Leonardo Journal of Sciences
ISSN 1583-0233
Issue 31, July-December 2017
p. 45-64

Development and optimization of operational parameters of a gas-fired baking oven

Afolabi Tunde MORAKINYO[1,*], Babatunde OMIDIJI[2], and Hakeem OWOLABI[2]

[1]*Department of Food Science and Technology, Faculty of Technology, Obafemi Awolowo University, PMB 13, Ile-Ife, Osun State, Nigeria*
[2]*Department of Mechanical Engineering, Faculty of Technology, Obafemi Awolowo University, PMB 13, Ile-Ife, Osun State, Nigeria*
E-mails: morakzotec@yahoo.com (*); bcomidiji@yahoo.com; howolabi@gmail.com

* Corresponding author: phone: +2348034207373

Abstract

This study presented the development and optimization of operational parameters of an indigenous gas-fired bread-baking oven for small-scale entrepreneur. It is an insulated rectangular box-like chamber, made of galvanized-steel sheets and having a total dimension of 920mm×650mm×600mm. This oven consists of two baking compartments and three combustion chambers. The oven characteristics were evaluated in terms of the baking capacity, baking efficiency and weight loss of the baked bread. The physical properties of the baked breads were measured and analyzed using Duncan multiple range test of one way ANOVA at significant level of $p<0.05$. These properties were optimized to determine the optimum baking temperature using 3D surface response plot of Statistical Release 7. The baking capacity, baking efficiency, weight loss and optimum baking temperature were: 12.5 kg/hr, 87.8%, 12.5 g, 200-220°C, respectively. The physical properties of baked bread dough were found to correspond with the imported product (control sample). These results showed that, the developed gas-fired baking oven can be adopted for baking of bread at domestic and commercial levels.

Keywords
Baking efficiency; Baking capacity; Weight loss; Combustion chamber; Baking compartments; Optimum temperature; Physical properties, Oven characteristics

Introduction

Almost in every continent, bread has become one of the most widely consumed non-indigenous foods and it is the second most widely staple food after rice [1]. More importantly, it is a ready to eat convenient food in Africa for both urban and rural communities. It is made from wheat flour dough that is cultured with yeast, proofed and baked inside oven [2]. There are many combinations and proportions of type of flour and other ingredients, likewise different traditional recipes, which resulted to wide varieties of breads, likewise in terms of shapes, sizes and texture [3]. In addition to bread, baking is used to prepare biscuit, cakes, pastries, pies, cookies and crackers. 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 [4]. During baking, the driving force of heat transfer is the temperature gradient while that of mass diffusion is concentration difference. However, both occur simultaneously within the food product from the outer part to the inner part of the food material. It was reported that during baking the moisture diffusion in the food material occurs mainly by convection and conduction, less by radiation [5]. Hence, the product loses moisture as baking continued. This author also reported that for the effective baking, heat losses should be minimal. Hence, in Nigeria, indigenous baking ovens are wood fired or electric types that were made from mud, metals and non-metals. Their shortcomings are: longer baking time, non-homogenous heat distribution and thermal energy losses which resulted to increase in the cost of production, likewise air pollution [6].

In Nigeria, increasing population, rapid urbanization, and changing food habits have resulted to preference for ready to eat convenient foods such as bread, biscuits, and other baked products, despite the increase in their prices [7-8]. Unfortunately, in Nigeria, the large-scale bakers utilize the imported ovens, which are unaffordable to small-scale or household bakers [6]. Presently, irregular supply of electricity in Nigeria has rendered electric baking oven unproductive across the all level of operations. Therefore, there is a need for the development of an indigenous gas-fired bread-baking oven, with the enormous availability of liquefied gas in Nigeria. It was reported that gas-fired baking oven enhances flavour and uniform distribution of heat transfer better than any type of oven [9-10]. It was also reported that the gas-fired oven is cheaper to run than diesel-fired oven, more so that it produced less greenhouse gas which resulted to global warming effect [2]. Hence, the aim of this work was to develop and evaluate a gas-fired bread-baking oven for small-scale entrepreneur at affordable cost using local contents approach.

Material and method

The materials used for the construction of this unit operation are represented in Table 1.

Table 1. Materials for the bread baking oven

S/N	Material	Source	Use
1	Galvanized steel sheets of varying thicknesses	Alaba Market, Lagos, Nigeria	For construction of inner and outer frames, outer cover and baking compartment
2	Seamless steel pipe	Alaba Market, Lagos, Nigeria	For construction of gas line and heat exchangers
3	Fibreglass	Alaba Market, Lagos, Nigeria	For insulation
4	Angle Iron	Alaba Market, Lagos, Nigeria	For oven stand
5	Regulator and thermocouple	Alaba Market, Lagos, Nigeria	As transducers

Design calculations

The capacity of the oven is directly proportional to the number of bread loaves/batch and baking pan dimensions (size of the baking pan and the dough weight).

Assume average weight of bread = 250 g as design basis, having volume of 1.17×10^{-3} m^3

Bread surface area = 0.018 m^2. The surface area occupied by 20 loaves of bread = 0.36 m^2.

Two baking compartments dimensions are then established as follows:

- The Surface area of baking tray for each compartment = 0.2 m^2
- The vertical height of the baking compartment proposed = 0.18 m

Therefore, Capacity of the oven = 0.036 m^3

Volume of the heat exchanger

The efficiency of the heat transfer depends on the volume of the heat exchanger and atomizing efficiency of the burners. Hence, the volume of heat exchanger is calculated as:

$$V = l \times b \times h \quad (1)$$

where l = length of the baking chamber (450 mm); b = width of the baking chamber (400 mm), h = height of the baking chamber (120 mm); Volume = 0.036 m^3

Energy generated by the heat source (gas burner)

The energy generated is given by the Eq(2) [11]:

$$H_g = H_p + H_c + H_m \quad (2)$$

where H_g = the quantity of heat produced by the gas burner; H_p = the quantity of heat gained by food product (Bread dough); H_c= the quantity of heat radiated to the heating chamber; H_m= the quantity of heat conducted through lateral walls (galvanized steel sheet)

$$H_p = M_p C_p \Delta T \ [11] \quad (3)$$

where M_p= Mass of food product; C_p= Specific heat capacity of food product (Bread dough = 2890J/kgK) [12]; ΔT_p= Change in temperature.

Baking of the dough for 30 minutes with 20 bread dough pieces at a time, while the an average dough weight is 250 g, hence total weight of dough is 5.0 kg, Hence, H_p = 4.3MJ

Energy radiated

The quantum of energy radiated was estimated using Equation 4 [11].

$$H_c = \delta (T_1^4 - T_2^4) \quad (4)$$

where δ = The constant of Stefan-Boltzmann (5.669×10^{-8} W/m^2K^4); T_1= Initial temperature of surrounding air, T_2 = Final temperature of surrounding air; H_c = 9.45 MJ

Thermal conductivity to the two baking chamber

The thermal conductivity of the baking chambers was calculated using Equation 5 [13].

$$H_m = KA\ (T^1 - T^2)/L \qquad (5)$$

where K = Carbon steel conductivity (54 Wm/K), A = Area of the baking chamber = 0.18 m^2; L = distance between the dough and the heating element (0.120 m); H_m = 28139.4 J/sec m^2 for 30.0 min. = 50.7 MJ/m^2 for the two compartments = 101.4 MJ/ m^2, for the baking compartment surface area of 0.36 m^2 , H_m= 36.5 MJ

The energy generated by butane gas

However, the energy generated using butane gas was estimated as depicted below:

- The calorific value of butane = 45.752 MJ/kg
- Total butane consumed for 30 min. = 1.25 kg
- Total energy generated by butane as input = 57.19 MJ

Description of the major working components

The assembly drawing and exploded views of the oven are shown in Figures 1 and 2, respectively.

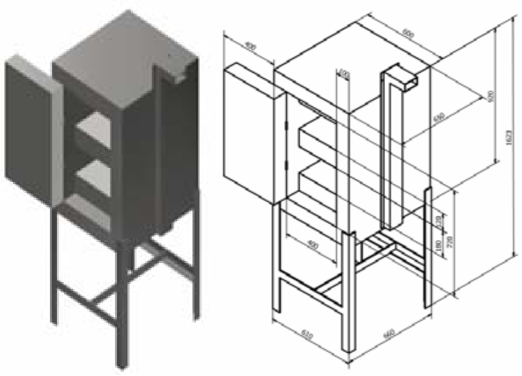
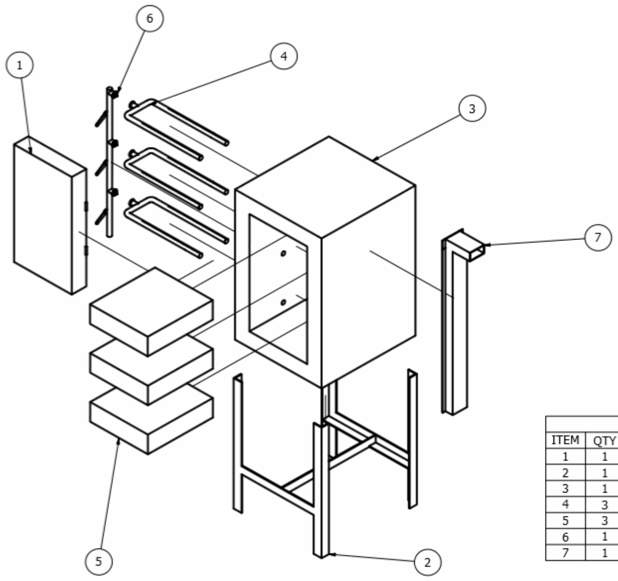


***Figure 1**. Solid view and assembly drawing of the gas fired oven*

The inner frame outer cover

This is made of galvanized steel sheet of 2.5 mm thickness internally and 1 mm externally. All the six walls were lagged with glass wool, having coefficients of thermal conductivity of 0.45 W/m°C. The gas-fired oven is a rectangular box-like chamber of 920mm×650mm×600mm shown in Figure 3.



PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Door	Stainless steel insulated
2	1	Stand.	steel mild
3	1	Body	Stainless steel insulated
4	3	Burner	steel mild
5	3	Gas combustion chamber	Stainless steel insulated
6	1	Gas delivery line	steel mild
7	1	Chimney	Stainless steel

Figure 2. *Exploded view of the oven*

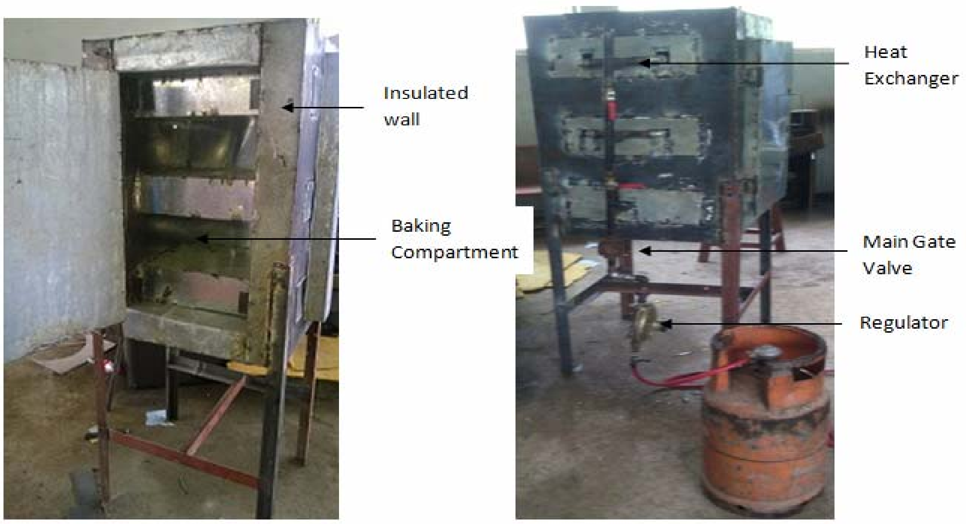


Figure 3. *Fabricated gas-fired bread baking oven*

The oven was designed such that the bread dough is loaded on the top surface of the two baking compartments. Each baking compartment has its own heat exchanger at the top and bottom for the effective heat and mass transfer during baking of bread dough.

Gas burner

This is made of seamless steel pipe of ϴ 25 mm. It was fabricated into a u-shape, drilled along its longitudinal length of 350 mm with 2.0 mm drill bit size to form a burner. A gas nozzle of 0.95 size was fitted to the inlet part of the burner, while the outlet part was closed to retain gas pressure for effective atomization. On the gas burner pipe there is an opening for atmospheric air admittance regulated with a shutter to enhance appropriate fuel and air mixture of a lean mixture.

The three gas burners were arranged inside the three heat exchangers vertically, with the help of a gas pipe. Each burner has its control gate valve for the regulation of gas flow rate. During baking operation, butane is discharged from the gas cylinder, which flows through the regulator to the main supply line then to the nozzle via a gas valve, and finally atomized through burner for combustion inside heat exchanger.

Heat exchanger

There are three heat exchangers in this gas-fired oven shown in Figure 3 as gas combustion chambers. They are made of galvanized steel sheet of 2.0 mm thickness with these dimensions: 400 mm×650 mm×120 mm. The three heat exchangers are connected to a common chimney which helps to vent exhaust gas from the heat exchangers. During evaluation of the oven performance thermocouples were installed to measure the temperature values both at the out wall and baking compartments.

Baking compartment

There are two baking compartments, where baking tray is suspended. They are the outer part of heat exchangers, having dimensions of 400 mm×450 mm×180 mm as shown in Figures 1 and 2. This baking oven has three heating exchangers for effective heat transfer from its bottom and top plates of each baking compartment.

The door

Both inner and outer walls of the door are made of galvanized sheet material of 2.5 mm and 1.0 mm respectively. The dimension of the door is 100 mm×450 mm×720 mm. It was hinged to the inner frame of the oven at two points to enhance adequate suspension. The door is lagged with glass-wood to prevent heat loss to the environment and baker.

The supporting frame

These are four legs that suspended the baking oven vertically. They are made of mild-steel angle iron of 75mm×75mm×3.0 mm.

Regulator

A gas regulator of 0 - 12 bar pressure value was installed to built-up gas pressure and to regulate the flow rate consistently on gas delivery line. It was located in between the gas cylinder regulator and the main gate valve.

Thermocouple

Four thermocouples were installed in each baking compartments and heat exchanger for measuring the temperature values during baking operation.

Dough preparation

The bread dough was prepared by mixing 2.8 kg of flour, 24.2 g of salt, 100 g of butter, 25 g of yeast, 3.0 litre of water and 50 g of sugar using a planetary dough mixer for 5 min. The dough was then divided into required measurements and kneaded into a ball shape. The kneaded dough was divided and weighed into 200, 250, 300, 350, 400, 450 (g) as one set. Three sets were made in triplicates, then moulded and placed inside clean and oiled baking-pans of six different sizes to develop moist surface. A set of six sizes of moulded dough was placed inside a proofer for 1 hour 30 min. at 45 ^{o}C. During the proofing process, alcohol is produced with carbon dioxide due to fermentation of sugar content by the yeast. This resulted to dough rising to almost a doubling height. After the proofing process, they were transferred and properly arranged on the baking tray then loaded inside oven and baked for 30 min at 180^{o}C temperature [9, 14]. These procedures were observed for other two sets of six-moulded dough at 200 and 220^{o}C baking temperature consecutively. The physical dimensions at an interval of 5 min. of loss in the weight and vertical height of dough were measured at a varying baking temperature.

Performance evaluation of the gas-fired oven

After fabrication of the oven, the performance evaluation based on the machine characteristics was carried out to establish optimum baking temperature at constant time, likewise the baking efficiency and capacity of the oven.

Baking capacity

The number of pieces of the bread dough in each baking compartment depends on the arrangement of the food samples in the baking chamber. The baking capacity of the oven was determined by putting into consideration the size of the baking pan and the dough weight.

Baking efficiency

The Baking efficiency of the oven is calculated using the Equation 6 [9].

$$\text{Baking efficiency, n} = (\text{Output energy})/(\text{Input energy})\times 100 \quad (6)$$

Weight loss in the food samples

The weight loss in the food samples (bread dough) was calculated by subtracting the weight of the food sample after heating from the initial weight of the food sample. The percentage of moisture loss was obtained using Equation 7.

$$\text{Weight loss} = (\text{Initial weight}) - (\text{Final weight}) \quad (7)$$

$$\%\ \text{Moisture loss} = [(\text{Initial weight}) - (\text{Final weight})]/(\text{Initial weight})\times 100$$

Oven spring

The sudden rise or rapidly expansion of dough during the first ten minutes in the oven is called oven-spring. Several factors may influence oven-spring such as: the quantum of heat energy and increase in volume of dough, moisture content, carbon dioxide and ethanol evaporation rate. All these causes increase in internal pressure of dough and the dough rises rapidly in the initial stage of baking. The yeast activity decreases as the dough warms and the yeast is inactivated at 55ºC [15]. This oven-spring of the baked bread dough was measured in terms of vertical height using a digital vertical-height venial calliper (0 - 300 mm, Mutitoyus, Germany).

Physical properties of the food sample

For the effective investigation of the oven-spring of the baked bread, these other physical properties were evaluated in terms of surface area, specific volume, density and relative density. Each property was determined using the mathematical Equations 8 - 11.

$$\text{The surface area} = 2(lb + bh + lh) \quad (8)$$

$$\text{Volume} = \text{length} \times \text{breadth} \times \text{height} \quad (9)$$

$$\text{Density} = (\text{mass})/(\text{volume}) \quad (10)$$

$$\text{The specific volume} = (\text{volume})/(\text{mass}) \quad (11)$$

Statistical analysis

The data of the physical properties of the baked bread dough of the developed oven and the imported proto-type (gas-fired baking oven in the Department of Food Science and Technology, Obafemi Awolowo University, Ile-Ife, Nigeria) was analyzed using Duncan multiple range test of one way ANOVA at significant level of $p<0.05$. The optimum baking temperature was also investigated and established using 3D surface response of STATISTICA Release 7.

Results and discussion

Performance evaluation of the gas-fire bread baking oven

During the baking process, the initial bread dough of white colour changed to varying degrees of brownness as baking temperature increased. The final product had an outer layer that is semi-rigid less fragile structure called the crust layer while the inner part of the dough had a crumb texture. Figures 4a, b and c depicted level of browning reaction of baked dough at various temperatures (180, 200, 220^{o}C). Both physical and bio-chemical changes of dough occurred as a result of heat and mass transfers through several mechanisms such as: convection, radiation, conduction, evaporation and condensation of steam. Generally, it was observed that starch gelatinization begins as baking temperature increases with subsequent amylase activity and gluten coagulation. The gluten matrix surrounding the individual cells transformed into a semi-rigid film structure and almost doubling oven-spring rate for every 10°C increase of temperature. It was also observed that the rate of oven-spring was higher at 220^{o}C baking temperature than other baking temperatures and that browning reaction increases as baking temperature increases (Figures 4 a-c). It was established further that visible browning reaction was more pronounced at baking temperature of 220^{o}C than any other lower temperature value as depicted in Figure 4. This browning reaction is chiefly responsible for the development of the attractive bread flavour and typical browning coloration of the bread crust which enhances the firmness. These observations were in agreement with the previous researchers. It was reported by [16] that increased in the baking time from 70 to 210 minutes and increased in the baking temperature from 220 to 260^{o}C

Issue 31, July-December 2017
p. 45-64

resulted to 5 or 3 fold increased in the migration of antioxidant content to the crust. More importantly, [17] reported on the basic mechanism of heat and water transport during bread and biscuit baking process and they postulated that the major transport phenomenon that occurred during confectionary baking is evaporation-condensation of water and not heat conduction. It was observed during this experiment that baking temperature and time depending on type of oven, recipes and thickness of the product. Furthermore, other researchers [10] reported that at different size of cake baked at a temperature range of the 170-180 ^{o}C using gas oven developed, the size of the cake is relative to baking time.

(a) **(b)** **(c)**

Figure 4. Bread baking at various temperatures of (a) 180^{o}C; (b) 200^{o}C; (c) 220^{o}C

Baking capacity

The gas-fired baking oven has two baking compartments, in each compartment, a total of 10 pieces of bread dough in baking pans of size 145 mm × 90 mm × 60 mm was attained. The baking chamber of the fabricated gas-fired bread baking oven has a volume of 0.036 m^3, can bake 20 pieces of bread dough in one batch. Therefore, the gas-fired baking oven has maximum baking capacity of 12 kg/hr.

The baking efficiency

The baking efficiencies increased relatively with increase in the baking temperatures. Table 2 presents this trend. The optimum baking efficiency of the oven occurred at the baking temperature of 220^{o}C most especially when the weight of dough was increased to 450 g. This may be due to the increased in the surface area of the bread dough to absorb maximum thermal energy dissipated from the heat exchangers. The baking efficiency of the gas-fired bread baking oven was obtained using calorific value of the butane as liquefied petroleum gas estimated as 87.8% as shown in Table 2.

Table 2. Baking efficiency of the gas–fired oven

Weight of Dough	**Baking efficiency (%) for different baking Temperatures (^oC)**		
	180^{o}C	**200^{o}C**	**220^{o}C**
200	85.45	85.80	86.80
250	85.47	86.85	86.85
300	85.49	86.95	87.90
350	85.62	87.25	88.25
400	85.75	87.50	88.30
450	86.00	87.80	88.70
Average Baking Efficiency (%)	85.63	87.02	87.80

Heat loss in the oven

The heat loss from the oven to the environment was estimated to be 6.95 MJ excluding the heat absorbed by the bread dough, heat radiated to the environment of the heating chamber and the heat conducted through metal surfaces.

The weight loss

The result of the weight loss during the baking process of the bread dough at different baking temperatures (180, 200 and 220°C) is showed in Figure 5. However, it can be seen from the Figure 5 that as the baking temperature increased the weight loss increased linearly. Furthermore, it can be observed that in Figure 5, the weight loss increased, with increased in time and baking temperature. More importantly in Figure 5, it was also observed that at the increased of baking temperature from 180 to 220°C, there was a corresponding increased in weight loss from 7.9 to 12.5 g at 30 mins. baking period. Likewise in Fig. 5, the minimum weight loss at the baking temperature of 180 ^{o}C was 0.7 g, while that of 220 ^{o}C was 2.2 g. Hence, there was no much disparity between the weight loss in dough during the baking at 180^{o}C and 200^{o}C. However, there was a tremendous weight loss at the baking temperature of 220^{o}C comparatively. Furthermore, as the baking time increased, moisture loss increased, which resulted to reduction in the final weight of the baked dough. [17, 10] reported the same observations on moisture loss and modelling heat transfer at the evaluation of the development gas-fired bread baking ovens. These results were also synonymous to previous research report of [18] on moisture loss during baking of bread dough using gas-fired oven.

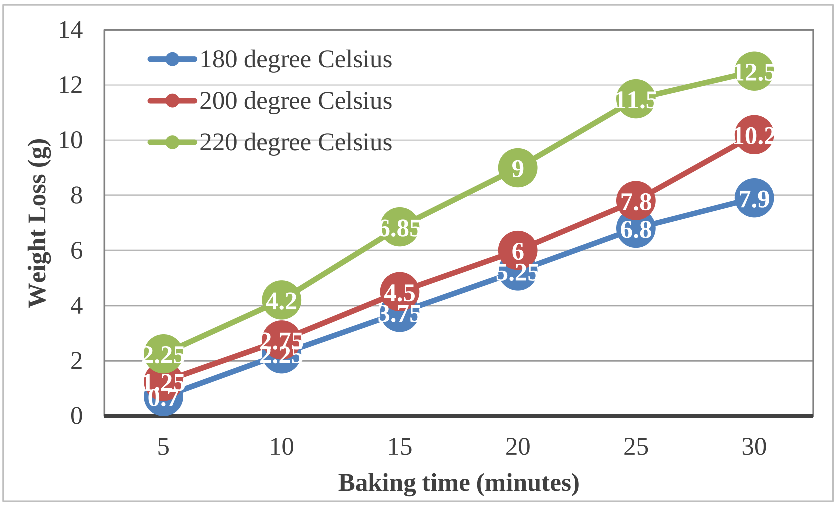


Figure 5. *Weight loss of dough at various level of baking period*

Physical properties of baked bread

The results of the physical properties of baked bread dough of 200, 250, 300, 350, 400 and 450 (g) in respect to the changes in their surface area, volume, density and specific volume at baking temperatures of 180, 200 and 220 (^{o}C) were showed in Figure 6-9. In Figure 6, it is clearly demonstrated that at increased of the dough weight, the surface area of baked bread increased relatively to the increased of baking temperature.

The effect of baking temperature on the surface area of the baked bread

However, it can be seen from Fig. 6 that the maximum surface area of the baked dough occurred at the optimum baking temperature of 220 ^{o}C, with the minimum surface area at 180^{o}C. The quadratic regression modelling equation relating surface area of the baked bread to the baking temperature at six (6) different weights of dough is shown as Equation 12.

$$\text{Surface Area}= 64.0189+1.4629X-2.626Y-0.0012X^2+0.0098XY+0.0082Y^2 \quad (12)$$

where X = Weight of dough and Y= Baking temperature

In comparison of the baking efficiency of this newly developed oven to that of imported proto-type, the surface area of baked breads were compared with the control sample at 180 , 200 and 220 (^{o}C) for 30 min. as showed in Tables 3 to 8. These results showed that the surface areas of the baked breads using newly developed oven at various temperatures were significantly different from the control sample, even between themselves at a level of $p>0.05$. The major reason was that the surface area of the control sample was found to be higher than the corresponding dough weight of 350 g baked by the newly developed gas-fired oven in Tables 3, 4 and 5.

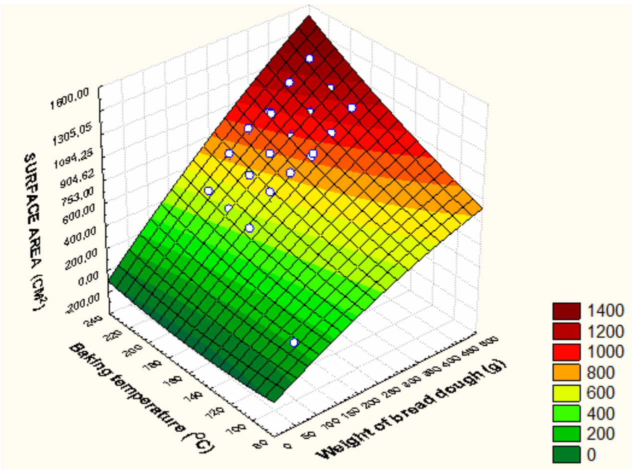


Figure 6. *Graph of 3D surface plot of determining the optimum baking temperature at varying surface area of the baked bread*

Table 3. Physical properties of baked dough at 180°C for 30 min

Weight of Un-baked Dough (g)	Surface Area (cm^2)	Volume (cm^3)	Density (g/cm^3)	Specific Volume (cm^3/g)
200	$424.00_a \pm 0.00$	$533.00_a \pm 1.0$	$0.38_e \pm 0.00$	$2.67_a \pm 0.01$
250	$665.67_b \pm 0.57$	$1134.33_b \pm 0.58$	$0.22_c \pm 0.01$	$4.54_c \pm 0.01$
300	$753.09_c \pm 0.16$	$1375.94_c \pm 0.64$	$0.22_c \pm 0.01$	$4.58_d \pm 0.00$
350	$812.67_d \pm 0.05$	$1547.01_d \pm 0.05$	$0.23_d \pm 0.01$	$4.42_b \pm 0.01$
400	$948.17_f \pm 2.3$	$1953.00_f \pm 0.00$	$0.21_b \pm 0.00$	$4.88_e \pm 0.01$
450	$1094.25_g \pm 0.05$	$2425.55_g \pm 0.05$	$0.19_a \pm 0.00$	$5.39_f \pm 0.00$
Control	$828.67_e \pm 0.57$	$1595.33_e \pm 0.58$	$0.22_c \pm 0.01$	$4.58_d \pm 0.01$

N=3, [*a,b,c] Means of variables on the same column are significantly different at $p<0.05$

Table 4. Physical properties of baked dough at 200°C for 30 min

Weight of Un-baked Dough (g)	Surface Area (cm^2)	Volume (cm^3)	Density (g/cm^3)	Specific Volume (cm^3/g)
200	$467.00_a \pm 0.58$	$623.68_a \pm 0.07$	$0.32_d \pm 0.01$	$3.12_a \pm 0.00$
250	$688.67_b \pm 0.58$	$1197.02_b \pm 0.02$	$0.21_c \pm 0.01$	$4.79_c \pm 0.01$
300	$801.86_c \pm 0.15$	$1519_c \pm 0.05$	$0.21_c \pm 0.01$	$5.07_e \pm 0.00$
350	$853.37_d \pm 0.32$	$1667.77_d \pm 0.06$	$0.21_c \pm 0.01$	$4.77_b \pm 0.01$
400	$1031.52_f \pm 0.03$	$2228.09_f \pm 0.08$	$0.18_b \pm 0.01$	$5.57_f \pm 0.01$
450	$1147.73_g \pm 0.29$	$3240.64_g \pm 0.01$	$0.14_a \pm 0.00$	$7.20_g \pm 0.01$
Control	$863.88_e \pm 0.03$	$1700.83_e \pm 0.03$	$0.21_c \pm 0.01$	$4.88_d \pm 0.01$

N=3, [*a,b,c] Means of variables on the same column are significantly different at $p<0.05$

Table 5. Physical properties of baked dough at 220 °C for 30 min

Weight of Un-baked Dough (g)	Surface Area (cm^2)	Volume (cm^3)	Density (g/cm^3)	Specific Volume (cm^3/g)
200	$512.00_a \pm 0.76$	$722.47_a \pm 0.06$	$0.32_d \pm 0.01$	$3.61_a \pm 0.00$
250	$765.37_b \pm 0.15$	$1396.53_b \pm 0.10$	$0.21_c \pm 0.01$	$5.60_b \pm 0.00$
300	$904.62_c \pm 0.03$	$1783.23_c \pm 0.02$	$0.20_c \pm 0.01$	$5.94_e \pm 0.00$
350	$975.49_e \pm 0.01$	$1990.22_e \pm 0.03$	$0.21_c \pm 0.01$	$5.69_d \pm 0.01$
400	$1162.89_f \pm 0.01$	$2674.63_f \pm 0.04$	$0.18_b \pm 0.01$	$6.69_g \pm 0.01$
450	$1305.05_g \pm 0.05$	$2957.56_g \pm 0.05$	$0.14_a \pm 0.01$	$6.57_f \pm 0.01$
Control	$956.10_d \pm 0.10$	$1981.98_d \pm 0.01$	$0.21_c \pm 0.01$	$5.66_c \pm 0.00$

N=3, *a,b,c Means of variables on the same column are significantly different at $p<0.05$

The effect of baking temperature on the volume of the baked bread

This optimum baking temperature was found to be within the range of the values (200-220±3.3°C) reported by [19], using electric static bread baking oven (Ariston FM 87-FC, Italy) under two different baking conditions of forced and natural convections. However, higher in value when compared with gas-fired cake baking oven reported by [10]. They reported that the effective oven spring occurs at the optimum baking temperature of 180°C under the baking period of 28 min. The quadratic regression modelling equation expressing mathematical relationship of volume of the baked bread against the baking temperature at six (6) different weights of dough is shown as Equation (13).

$$Volume=200.1419-6.8726X+1.9004Y+0.0094X^2+0.045\,XY+0.0157Y^2 \quad (13)$$

where X= Weight of dough, and Y= Baking temperature

Tables 3-8 showed the comparison of the physical properties of dough baked using the newly developed oven to that of imported proto-type, in terms of volume (oven spring) were compared with the control sample at 180, 200 and 220 (°C) for 30 min. These results showed that the oven spring of the baked breads at various temperature using newly developed oven were significantly different from one another even to the control sample at a level of $p>0.05$. It can be seen empirically that as the baking temperature increased from 200 to 220°C, the values of the oven spring of newly developed oven were found to be lower considerably compared with that of imported product.

The effect of baking temperature on the density of the baked bread

The effect of baking temperature on different weight of baked bread dough in related with density of finished product was showed in Figure 8. It can be observed that in Figure 8, the maximum density of the baked bread occurred at 200 °C. However, the optimum density of the baked bread that occurred consistently in respective of varying the dough weight can be deduced in Table 7 as 0.21 g/cm^3. This was can be further established by considering the density value of baked bread using imported gas-fired oven which has the same value of 0.21 g/cm^3. The quadratic regression modelling Equation 14, expressed the mathematical relationship of the density of the baked bread against the baking temperature at six (6) different weights of dough.

$$Density = 391.402-0.118X-3.7279Y+4.2946\times10^{-5}X^2+0.045\,XY+0.089Y^2 \quad (14)$$

where X= Weight of dough and Y= Baking temperature

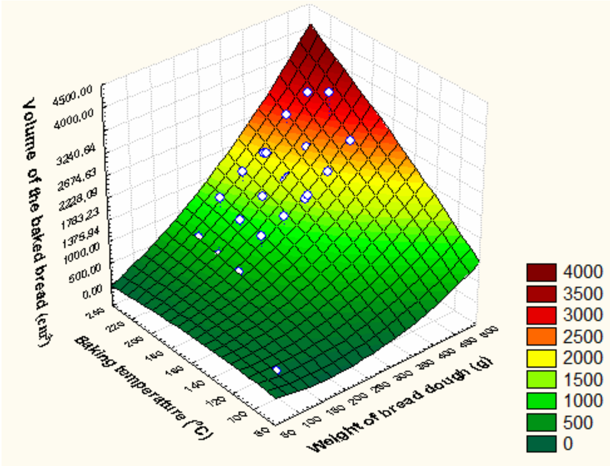


Figure 7. *Graph of 3D surface plot of determining the optimum baking temperature at varying volumes (Oven-Spring) of the baked bread*

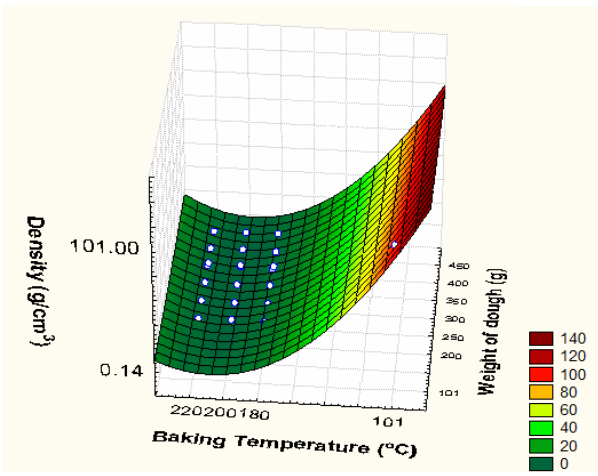


Figure 8. *Graph of 3D surface plot of determining the optimum baking temperature at varying volumes (Oven-Spring) of the baked bread*

The effect of baking temperature on the specific volume of the baked bread

The specific volume as one of the physical properties of baked bread was investigated to establish the optimum baking temperature on different weight bread dough. The result of this property was showed in Figure 9. It can be seen from the Figure 9 graphically, that the maximum specific volume of the baked bread occurred at baking temperature of 200 °C. Hence, in Tables3-8 the specific volume of the baked bread value at varying weights were significantly different at level of $p<0.05$ respective of increased in the baking temperature. The quadratic regression modelling Equation 15 expressed the mathematical relationship of the specific volume of the baked bread against the baking temperature at six (6) different weights of dough.

$$\textit{Specific Volume} = 389.93-0.1032X-3.738Y+2.1219\times10^{-5}X^2+0.0005XY+0.009Y^2 \quad (15)$$

where X= Weight of dough and Y= Baking temperature.

The graph of an algorithm for the bread baking is shown as Fig. 10 below for the illustration of labouratory procedures observed during the baking processes.

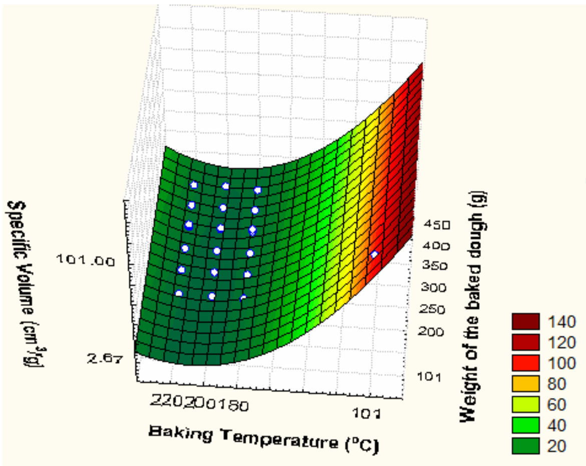


Figure 9. *Graph of 3D surface plot of determining the optimum baking temperature at varying specific volumes (Oven-Spring) of the baked bread*

Conclusions

Gas-fired baking oven was designed, constructed and evaluated using six different weight of bread dough of the same recipe. The dough were baked at various temperature ranges from 180-220°C. The physical properties of baked bread were compared with imported oven product as control. It was observed during this experiment that baking temperature and baking period influence the rate of weight loss during baking process.

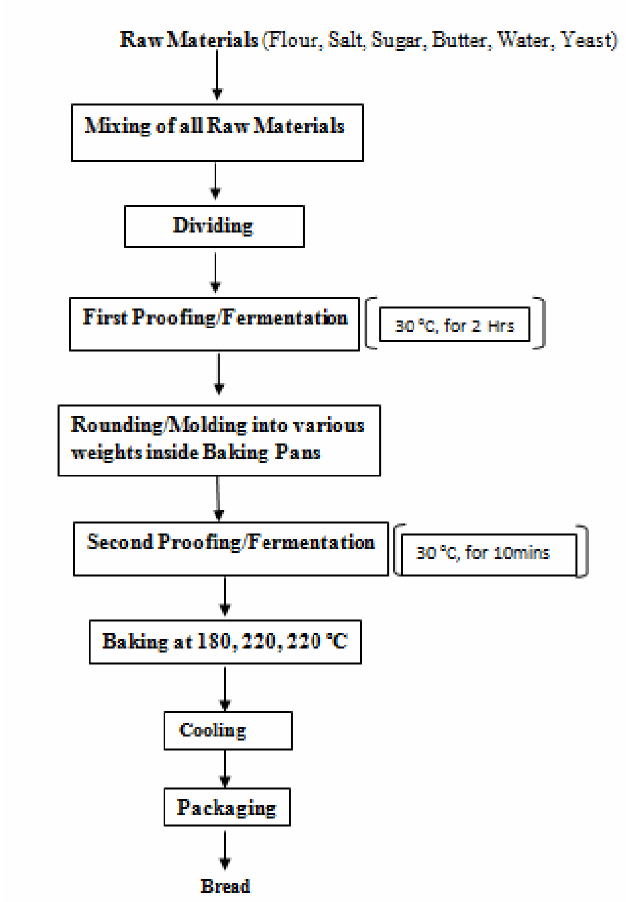


Figure 10. *Graph of an algorithm for bread baking*

The baking capacity, baking efficiency, weight loss and optimum baking temperature were: 12.5 kg/hr, 87.8%, 12.5 g, 200-220°C, respectively. The physical properties of baked bread dough were found to correspond with the imported product (control sample). These results showed that, the developed gas-fired baking oven can be adopted for baking of bread at domestic and commercial levels. The physical properties of baked bread compared with that of imported gas-fired oven (control) were significantly different from each other at level of 5%, but with optimum baking temperature between 200-220°C. Therefore, the newly developed oven can be used for the baking of dough both at domestic and industrial level.

Acknowledgments

The authors acknowledge the contributions of the technical and labouratory staff of both Department of Food Science and Technology and Department of Mechanical

Engineering, Faculty of Technology, Obafemi Awolowo University, Ile-Ife, Osun state, Nigeria during the development and evaluation of the baking oven.

References

1. Abdelghafor R. F., Mustafa A. I., Ibrahim A. M. H., Krishnan P. G., *Quality of bread from composite flour of sorghum and hard white winter wheat*, Advanced Journal of Food Science, 2011, 3, p. 9-15.
2. Komlaga G. A., Glover-Amengor M., Dziedzoave N.T., Hagan L.L., *Consumer acceptability of wheat cassava composite bread,* World Rur. Observatory, 2012, p. 78-81.
3. Shittu T. A., Rajji A. O., Sanni L. O., *Bread from composite cassava-wheat flour: I. Effect of baking time and temperature on some physical properties of bread loaf*, Food Research International, 2007, 40, p. 280-290.
4. Mondal A., Datta A. K., *Bread baking - A review*. Journal of Food Engineering, 2008, 86, p. 465-474.
5. Basil E., Blessent J., *Development and Application of a Uniform Testing Procedure for Ovens*, Pacific Gas and Electric Company Department of Research and Development Report, 2014, 4, p. 10-25.
6. Aborisade D. O., Adewuyi P. A., *Evaluation of PID Tuning Methods on Direct Gas-Fired Oven,* International. Journal of Engineering Research and Applications, 2014, 4 (03), p. 1-9.
7. Ogunjobi M. A., Ogunwole S. O., *Physiochemical and sensory properties of cassava flour biscuits supplemented with cashew apple powder*, Journal of Food Technology, 2010, 8, p. 24-29.
8. Adebowale A., Adegoke M., Sanni S., Adegunwa M., Fatuga G., *Functional Properties and Biscuits Making Potentials of Sorghum-Wheat Flour Composite*. American Journal of Technology, 2012, 7, p. 372-379.
9. Okafor-Basil E., *Simple Design of a Dual-Powered Domestic Oven*, International Journal of Engineering and Technology, 2014, 4(5), p. 1-13.

10. Genitha I., Lakshmana-Gowda B. T., Raj D. J., *Design, Fabrication and Performance Evaluation of Domestic Gas Oven*, IOSR Journal of Engineering, 2014, 4(5), p. 35-38.
11. Mayilsamy K., Rudramoorthy R., *Heat Transfer- Theory and Problems.* (first, Ed.) New Delhi: Dorling Kindersley Pvt. Ltd, 2006, p. 129-174.
12. Zheleva I., Kambourova V., *Identification of heat and mass transfer processes in bread during baking*, Thermal Science, 2005, 9(2), p. 73-86.
13. Kreith F., Boehm R. F., *Heat and Mass Transfer. Mechanical Engineering Handbook*, Edited by A. Frank Keith. BOREA Raton. CRC PRESS, London New York Washington, D.C. 1999, 4, p. 3-4.
14. Adegbola A. A., Adegbeji O. V., Abiodun O. I., Olaoluwa S., *Design, Construction and Performance Evaluation of Low Cost Electric Baking Oven*. Innovation Systems Design and Engineering, 2012, 3(11), p. 38-49.
15. Khatkar B. S., *Bread industry and processes, Thesis of post graduate diploma in Bakery Science and Technology*. Directorate of Distance Education Guru Jambheshwar University of Science and Technology, 2004, HISAR-125001, p. 1-86.
16. Hoffman T., Lindenmeier M., *Influence of baking conditions and precursors supplementation on the amounts of the antioxidant pronyl-L-lysine in bakery products*, Journal of Agricultural and Food Chemistry, 2004, 52, p. 350-354.
17. Carvalho M., Martins N., *Mathematical modelling of heat and mass transfer in a forced convection baking oven,* AICHE Symposium Series – Heat Transfer, 1993, 88 (288),p. 205–211.
18. Bahnasawy A. H., Khater E.G., *Heat and Mass Balance for Baking Process*, Journal of Bioprocess Biotechnology, 2014, 4, p. 3-6.
19. Purlis E., Salvadori V. O., *A moving boundary problem in a food material undergoing volume change - Simulation of bread baking*, Food Research International, 2010, 43, p. 949-958.