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# Development of Equations for Estimating Energy Requirements in Small Scale Bread Production Factories in Benue State, Nigeria

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**ABSTRACT**

The study examined the energy consumption in the production of bread in small scale bread factories in selected industrially feasible six local government areas in Benue state of Nigeria. Eighteen randomly selected factories were investigated within these locations. Equation was developed for each unit operation to relate energy requirement to raw material input. The seven readily defined unit operations are; sieving, weighing, mixing, kneading, cutting/dough shaping, panning and baking. The equations were used to estimate energy consumption in the production using measured input data. The application test of the equations shows that about 3604.12MJ was averagely needed to process about 316 kg of raw material input in the studied area, while energy requirement for each unit operation in each location was also estimated. Results showed no significant difference at 95% confidence level of the energy requirements for the eighteen factories studied with respect to the identified unit process of production.

**Keywords**: Bread, development, energy equation, raw material, requirement.

## 1. INTRODUCTION

Energy is one of the most important parameters in the manufacturing industries. In most cases, energy cost outweighs the costs of other resources such as raw material, labour, depreciation and maintenance [1]. Scientific production and analysis of energy consumption will be of great importance for the planning of energy strategies and policies.

Nowadays, energy usage in agriculture has been intensified in response to continued growth of human population, tendency for an overall improved standard of living and limited supply of arable land; thus, the farmers use their inputs in excess and inefficiently, particularly when the inputs have low price or are available in plenty. The enhancement of energy efficiency not only helps in improving competitiveness through cost reduction, also results in minimized energy-related environmental pollution, thus positively contributing towards sustainable development [2, 3].

Bread is a baked food produced from flour that is moistened, kneaded, proofed with the addition of yeast. Bread is a convenience food made from wheat flour derived from bread wheat, the technology of which dates back to the ancient Egyptians at about 4000BC. Other raw materials for bread making apart from wheat flour include sugar, baking fat, yeast, vegetable oil, salt and water. Hard wheat flour is used for bread making because of gas produced by yeast during proofing and baking [4]. The bakery production which has been increasing steadily in the country is among the largest processed food industries in Nigeria. The two major bakery industries are bread and biscuit accounts for about 82% of the total bakery products. The bakery industries in Nigeria comprise organized and unorganized sectors. The organized sector consists of large, medium and small scale manufacturers who produced packaged biscuits and bread. The unorganized sector consists of small bakery units, cottage and household-type manufacturing goods and distributing their goods in the surrounding areas [5]. Bakery products are manufactured from combinations of wheat or other flours, sugar, baking powder, condensed milk, fat (ghee), salt, jelly, dry fruits, various essences and flavoring [6].

Energy audit is an important management tool required for economic utilization of energy resources in any manufacturing outfit. Inefficient energy utilization could lead to huge economic losses and energy is one of the most critical input resources in the manufacturing industry. Excessive energy consumption adds to the cost of goods produced especially in energy intensive industries.

In small scale bread production industries in Nigeria, clay oven with fuel wood (from biomass energy) as energy source for baking is used. In view of the huge amount of wood fuel required in most small scale industries in Nigeria, the increasing energy demand coupled with the finite energy resources, the rising cost of fossil fuel, deforestation and its attendant environmental impacts necessitate an understanding into energy requirements of bread production industry.

There is therefore no known report of any work in the literature on the energy requirement in bread production in Benue State, Nigeria or elsewhere in the world.

The aim of this study is to develop an energy use equation which can assess energy requirements of all processing operations in bread production as practiced in the middle belt region of Nigeria with specific study area of Benue State.

## 2. MATERIALS AND METHODS

Data for quantification of energy used for each unit operation of bread production were collected from eighteen bread production factories. Methodology used includes on-site study of all unit operations in the factories, well-structured questionnaire, and oral interview of the workers.

An inventory of number of persons involved, time required for production in hours (hr), quantity of liquid fuel used in liters (L), and quantity of wood fuel used in kilogram (kg) and material flow for the seven readily defined unit operations was made. The basic unit processes for bread production is shown in Figure 1.

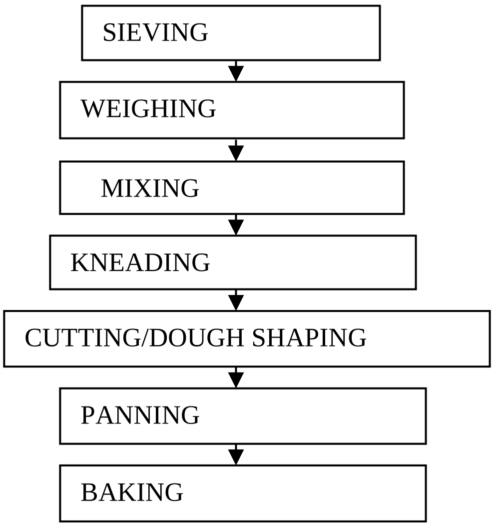


**Figure 1: Basic Unit Processes for Bread Production**

The primary energy resources utilized in the plant were identified to be manual (obtained from human labour), liquid fuel energy (obtained from fossil fuel), and wood fuel energy (obtained from wood fuel).

The weight of sample input was measured from a weighing balance. For each of the operations, the number of persons involved was counted and the time taken was also recorded using a stopwatch with all intermittent resting and idle period deducted. Before kneading operation was carried out, known quantity of fuel was measured using a calibrated plastic cylinder. The capacity of the cylinder was four liters. After the completion of the batch, the quantity of fuel left in the tank was recorded. The difference in these readings represented the quantity of fuel used. The weight of fuel wood used was determined by similar difference [7]. From this procedure, it was possible to assign, wood fuel energy, manual energy and liquid fuel energy, and a combination of two or all the forms of energies as the case may be, to each unit operation.

The raw data that was used to estimate the energy consumption at every processing unit were then converted to energy equivalent using developed energy equations (1), (2), (3) and (4)

The processing facilities of all the industries were similar. All the industries selected were evaluated over the same period and seasons, and as a result the error of seasonal variation changes was eliminated.

From the observed operating conditions for all the unit operations in bread production, it was concluded that manual energy estimation can be computed based on the value recommended by [8] given in equation 1.

$$E_m = 3.6(0.075N.T) \text{ (kWh)} \qquad (1)$$

Where:

$E_m$ = manual energy

3.6 = conversion factor (1kWh = 3.6 MJ)

0.075 = the average power of a normal human labour in kW;

N = number of person involved in the operation; and

T = useful time spent to accomplish a given task (operation), hr.

The energy demand (E) for operations utilizing fuel to run internal combustion engine is directly proportional to the quantity of fuel used (W), E α W, [9, 10, 11] given in equation 2.

$$E = C_f W \quad (MJ) \quad (2)$$

Where, $C_f$ is the constant of proportionality which represents the calorific value (heating value) of fuel.

For Diesel:

$E_{FLD}$=47.8D $E_{FLD} = 47.8D$ [12] (3)

Where $E_{FLD}$= liquid fuel energy input for diesel, MJ

47.8 = Unit energy value of diesel, $MJL^{-1}$

D = Amount of diesel fuel consumed per unit operation, (liter) [12]

For Petrol:

$$E_{LLP} = 42.3P \ (MJ) \quad (4)$$

Where:

$E_{LLP}$ = liquid fuel energy input for petrol, MJ

42.3 = Unit value of petrol,

$MJL^{-}$P = Amount of petrol consumed per unit operation, (liter).

To perform any of the unit operation wood fuel, liquid fuel, or manual energy is used. It is possible to use a combination of two.

## 3. DEVELOPMENT OF ENERGY EQUATIONS

At each stage of unit operation, some level of energy input was required in the form of manual, thermal and fossil fuels. The type and magnitude of the energy input is a function of the technology employed as well as the quantity of bread being processed. To compute these energy demands, quantitative data on operating conditions for each unit operation were measured. The types and magnitude of the parameters required for the energy evaluation of each unit operation are presented in Table 1.

The energy components from each source for the respective unit operation were calculated using the following procedure:

**Sieving:** Manual energy was involved in sieving operation. The energy required for sieving operation was computed using the expression:

$$E_s = 3.6(0.075N_s.T_s) \ (MJ) \quad (5)$$

**Weighing:** Manual Energy was involved in weighing operation. The energy required for weighing operation was evaluated using the expression:

$$E_w = 3.6(0.075N_w.T_w) \quad (MJ) \quad (6)$$

**Mixing:** Manual Energy was involved in mixing operation. The energy required for weighing operation was estimated using the expression:

$$E_m = 3.6(0.075N_m.T_m) \quad (MJ) \quad (7)$$

**Kneading:** Both manual and energy from liquid fuel was involved in kneading operation. The energy required for weighing operation was estimated using the expression:

$$E_k = W_k C_K + 3.6(0.075N_k T_k) \quad (MJ) \quad (8)$$

**Cutting/Dough Shaping:** Manual Energy was involved in cutting/dough shaping operation. The energy required for weighing operation was calculated using the expression:

$$E_C = 3.6(0.075N_c.T_c) \quad (MJ) \quad (9)$$

**Panning:** Manual Energy was involved in panning operation. The energy required for weighing operation was evaluated using the expression:

$$E_p = 3.6(0.075N_p.T_p) \quad (MJ) \quad (10)$$

**Baking:** Manual and thermal energy were involved in baking operation. The energy required for weighing operation was computed using the expression:

$$E_b = W_b C_b + 3.6(0.075N_b T_b) \quad (MJ) \quad (11)$$

**Total Energy input:** The total energy consumption in producing bread in each industry was calculated by summing up all the energy components involved in the process. Thus the total energy was computed using the following expression:

$$T.E = E_s + E_w + E_m + E_k + E_c + E_p + E_b \quad (MJ) \quad (12)$$

Equation (12) was used to determine the total energy required in the factories producing bread at a given production rate. The data obtained from the computations were further employed to generate equations relating energy requirement and raw material input for the identified unit operations using Microsoft Excel.

**Table 1:** Measured Parameters for Estimating Energy Input into Bread Production

| S/N | Operations | Required parameters |
|---|---|---|
| 1 | Sieving | Time taken for Sieving in hour (hr) |
| | | Number of persons involved |
| 2 | Weighing | Time taken for Weighing in hour (hr) |
| | | Number of persons involved |
| 3 | Mixing | Time taken for Mixing in hour (hr) |
| | | Number of persons involved |
| 4 | Kneading | Time taken for Kneading in hour (hr) |
| | | Number of persons involved |
| | | Quantity of fuel used in liter (L) |
| | | Calorific value of fuel used (MJ/L) |
| 5 | Cutting/Dough shaping | Time taken for Cutting/Dough shaping in hour (h) |
| | | Number of persons involved |
| 6 | Panning | Time taken for Panning in hour (hr) |
| | | Number of persons involved |
| 7 | Baking | Time taken for Baking in hour (hr) |
| | | Number of persons involved |
| | | Quantity of wood fuel used (Kg) |
| | | Calorific value of fuel used (MJ/Kg) |

## 4. RESULTS AND SISCUSSION

### Result of Analysis of Variance for Energy Requirement

Before the development of the equations for estimating the energy requirements of unit operations, analysis of variation (ANOVA) at 5% significant difference was conducted for the eighteen cases for the energy requirement and the different unit operations for the production of bread as presented in Table 2. There was no significant difference in the energy requirements for all the eighteen factories at 95% confidence level implying that the system has been standardized. The mean values therefore became consequential to be employed for the development of the equations.

**Table 2:** ANOVA of Bread Production Factories

| ***Source of Variation*** | ***SS*** | ***DS*** | ***Mf*** | ***F*** | ***P-value*** | ***Fcrit*** |
|---|---|---|---|---|---|---|
| Rows | 8457545 | 17 | 497502.7 | 1.177332 | 0.296305 | 1.723833 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Columns | 1.71E+08 | 6 | 28509219 | 67.46661 | 2.76E-33 | 2.188761 |
| Error | 43101921 | 102 | 422567.9 | | | |
| Total | 2.23E+08 | 125 | | | | |

**Ho:** $F \leq F_{Critical}$ **α = 0.05**

**Ha:** $F > F_{Critical}$

**Result of Energy Requirement**

The average energy requirement at different stages of bread production process in all the six locations investigated is presented in Figure 2. These represent the energy consumption level for production of bread of all the locations investigated. Wood fuel energy was the most used energy source, followed by liquid fuel energy and manual energy. This shows that all the industries extensively use wood fuel for operation. 93.27% of the mean energy consumption in the locations was obtained from wood fuel source, followed by 6.56% and 0.17% from fuel and manual energy sources as shown in Figure 3. This clearly indicates that most of the energy intensive operation involved in bread production was performed by heating and use of liquid fuel. Table 3 presents regression equations relating energy consumption to raw material input for each unit operation in the study area.

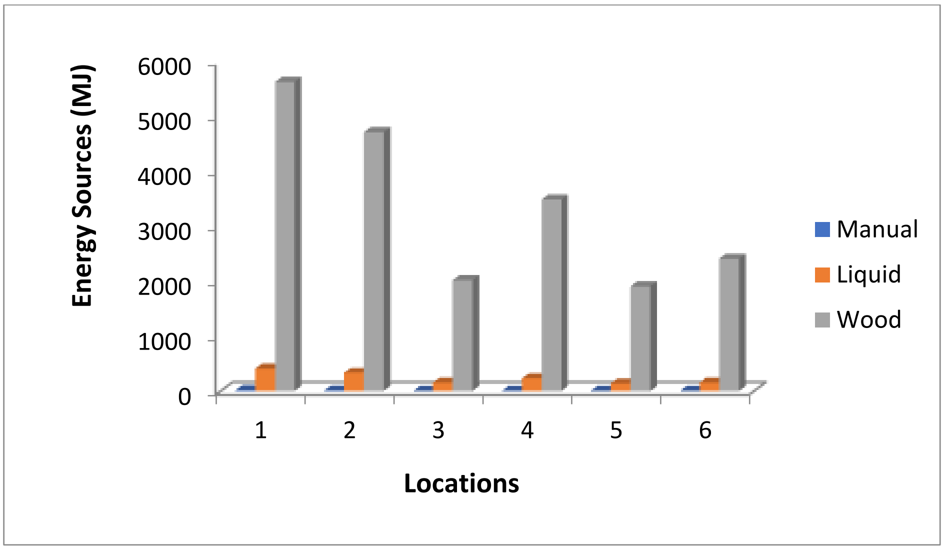


**Figure 2:** Mean Energy Types and Consumption Levels for Bread Production in the Study Area

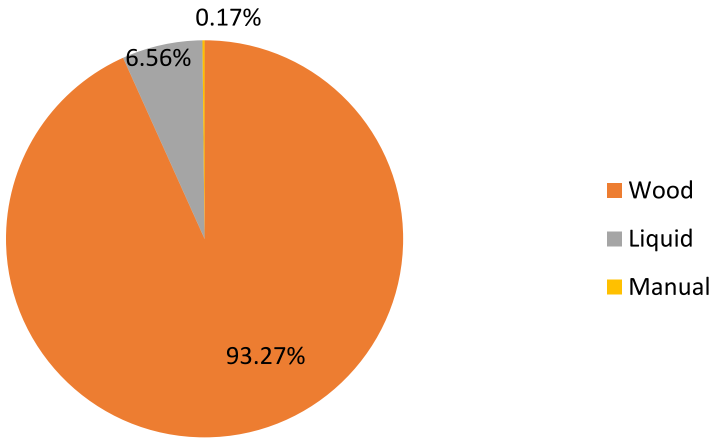


**Figure 3:** Consumption Level of Energy Sources for Bread Production in the Study Area

**Table 3:** Model Equations for Energy Requirements and Raw Material Input (Mean Case Material Input – 316 kg)

| Unit Operation | Model Equations | $R^2$ Value |
|---|---|---|
| Sieving | $Y = 0.004x - 0.478$ | 0.946 |
| Weighing | $Y = 0.001x - 0.002$ | 0.931 |
| Mixing | $Y = 0.004x - 0.423$ | 0.933 |
| Kneading | $Y = 0.689x + 22.03$ | 0.982 |
| Cutting/dough shaping | $Y = 0.009x - 1.370$ | 0.864 |
| Panning | $Y = 0.007x - 1.043$ | 0.904 |
| Baking | $Y = 9.496x + 354.6$ | 0.996 |

The coefficient of determination ($R^2$) for the estimated regression in all cases considered are greater than 0.8 showing that the raw material input mostly influenced the quantity of energy consumption assuming that all factors are constant. The results so far discussed the usefulness of the development of energy use profiles in the study area.

## 5. CONCLUSION

A study was conducted in eighteen bread production areas in Benue State of Nigeria to develop a set of equations that were capable of estimating energy requirements in each of the processing operations involved in bread production.

The study concluded that the ANOVA of the industries studied showed no significant difference at 95% confidence level implying that the system is standardized. The application test of the developed equations gave an average energy involved and energy consumption in relation to unit operations of 3604.12 MJ. This means that future energy requirement can be predicted by these equations.

The equations developed have provided fundamental information for carrying out budgeting and expansion planning, and predicting energy requirement in bread production factories.

The study has provided the basis upon which optimization of energy consumption of bread can be carried out.

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