C at 20 minutes at charcoal emitted heat of 861000 KJ. The oven has the capacity of generating 455.9^{o}C at 270 minutes time interval. The oven has bread baking capacities of 56, 36, 28, 22 and 18 pieces of bread per batch operation using dough mass of 0.5kg, 0.75kg, 1.00kg, 1.250kg and 1.500kg respectively. It is sensitive to the baking time and temperature in relation to dough mass with resolution value of 0.22. Charcoal-powered oven, is cheap and efficient and can be used both in the rural and urban settlement for domestic consumption and small-scale business.

Keywords: *charcoal, oven, bread, temperature, baking bread, dough, resolution*

1. 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 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]. An oven is thermally insulated with chambers in which heat is generated and conserved within it and can be applied to a variety of heating processes. Domestically a bread oven can be used for baking, roasting of foods such as cakes, breads and also drying of fishes and meat [2].

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 [3]. 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.

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 [4]. 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.

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 [5]. 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 [6]. Having considered the associated constraints with electric oven such erratic power and poor coverage of power supply in some of Nigeria villages and towns, this research study is therefore focused on the design and construction of a portable charcoal-powered bread baking oven.

2. Materials and Methods

2.1. Design considerations

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). Plate 1 and 2 show the views of the oven. The component parts of the oven are comprehensive described below.

2.1.1. Design calculations

i. Heat Emitted by Charcoal*:*

The heat emitted by charcoal of recommended mass of 5.0 kg was 1722000 KJ. [1] mathematically calculated emitted heat as follows:

$$Q = A * \frac{\mathrm{dt}}{\mathrm{dx}} \qquad (1)$$

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

A = surface area of heat flow (perpendicular to the direction of flow) m^2
dt = temperature difference of the face of block (homogeneous solid) of thickness dx through which heat flows in ^0C or ^oK.
dx = thickness of body in the direction of flow, m.

$$Q = \frac{dT}{\sum R} = \frac{T1 - T?}{\sum R} \quad (2)$$

$$\sum R = \frac{1}{hiA} + \frac{1}{hoA} + \frac{La}{KaA} + \frac{Lb}{KbA} + \frac{Lc}{KcA} \quad (3)$$

Where:
R=resistance to heat flow
Hi and ho = inner and outer convective heat transfer coefficient
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

ii. Heat Loss to Baking Space

The heat loss to baking space as calculated was found to be 10, 284 kJ.

iii. Thickness of Insulation*:*

The thickness of the insulation was calculated to be approximately 35 mm.

2.1.2 Capacity of the Oven

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

i. Mass of dough (Before baking) = (500g) 0.5kg

Size of tray = 0.9 m (length) x 0.8 m (width) = 0.72 m^2

Size of bread (Dough after baked) considered

= 0.16 m (length) x 0.08 m (width)= 0.0128 m^2

Capacity of Oven using dough mass of 0.5 kg:

= Size of tray / Size of bread
= 0.72 / 0.0128 = 56 pieces of bread per batch

ii. Mass of dough (Before baking) = (750g) 0.75kg

Size of bread (Dough after baked) considered

= 0.18 m (length) x 0.11 m (width)= 0.0198 m^2

Capacity of Oven using dough mass of 0.75 kg:

= Size of tray / Size of bread
= 0.72 / 0.0198 = 36 pieces of bread per batch

iii. Mass of dough (Before baking) = (1000g) 1.000kg

Size of bread (Dough after baked) considered

= 0.20 m (length) x 0.13 m (width)
= 0.026 m^2
= 0.72 / 0.026 = 28 pieces of bread per batch

iv. Mass of dough (Before baking) = (1250g) 1.250kg

Size of bread (Dough after baked) considered

= 0.22 m (length) x 0.15 m (width) = 0.033 m^2

Capacity of Oven using dough mass of 1.250 kg:

= Size of tray / Size of bread
= 0.72 / 0.033 = 22 pieces of bread per batch

v. Mass of dough (Before baking) = (1500g) 1.500kg

Size of bread (Dough after baked) considered

= 0.24 m (length) x 0.17 m (width) = 0.0408 m^2

Capacity of Oven using dough mass of 1.500 kg:

= Size of tray / Size of bread

= 0.72 / 0.0408 = 18 pieces of bread per batch

`2.1.3. Heat Requirement

Average baking (oven) temperature = 400-450^oC = 673.2K

Let, Md = Mass of of dough, 0.5kg

Cb = Specific heat capacity of bread, 2900J/kgK (Vogel, 2005)

TRM = Oven room temperature, 30.2^0C = 303.4K

Heat required:

$QH = Md \times Cb \times TRM$ (4)

QH = 0.5 kg x 56 x 2900J/kgK x (673.2 – 303.4)

K = **30027760 Joules**

This is the quantity of heat required to bake 56 pieces of bread per batch.

2.1.4. Energy Requirement

Heat formation of Carbon IV Oxide;

$C (s) + O_2 (g) \; CO_2 (g)$ -------- 493.5 kJ (5)

Heat formation of water vapour;

$2H (g) + O (g) \; H_2O (g)$ --------- 241.8 kJ (Vogel, 2005) (6)

The combustion reaction of methane is given by;

CH_4 (g) + $2O_2$ (g) CO_2 (g) + $2H_2O$ (g) + Heat (kJ) (7)

Also heat of combustion of methane = 104.8 kJ

Thus, Total Heat involved in the combustion reaction of methane is:
(Heat of formation of CO_2 + 2 x Heat of formation of H_2O) – (Heat of combustion of CH_4 + 2 x Heat of combustion of O_2) =

-493.5kJ + 2 x (-241.8kJ) – (-104.8kJ + 2 x 0kJ) = **- 802.3 kJ** (8)

Thus, total heat involved in the combustion reaction of methane is **- 932.3kJ** (note that the negative sign indicates that the reaction emits heat to the environment, i.e. exothermic reaction)

3. Results and discussion

3.1. Calibration of charcoal-powered bread baking oven

The constructed oven was subjected to calibration test in order to determine the heating capacity of the developed oven by powering with 2.5 kg of charcoal for 270 minutes. The calibration result is shown in table 1. Maximum temperature of 455.9 0C, 729.1K was obtained at heating period (HP) of 270 minutes with initial room temperature of 30.2 0C at (HP) of 0.0 min. Calibration analysis in fig.1 shows there is a strong relationship between the generated oven temperature and the heating period (HP) with the R^2 values of 0.98 and 0.94 for both logarithm and linear trend iterations. Baking temperature-heating interval of the oven as computed at 100^oC at 20 minutes at charcoal emitted heat of 861000 KJ.

Table 1. Calibration of charcoal-powered baking oven

N/S	HP(mins)	Temp(^oC)	K
1	0.0	30.2	303.4
2	30.0	155.7	428.9
3	60.0	209.4	482.6
4	90.0	256.7	529.7
5	120.0	289.7	562.9
6	150.0	315.9	589.1
7	180.0	367.9	641.1
8	210.0	398.4	671.6
9	240.0	408.9	682.1
10	270.0	455.9	729.1

Source: Experimental data, 2015

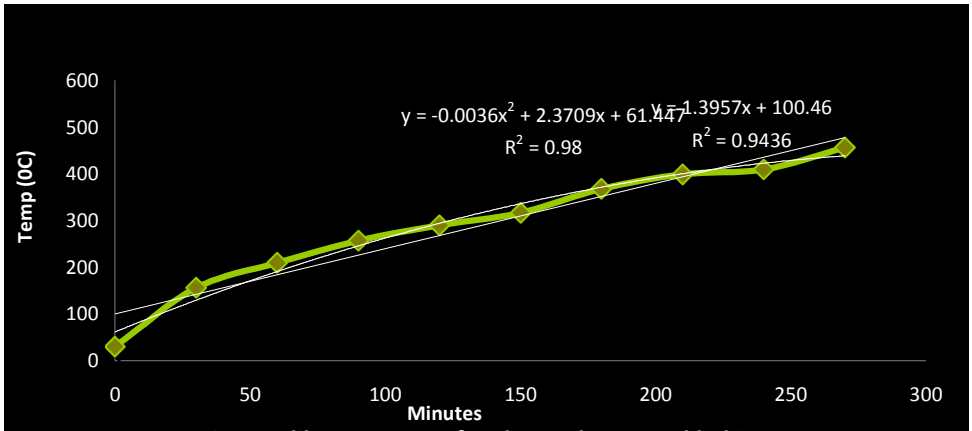

Fig 1: Calibration curve for charcoal-powered baking oven

3.2. Performance test

The efficiency of an oven was determined using variables such time taken to bake a batch of dough to the desired taste, colour, texture and moisture content. The performance test shows the baking period, baking temp and different dough mass (g) as shown in table 2. It took approximately 27.7 minutes at oven temperature of 153^{o}c to bake a batch of dough 500g to the desired quality against the designed temperature and time of 145.7^{o}C and 25.3minutes. Maximum (BT) of 165.9^{o}C was obtained at 35.9 minutes for baking dough of mass 1500g to required standard. The designed baking temperature and period for dough of 1500g are 160.7^{o}C and 33minutes respectively. The oven baking efficiencies for dough 500g and 1500g were 91.3% and 92% respectively. Different sizes of dough were baked to examine the effect of dough mass on baking time and temperature. Figure 3 and 4 show the result obtained. There is strong relationship between the dough mass, baking period-temperature with R^2 = 0.9567 and 0.8619 respectively.

Table 2. Testing of charcoal-powered bread baking oven

N/S	Dough (g)	BP (Mins)	BT(^{o}C)
1	500	27.7	153.8
2	750	28.3	160.9
3	1000	32.2	162.4
4	1250	34.8	164.3
5	1500	35.9	165.9

Source: Oven performance output, 2015

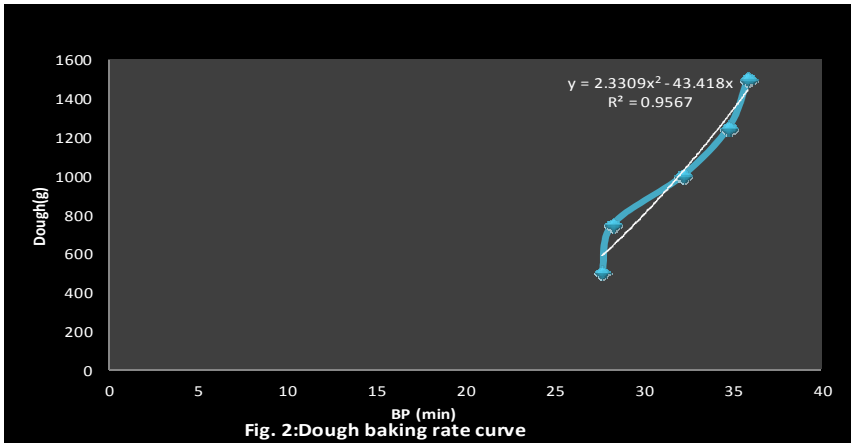

Fig. 2:Dough baking rate curve

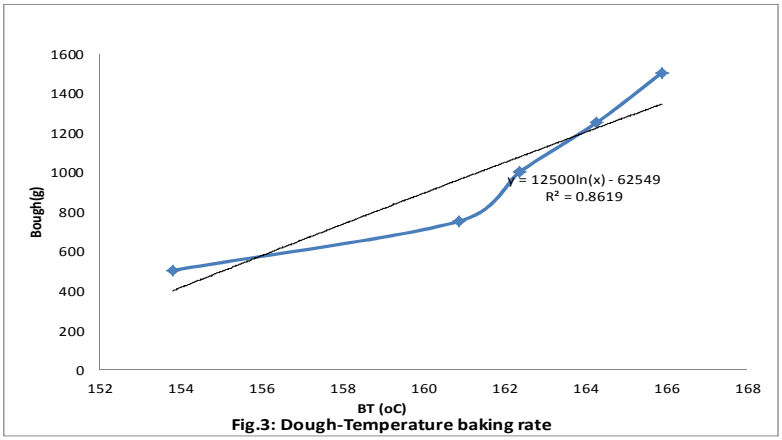

Fig.3: Dough-Temperature baking rate

4. Conclusion

The charcoal-powered bread baking oven is highly effective and sensitive to the mass of dough in relation to baking period and temperatures. It is further observed that there is less marginal increase in baking time as the size of dough is increased beyond a certain point. The high efficiency of 91.3 and 92% obtained with baking dough of mass 500g and 1500g were attributed to the 15 % allowance for sensible heat transfer considered in the design. Excess heat would destroy the dough. With a very small quantity of charcoal, bread can be baked in a short baking time. The oven does not rely on electricity for heat supply, but mainly on charcoal which is readily cheap and available .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.

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