

## Energy Utilization in Bread Production in Osogbo, Nigeria

W. O. Adedeji\*, O. Olukayode, S. Oyelami and B. S. Adeboye

Department of Mechanical Engineering, Osun State University, Osogbo, Nigeria

\*Corresponding Author: wasiu.adedeji@uniosun.edu.ng

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### ABSTRACT

*The aim of this study is to examine the energy consumption rate during bread production in Nigeria and determine the most energy-intensive stage. Extensive research conducted by various scholars on energy usage in bread production and the different types of ovens employed was thoroughly reviewed. The research methodology involved gathering and analyzing data from bakery industries that exclusively utilize electric ovens. A well-structured questionnaire was utilized to investigate energy usage patterns in the bakery industry, and oral interviews were also conducted. The total energy consumed (including electrical, human, and thermal energy) at each production stage was recorded, and the percentage of total energy consumption was calculated. The findings revealed an overall energy consumption of 21.37 MJ/h during the production process. Thermal energy accounted for the highest proportion at 7.66 MJ/h (35.84%), followed by electrical energy at 7.14 MJ/h (33.41%), and finally human energy at 6.57 MJ/h (30.74%). This indicates thermal energy as the most dominant form of energy consumed. Additionally, the mixing process was identified as the most energy-intensive stage, with a consumption level of 5.1 MJ/h (24.9%), while de-lidding and de-tinning had the lowest energy consumption at 0.53 MJ/h (2.48%). In conclusion, the primary energy sources were manual (human), electrical, and thermal. Thermal energy constituted the highest energy consumption. Manual energy usage was relatively low compared to the combined electrical and thermal energy, as determined by several generalized mathematical models examining Total Exergy (TEx), Embodied Energy Intensity (EEI), Energy Cost of Production (EsC), and Carbon IV Oxide Emission (COE) for further parametric studies. It is evident that reducing energy wastage during the production process and promoting sustainability are crucial for minimizing bread production costs.*

### 1. INTRODUCTION

Bread is an essential food item, particularly in Nigeria and worldwide. Its production is primarily carried out in bakeries. It is believed that bread served as a convenient food source for nomadic individuals, contributing to the population growth (Revedine *et al.*, 2010). Bread holds significant importance in households, often consumed as a staple breakfast with tea, fried eggs, stew, or on its own (Holderbeke, 2003; Tannahili, 2002). Its simplicity eliminates the need for additional food preparation, making it a convenient choice for labourers and saving valuable time. The high demand for bread from consumers has resulted in increased production costs, requiring more labour and energy (FAO, 2012). Considering the significance of bread, it is crucial to examine the impact of energy consumption on its production.

Addressing the challenge of achieving efficient bread production requires tackling issues related to securing a competent workforce and ensuring a reliable energy supply with a safe application of energy (Gordon, 2014; Ekechukwu *et al.*, 2010; Jekayinfa, 2008). The process of bread production involves the mixing of bakery raw materials with ingredients and transforming them into the final product, which is then distributed to consumers through various means of transportation. However, the entire system may not be feasible without sufficient energy supply and adequate human input. Reliable energy is essential for operating the bakery's equipment and machines to efficiently convert raw materials into bread, while competent human effort is necessary to maintain sustainable managerial functions within the bakery.

The primary ingredients utilized in the production of bread consist of wheat flour, a cereal crop that has been recognized for its high protein and mineral content. Wheat flour constitutes the majority portion, comprising 60% of the bread's composition. Additional ingredients combined with the flour include sugar, salt, yeast, butter (vegetable oil), bread improver, baking powder, egg, milk, and functional additives such as flavors, colorants, preservatives, and water (Ragab *et al.*, 2005). Hadi *et al.* (2020) investigated experimentally and numerically the effect of different heat flux profile on bread quality and discovered that both the profile difference and heat flux profile affected the bread quality. Fatemeh *et al.* (2022) studied the energetic, economic and environmental impact of bread production in Iran and they came up with values of energy expended per kilogram of bread and the tonnage of CO<sub>2</sub> realized into the atmosphere and also the economic analysis of the production process. Briceno- Leon (2021) also evaluated the energy efficiency in the bakery industry at enhancing competitiveness and sustainability and concluded that electrical energy consumption in Quito- Ecuador is more efficient to other bakeries energy sources. Kheiralipour and Sheikhi (2021) investigated the effect of material energy flow in bread production were able to optimized bakery unit in both energy and material consumption in bread production. Smah *et al.* (2021) investigated different sources of energy temperatures and time of baking in bakeries. They were able to calculate different percentages of the energy carriers used in two northern state of Nigeria.

The production stages of bread involve various steps, including mixing, kneading, molding, fermentation, baking, cooling, slicing (not applicable in certain bread types), and wrapping. Energy usage is essential in providing heat in the furnace, generating electromotive force to power machines and equipment, and applying heat to raise the dough to the required temperature (Nwanya, 1998). Additionally, the radiation of heat during the baking process consumes energy. Researchers have examined the temperature range of the oven to be between 210-240°C, with a baking duration of 15-30 minutes to achieve a smooth and well-developed crust. The production of bread in Nigeria faces challenges such as low output and unhygienic practices resulting from manual operations (Olaoye *et al.*, 2006). To overcome these issues and achieve increased output and hygienic bread production, the utilization of modern equipment and machines is crucial. Nigerian bakeries also encounter additional problems, including the need to refine local agricultural products like cassava, soybeans, and plantain into flour to reduce reliance on imported wheat flour in bread production. Furthermore, the rising fuel prices, shortage of skilled manpower, and inadequate inventory management pose further challenging factors.

In the production of bread, several essential chemicals, biochemical, and physical processes occur, including water evaporation, volume expansion, starch gelatinization, protein denaturation, crust formation, carbon dioxide production, the development of a porous structure, and browning reactions (Purlis and Salvadori, 2009). These processes form the fundamental basis for bread production. There are two primary methods used in bread production, namely the Bulk Fermentation Process (BFP) and the Chorleywood Bread Process (CBP). The BFP is a conventional bread-making method in which ingredients are combined to form a dough that undergoes fermentation for a duration of up to three hours. This fermentation process transforms the dough from a dense mass into a flexible product that can be baked and subsequently cooled. However, the BFP has been largely substituted by the CBP. The CBP was created in the early 1960s and has become widely adopted in the commercial bread industry. Unlike the BFP, CBP eliminates the

requirement of fermenting the dough in bulk. Commercial bakers find several advantages in utilizing CBP, including significantly faster bread production, leading to improved efficiency compared to BFP. Moreover, CBP allows for the use of a higher proportion of flour, resulting in a finished product with more consistent color, volume, and quality in terms of its shelf life. Furthermore, heat transfer in bread production is in the three fundamental forms of transfers; Conduction, Convection and Radiation. All three aforementioned modes have specific relevance to bread production, for example in a baking oven, heat is transferred to the bread through a combination of convection and radiation, and then heat is conducted from the surface (crust) to the core of the crumb (Russell *et al.*, 2008; Incropera and Dewitt, 2007; Rohsenow *et al.*, 1998).

This research aims to enhance the production of staple food by establishing a harmonious relationship between the availability of bakery materials to meet customer demands and the efficient utilization of energy within the bakery industry. Additionally, the research findings will provide valuable information to assist potential investors in establishing a bakery, including details on facilities, costs, and potential profits. Implementing effective energy consumption practices during production stages is expected to result in cost reductions, particularly considering the high demand for bakery food among the economically active population, primarily children and adolescents. This demographic constitutes a significant customer base for bakery products compared to other food categories.

## 2. METHODOLOGY

### 2.1 Data Collection

The researchers gathered comprehensive data on energy consumption and usage patterns within the bakery industry in Osogbo. This data formed the basis for their analysis and subsequent findings in the study. The data for this research study were collected specifically from bakeries that utilize electric ovens in their operations. The researchers gathered information on various aspects of the bakeries, including their production capacity (measured in bags of flour baked per day), the manpower employed, energy consumption, working hours per day, working days per month, and the types of facilities available.

#### On-site study of unit operations

An extensive examination of all the unit operations within the bakery industry was conducted. This involved observing and analyzing the various processes and activities taking place at the actual bakery sites. By closely studying these operations, the researchers gained valuable insights into the energy usage patterns specific to the industry.

#### Administration of a structured questionnaire

A well-designed questionnaire was developed to gather data on the patterns of energy use in the bakery industry. This questionnaire was carefully crafted to ensure that it captured relevant information regarding energy consumption, sources of energy, equipment and machinery utilized, and any energy-saving measures implemented. The questionnaire was distributed to bakery establishments, and responses were collected and analyzed to obtain quantitative and qualitative data on energy usage.

#### Oral interviews

In addition to the questionnaire, oral interviews were conducted with individuals involved in the bakery industry. These interviews provided an opportunity to gather firsthand information and insights from bakery owners, managers, workers, and other relevant stakeholders. The researchers engaged in structured conversations, asking specific questions related to energy use in the industry. The information obtained from these interviews added depth and context to the data collected through other methods.

## 2.2 Bread Energy Consumption and Production Stages

Sources of energy for bread production can be found from electrical energy, thermal energy (wood, petrol, diesel and gas) and human energy. Energy contents found in fuels for bread production are listed in Table 1. Figure 1 depicts the stages involved in bread production to include mixing, dividing, molding, tinning and lidding, final proofing, baking, de-lidding and de-tinning, slicing and packaging respectively.

**Table 1:** Energy Content in Fuels

Unit	Fuel(s)	Energy content(Kwh)
1 kwh	Electricity	1
1m <sup>3</sup>	Gas	11
1litre	Petrol	9.7
1litre	Diesel	10.7
1litre	Bio-Diesel	9.9
1litre	Kerosene	10.5
1kg	Coal	6.64
1kg	Greenwood 10mJ/kg	2.78
1kg	Air seasoned 16mJ/kg	4.41
1kg	Kiln Dried Wood 19-0MJ/kg	5.6



**Figure 1:** Bread production stages flow chart

## 2.3 Energy Usage Calculations

According to Pimentel (1992), the male manual energy input is estimated to be 0.75 MJ per hour (MJ/h). To calculate the energy input of an average male laborer, the formula in equation (1) was used. Similarly, for an average female adult, the formula to calculate the female manual energy input is in equation (2).

$$EM_m = 0.75T_o \text{ MJ/h} \quad (1)$$

$$EM_f = 0.68T_o \text{ (MJ/h)} \quad (2)$$

Where  $EM_m$  represents the male manual energy input (in MJ), 0.75 represents the energy input of an average adult male (MJ/h),  $T_o$  represents the useful time spent by a male worker per unit operation (in hours) and

EM<sub>f</sub> represents the female manual energy input (in MJ), 0.68 represents the energy input of an average adult female (MJ/h). These formulae allow for the estimation of the manual energy input based on the useful time spent by male or female workers in a particular task or operation. For electrical energy, the data was estimated based on past Power Holding Company of Nigeria (PHCN) bills. These values were converted into common energy units (MJ) using the appropriate conversion coefficient as shown in equation (3). It is known that one kilowatt-hour (kWh) of electricity is equivalent to 11.99 MJ (Pimentel, 1992).

$$EE = 11.99 * 1 \text{ kWh (inMJ/h)} \quad (3)$$

Where EE represents the electrical energy in megajoules (MJ).

For liquid fuel energy, the energy input is calculated separately for diesel and petrol. This is demonstrated in equations (4) and (5) for diesel fuel and petrol fuel energy respectively. Where EFLD represents the energy input from diesel fuel in megajoules (MJ) and D represents the amount of diesel consumed in liters. EFLP represents the energy input from petrol fuel in megajoules (MJ) and P represents the amount of petrol consumed in liters. The values 47.8 and 42.3 are the unit energy values for diesel and petrol fuel, respectively, in MJ per liter (MJ/L).

$$\text{Diesel} \rightarrow EFLD = 47.8 * D \text{ (in MJ)} \quad (4)$$

$$\text{Petrol} \rightarrow EFLP = 42.3 * P \text{ (in MJ)} \quad (5)$$

Using the total energy (TE) utilized in bread production obtained from this research, further analysis can be conducted by applying earlier generalizations. For instance, the embodied energy intensity (EEI) can be calculated using the mathematical model developed by Adedeji (2015) as presented in equation (6). Other parameters such as carbon oxide emissions (COE), energy cost of production (EaC), and total exergy (TE<sub>x</sub>) can also be calculated based on TE as presented in equations (7) – (9).

$$EEI = 5.2 * (TE)^{0.0035} \quad (6)$$

$$COE = -9.4 \times 10^8 + 7861 * (TE) + 4.5 \times 10^{-4} (TE)^2 \quad (7)$$

$$E_nC = 3.39 \times 10^3 * (TE)^{0.12} \quad (8)$$

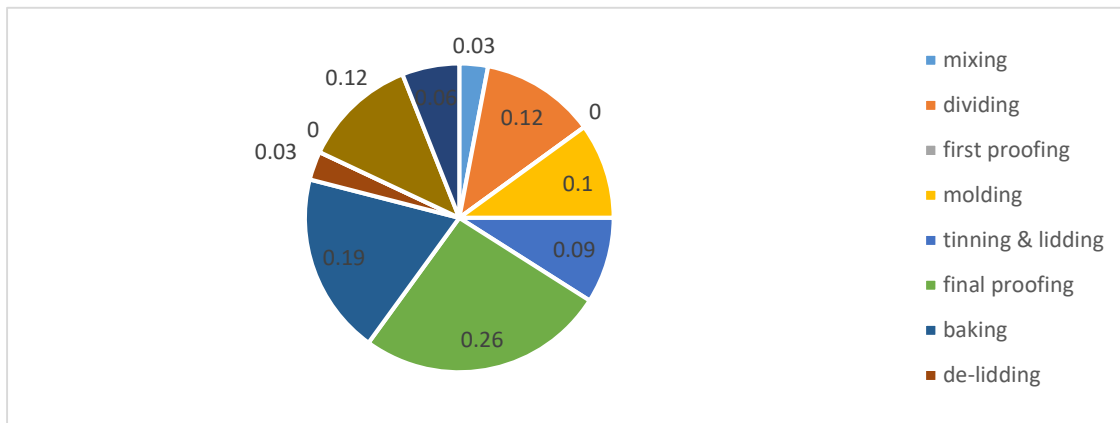
$$TE_x = 3.37 \times 10^3 * (TE)^{1.35} \quad (9)$$

### 3. RESULTS AND DISCUSSION

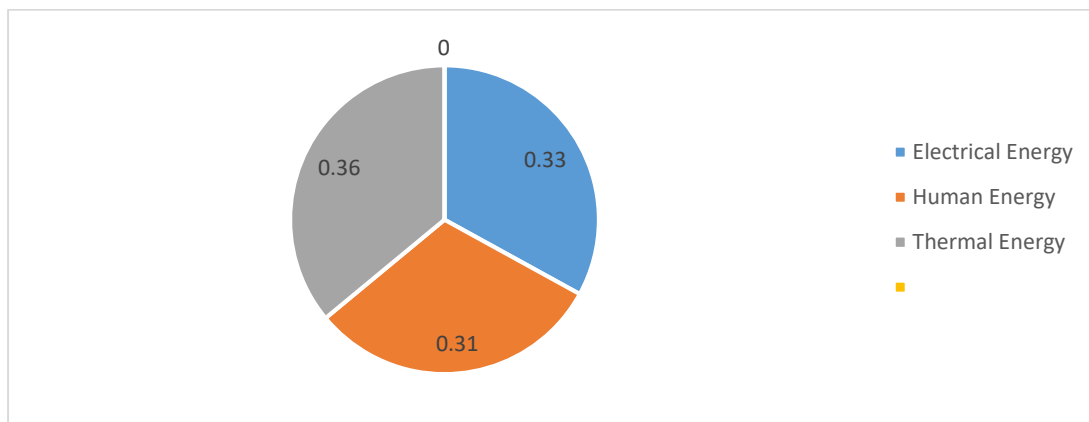
Table 2 presents the derived energy usage value in bread production process in Osogbo, Nigeria. It was found that the overall energy usage in the bread production process is 21.37 MJ/h. The breakdown of energy consumption by each production stage is displayed in Figure 2. The figure shows that mixing takes the highest energy input. This can be understood because dough smoothness and proper blending of the ingredients determines significantly, quality of the bread produced (Scanlon and Zghal, 2001). Among the different processes, the mixing process was found to be the most energy-consuming, accounting for 5.11 MJ/h (24%) of the total energy consumed. De-lidding and de-tinning processes, on the other hand, had lowest energy consumption of 0.53 MJ/h (2.48%). Figure 3 shows the daily energy consumed in bread production. It was observed that the highest value 35.84% needs critical amelioration, because of its adverse environmental effect; thermal pollution, and global warming. Thermal energy accounts for 7.66 MJ/h (35.84%), followed by electrical energy at 7.14 MJ/h (33.41%), and human energy at 6.57 MJ/h (30.74%). These results indicate that thermal energy is the highest contributor to energy consumption, although the significance of electrical and human energy should not be overlooked in bread production (Fuhrmann *et al.*, 1984).

**Table 2:** Derived Energy Usage Value

Processing	Total energy consumed (MJh <sup>-1</sup> )			Total Energy consumption (MJh <sup>-1</sup> )	% of Total Energy Consumption
	Electrical Energy (MJh <sup>-1</sup> )	Human Energy (MJh <sup>-1</sup> )	Thermal energy (MJh <sup>-1</sup> )		
Mixing	2.08	1.12	1.91	5.11	24
Dividing	0.79	0.23	0.96	1.98	9.27
First Proofing	-	-	-	-	-
Molding	0.79	-	0.96	1.75	8.19
Tanning and lidding	-	1.44	-	1.11	6.74
Final proofing	1.92	0.45	1.91	4.28	20.03
Baking	0.72	1.52	0.96	3.20	14.97
De-lidding and de-tilling	-	0.53	-	0.53	2.48
Cooling	-	-	-	-	-
Slicing	0.84	0.23	0.96	203	9.50
Packaging	-	1.05	-	1.05	4.91
Total	7.14	6.57	7.66	21.37	100
%of Total Energy Consumption	33.41	30.74	35.84		



**Figure 2:** Energy consumed by each production stage



**Figure 3:** Daily energy consumed



Table 3 shows the summary of results of equations (6) - (9). The Embodied Energy Intensity (EEI) value of 5.256 by the assessment of global best practice is too high compared with the range acceptable of 2.9 – 3.2 (Worrel *et al.*, 1997). This is responsible for the high cost of production and hence the sales prices of bread among other parameters that are used in price determination. Also, the Carbon IV Oxide Emission (COE) for just one day operation generated 38.19 g of Carbon IV Oxide per day (13,748.4g per annum). This is alarming when aggregated for all such cottage industries. This release is largely due to the energy mix being employed (thermal energy, electrical energy and human energy). A more efficient friendly source of energy, should be used, like Power Holding Company of Nigeria (PHCN) to reduce this large amount of Carbon IV Oxide (greenhouse gasses) production and the attendant environment fall out of global warming, ozone layer depletion, acid rain and so on (Adedeji, 2015).

The Energy Cost (EnC) of production value of appropriately ₦5,000 per day, is more than one-third of the cost of one bag of flour (₦14,800) at the time of this research work. This is disproportionately high and ineffective, this energy supply mix should be readjusted to have a lower cost of bread production and the selling price of bread. Finally, the Total Exergy (TE<sub>x</sub>) obtained in the calculation was 0.2362 MJh<sup>-1</sup> compared with the total energy deployed 21.37 MJh<sup>-1</sup> depicts energy wastage of above 21.1 MJh<sup>-1</sup>, just a very minute quantity of the total energy deployed is effectively doing reversible work. Higher exergy producing energy sources be deployed to reduce wastages and inefficiency.

**Table 3: Summary of Results**

Parameters	Value	Standard value for best practices	Comment
EEI	5.256	2.9 -3.2 GJ/t (Worrel <i>et al.</i> ,, 2004)	5.2 is well outside the acceptable range, hence high cost of production. This due largely to the total energy and the energy mix used.
COE	38.19	Not Applicable	Amount of carbon released into the atmosphere (Greenhouse effect, acid rain, global warming, Ozone depletion)
E <sub>n</sub> C	4881.6	None set for the process under review	Hence, the over much exorbitant price of the product
TE <sub>x</sub>	0.2362	Comparing with input energy of TE <sub>n</sub> = 21.37 MJh <sup>-1</sup> energy wastage is absolutely too high	Percentage energy wastage is in the regime of 98% meaning that only 2% of the energy generated is used for reversible work

#### 4. CONCLUSIONS

The study examined the energy consumption rate during bread production in Nigeria and determine the most energy-intensive stage. The methodology involved gathering and analyzing data from bakery industries that exclusively utilize electric ovens. Questionnaire and oral interviews were utilized to investigate energy usage patterns in the bakery industries. The total energy consumed at each production stage was recorded, and the percentage of total energy consumption was calculated. The research revealed the following findings:

- i. The primary energy sources in the bread production process were manual (human), electrical, and thermal energy. Among these, thermal energy was found to be the highest in terms of consumption. The combination of electrical and thermal energy usage exceeded the consumption of manual energy.
- ii. The study identified lapses in energy use (Energy mix deployed), which were primarily attributed to the lack of proper energy conversion and conservation practices. This includes the need for practices such as replacing worn engine parts and addressing the aging of machines and equipment used in the production process.

To optimize energy use and achieve maximum production in bread production, the following recommendations are suggested:

- i. Operators of machines and equipment should receive adequate training and possess the necessary skills to ensure efficient usage of energy. This can help minimize energy waste and enhance overall productivity.
- ii. It is recommended to replace old machines and equipment with new ones. Aging machinery may have leakages and inefficiencies that contribute to energy wastage. By investing in newer and more energy-efficient equipment, energy consumption can be stabilized and unnecessary energy losses can be prevented.
- iii. It is important to maintain proper documentation, including equipment manuals and related documents, to facilitate energy consumption analysis. This enables manufacturers to evaluate energy usage throughout the production process, including manufacturing, transportation, and repair activities. By analyzing energy consumption data, areas of improvement can be identified and appropriate measures can be taken to optimize energy use.

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