

Research Article

Evaluation and Verification of Small-scale Portable Biomass Bread Baking Oven

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Abstract

Bread baking was the most energy-intensive activity in Ethiopia and preparation of bread was rather a long process relative to other Ethiopian food. This study presented the evaluation and verification of small-scale portable biomass bread-baking oven parameters of an indigenous wood-fired bread-baking oven for small-scale farmers, householders, and small-scale entrepreneurs, pre-urban and urban populations with an electrification shortage. It was an insulated rectangular box-like chamber made of mild and stainless steel sheet metal with a total dimension of 1350mm*1030mm*845mm. The oven characteristics were evaluated in terms of the baking capacity, baking efficiency, and weight loss of the baked bread. This oven comprises two baking compartments within one chamber and two combustion chambers. Each compartment bread carrying capacity for small, medium, and large bread trays with bread dough weights of 100 g, 500 g, and 2000 g of bread was 80, 16, and 4 pieces of bread. When fully loaded it has the carrying capacity of 160 pieces of loaf bread per batch of operation at two compartments baking capacity and efficiency of 96.6% and 86.9%, respectively, and a weight loss of 12.6% on average. The machine's baking time was observed at 100 g, lying between 10-15 minutes, and with a single biomass fuel feed of 5kg by 5kg for each fire chamber, the machine's performance was very effective.

Keywords

Bread, Baking Capacity, Baking Efficiency, Baking Temperature, Oven

1. Introduction

Baking is the final and most important step in bread production, and it can be defined as the process that transforms dough, basically made of flour, water, and leavening agents, into food with unique sensory features by the application of heat inside an oven [7].

The oven is one of the key food processing equipment that uses complex simultaneous heat and mass transfer processes in the food industry. It is a thermally insulated chamber used for heating, baking, cooking, or drying of food substances [3, 8]. Baking is a widely used processing technique that plays an

important role in determining the quality of the final product. Bread, cakes, biscuits, brownies, casseroles, cookies, pastries, puddings, and tarts are examples of baked products. For efficient baking, there must be minimal moisture loss. According to [8], during baking, the driving force of heat transfer is the temperature gradient, while that of mass diffusion is the concentration difference. The heat and mass transfer occur simultaneously within the baked food material from the outer part to the inner part of the food material. The moisture diffusion while baking the food material occurs mainly by con-

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vection and conduction, and less by radiation [4]. The quality of baked products is usually affected by the time and temperature of the baking process [7]. During baking, different changes such as volume expansion and crust formation occur in the dough depending on time and temperature [10].

Baking is the most common and oldest form of food processing that uses sustained dry heat through convection instead of thermal radiation, normally in an oven, but also in ashes or hot stones [11]. It is a dynamic method of simultaneous heat and mass transfer widely used in food industries. A baking oven is the most used appliance in the food service industry. An oven can be simply described as a fully enclosed, thermally insulated chamber used for the heating, baking, or drying of a substance [7]. In the baking oven, the hot air flows over the material either by natural convection or forced by a fan, the convection heat transfer from air, the radiation heat transfer from the oven heating surfaces, and the conduction heat transfer across the contact area between the product and the metal surface [9]. [4] Reported that the 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.

In Ethiopia, increasing population, rapid urbanization, and changing food habits have resulted in a preference for ready-to-eat convenient foods such as bread, biscuits, and other baked products, despite the increase in their prices [2]. Unfortunately, the large-scale bakers utilize imported ovens, which are unaffordable to small-scale or household bakers [1]. Presently, irregular supply of electricity in Ethiopia and Oromia has rendered electric baking oven unproductive across all levels of operations. Therefore, there is a need for the on-farm evaluation of an indigenous wood-fired baking oven, with the enormous availability of biomass fuel. [12] An unpublished paper also reported that the existing BAERC Model wood-fired oven is cheaper to run than any other oven type. So, it is portable and produces very little smoke/CO₂ (greenhouse gas), which will contribute to the reduction of the global warming effect. According to [5], conventional ovens, which are usually powered by natural gas or electricity, can be very expensive. This, in turn, discourages baking for domestic purposes because it becomes more economical to buy already-baked foods such as bread. In recent days, the electric oven users are facing a problem due to the erratic power cuts in the middle of the operations, which causes the loss of the quality of the end product and the loss of capital, and the electric oven consumes more energy [6]. The use of gas as the energy source for baking ovens is commercially necessary for most regions because electricity, by comparison, is prohibitively expensive [10].

Study and evaluation of baking ovens is important because it could lead to a more efficient baking process, favorable energy efficiency, and better product quality [6]. The baking process usually requires significant energy consumption as a relatively high temperature is applied to remove moisture in baked products and create the desired texture. Hence, this

work aims to evaluate an existing BAERC Model wood-fired/powered baking oven for small-scale entrepreneurs (unemployed youth) at an affordable cost using a local content approach. Despite this tremendous effort made by several researchers, there is still a paucity of information on the design of Small-scale portable wood-powered/fired ovens (Bako model). Little attention had been paid to incorporating an interconnected ash removal chimney inside an oven. Therefore, the objective of this paper was to evaluate the performance and efficiencies of the Bako model wood-powered bread-baking oven for unemployed youths as a potential job-creation technology in the selected rural towns.

2. Materials and Methods

2.1. Materials

Materials and apparatus used in this experiment for construction and evaluation are: Mild steel sheet metals, Stainless steel sheet, Round bar, Flat irons, Square pipes, Angle irons, Water pipes, Bat hinges, Stopwatch, Digital balance, Digital thermometers, Aluminum reinforced fiberglass, Infrared radiation, Wheel, Shafts, Cement, Fine sand and K-type thermocouple probe, Oven dry, Hygrometer, Fuel wood, Wheat flour, Ingredients and Water.

2.2. Description of the Main Components of the Wood-powered Oven

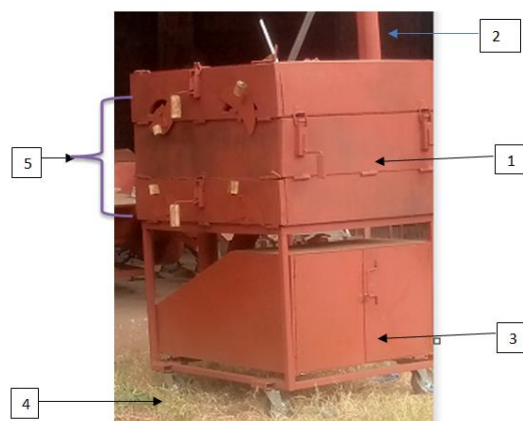


Figure 1. Picture of the oven with its main components.

Bread chamber door, 2- Chimney, 3- Steam/proofer chamber, 4-Transportation wheel and, 5- Upper and lower fire door.

*This oven has five main compartments: Two firing chambers: lower and upper, The Baking chamber (room) inner walls were made of stainless steel and mild steel sheet metal of 2mm and had dimensions of 840mm*285mm*15mm respectively. To minimize heat loss, fiberglass was used as insulation in the upper and lower firing chambers as well as*

the baking chamber (40mm). A layered baking chamber carries the trays. Each layer carries two trays, which are made up of a stainless-steel sheet. The chimney was provided by connecting the two firing chambers.

2.3. Determination of Evaluation Parameters

Volume of oven baking chamber: The baking oven chamber is the enclosed chamber where the baking takes place and the volume was calculated using Eq. described by Clements et al. (2001).

$$V = BCL \times BCW \times BCH \quad (1)$$

Where V is the baking chamber volume, BCL is the baking chamber length, BCW is the baking chamber width, and BCH is the baking chamber height.

Oven Capacity: the oven's capacity is the number of loaves of bread that can be baked per batch and determined the capacity using Equation (2):

$$C_o = \frac{\text{size of tray}}{\text{size of bread}} \quad (2)$$

Baking Capacity: the baking capacity of the oven was determined in terms of it carrying capacity of dough to its baking time by the following formula:

$$B_C = \frac{M_D}{B_T} \quad (3)$$

Where, B_C = baking capacity, M_D = mass of dough (kg), and B_T = Baking Time (hr.)

Burning rate: The burning rate is the ratio of the mass of the fuel burnt (in grams) to the total time taken (in minutes). It was calculated by using the following equation:

$$B_R = \frac{F_{cb}}{T_b} \quad (4)$$

Where, B_R = Burning rate (g/min), F_{cb} = Equivalent dry

fuel consumed, T_b = Time to baking (min)

Baking Efficiency: The baking efficiency of a biomass-powered oven was calculated using the following Equation below.

$$\text{Baking Efficiency (\%)} = \left(\frac{\text{Useful energy output}}{\text{Total Energy Input}} \right) * 100 \quad (5)$$

where, Useful Energy Output is the energy that is effectively used for baking (KJ), and Total Energy Input is the energy provided by the biomass fuel used (KJ/Kg).

Specific fuel consumption: it is a ratio of the total fuel consumed to produce a unit product, given by the following formula:

$$\text{SFC} = \frac{\text{Fuel Mass (kg)}}{\text{Bread Mass (kg)}} \quad (6)$$

2.4. Experimental Setup

The experiment was conducted using two different locally available biomass species, Eucalyptus (Bergamo in the local name) and Gravilia, with a 50cm length. The required fuel wood consumed for each test was pre-weighed and the same mass of fuel wood (5kg) was applied for both the lower and upper fire chamber.

2.5. Dough Preparation

The bread dough was prepared by using a mechanical mixer. By professional advice, 12kg of dough per batch was mixed using the following ingredients.

100g of salt, 70g of dry yeast, 7 liters of water, 80g of mace 80 g of baking powder, and 100g of sugar. The dough was then placed on a flat table divided into required weights and loaded into the proofing chamber. After staying in the proofing room for 20 to 30 minutes at 25 to 40 °C it was ready to bake.



Figure 2. Bread baking process, (a) Wood weighing, (b) Dough shaping, (c) Inserting into bread chamber.

2.6. Data Collection and Analysis Tools

All the collected data were analyzed using Excel software and the origin for preparing their figures.

3. Results and Discussion

A prototype of a biomass bread baking oven was fabricated and evaluated for baking purposes. The Wood fired bread baking oven was a compact type of oven that uses the three modes of heat transfer (conduction, convection and radiation) to bake food products.

During the baking process, the initial bread dough's white color was changed to varying degrees of brownness as the baking temperature increased. The final product had an outer layer that was a semi-rigid, less fragile structure called the crust layer while the inner part of the dough had a crumb texture.

3.1. Baking Capacity

The wood-fired bread baking oven has two baking compartments, in each compartment, a total of 160 bread dough was baked per batch in baking pans of 985mm × 390mm × 60mm, for a small loaf of bread was attained. The baking chamber of the fabricated wood-fired bread baking oven (WPBO) has a volume of 2.614m³. Therefore, the WPBO has a maximum baking capacity of 36kg/hr. at producing baked bread 480, dough masses of 100 g per batch of operation. According to Usman K, et al. (2021) reported the maximum baking capacity was 30kg/hr. The result was almost in agreement with the report.

3.2. Oven Capacity

The capacity of the oven is directly proportional to the number of bread loaves/batch and the baking pan dimensions (size of the baking pan and the dough weight). The average weight of bread for bread dough for a small loaf of bread after baking was 9.133g, as design basis, having a volume, whereas the bread average surface area for each bread type was 3.049*10⁻³m². The surface area occupied by 160 loaves of bread for each with a bread weight of 100g, per batch = 0.39m². Therefore, the capacity of the oven for small bread dough weight, and size trays were 160 pieces of bread per batch for 12kg of flour, and 320-480 pieces of bread per hour. The result obtained was in agreement with the result of an unpublished paper reported by [12].

3.3. Weight Loss of Baked Bread

The weight loss in the food samples (bread dough) was calculated by subtracting the weight of the food sample after baking (heating) from the initial weight of the food sample. The moisture loss in baked bread was minimal. Therefore, the average weight loss or moisture for bread dough of 100g was 8.71%.

3.4. Baking Process Temperature Profile

The baking process temperature profile is another important indicator of the energy consumption behavior of the equipment (bread dough). The temperature profile of the bread oven showed that as the baking temperature increased, the baking time decreased.

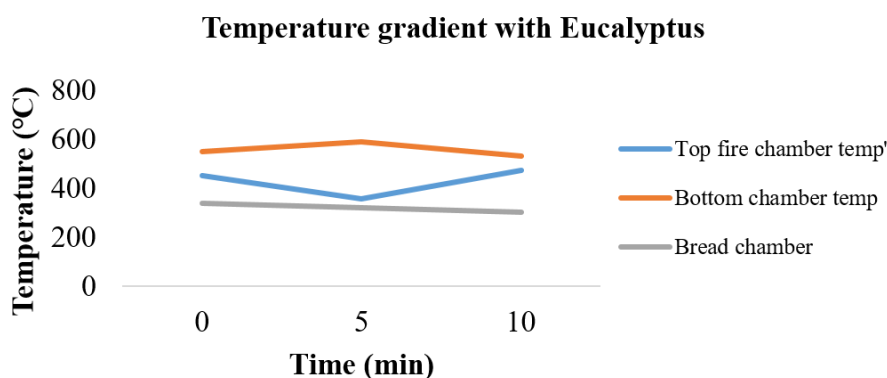


Figure 3. Comparisons of temperature distribution in the chamber with Eucalyptus wood.

This result showed that the oven performs well above 310 °C but is more efficient at an average baking temperature of 324 °C. As Figure 3 shows, as the temperature increases, there is a reduction in the baking time. This could be attributed to an increase in temperature profile due to heat transfer, which accelerates the baking rate and thus reduces the baking time. The results are in agreement with the findings of [12]

that, no matter the conventional mode of heat transfer, baking time decreases with an increase in oven temperature.

The experimental results showed on the figure 4 that, the locally available biomasses, such as eucalyptus, have better thermal efficiency than Graviillea. However, their thermal efficiencies and heating time were lower than those of eucalyptus, which lasted up to 5 minutes with the same weight of

wood sample loaded for each batch of baking operation. As wood fuel feed per batch, the chamber temperature is kept constant temperature with Gravidia, while with eucalyptus shows temperature variation.

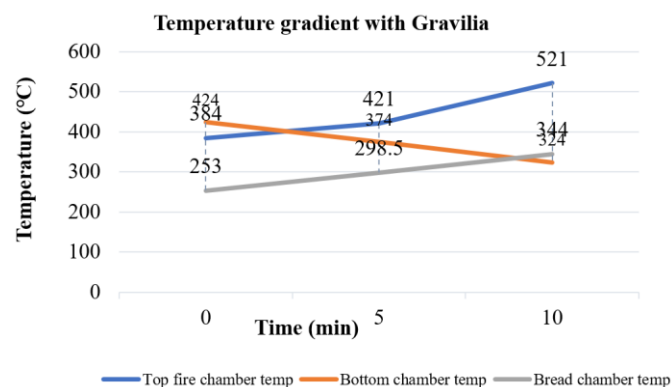


Figure 4. Comparisons of temperature distribution in the chamber with *Grevilia* wood.

4. Conclusions and Recommendations

The portable biomass bread baking oven was constructed and evaluated using two different fuel wood and weight of bread dough of 100g. The dough was baked at an average temperature of 324 °C with in the average ten minutes. The average weight losses or moisture for of bread dough of 100g, was 8.71%. It was observed that during this experiment baking temperature and baking period influence the rate of weight loss during baking process. The quality factors or process outputs are varied with process input variables such as oven temperature, moisture, and process time. The process of baking was complicated because it involves physical changes, such as temperature and moisture because of heat transfer and moisture transfer, also chemical reactions to generate the desired final product quality. The oven can be used for the baking of bread and all bakery products with good quality parameters like color, texture, taste, and volume. The preheating time of the oven was reduced; this in turn consumes very little energy and the time of the baking, this can be used for small entrepreneurs and can be popularized in areas where power cuts are more frequent and where power is not available. The performance evaluation of the oven showed that the baking oven was efficient, with a baking capacity and baking efficiency of 30-40kg/hr. and 86.9%, at baking respectively for a period of 10 minutes for small bread baking.

The designers cannot claim that the baking oven was one hundred percent efficient, since from the knowledge of thermodynamics, no heat transferring device can deliver heat with 100% efficiency due to some heat losses and lack of uniformity of heat transfer. But ensure that a good finish was given to the development of the equipment. Further research should be encouraged along the lines of the project research.

Abbreviations

BCL	Baking Chamber Length,
BCH	Baking Chamber Height
BCW	Baking Chamber Width
B _R	Burning Rate
SFC	Specific Fuel Consumption
WPBO	Wood-powered Baking Oven

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Conflicts of Interest

The authors declare no conflicts of interest.

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