

ENERGY USE IN NON-CONVENTIONAL BAKERY OVENS: A CASE STUDY OF SOME BAKERIES IN MAIDUGURI, NIGERIA

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Abstract

A study was conducted on energy use in ovens of some bakeries in Maiduguri Metropolis of Borno State, Nigeria. The results obtained showed minimum and maximum energy utilization indices of 20.95% and 31.07% with a corresponding maximum and minimum heat loss indices of 79.05% and 68.93%. Thus, a large proportion of the energy generated is wasted in non-conventional ovens. The paper recommends ways of possible improvement of the energy use of the non-conventional ovens.

1. Introduction

Energy is of central importance and influence in the development of all nations. Several sources of energy are available to energy consumers in Nigeria. The patterns of consumption of these different fuels vary as their costs change. Increasing domestic energy costs for electricity, gas and kerosene, coupled with the fact that these commodities are not readily available led to a significant increase in the use of fuelwood (Sambo, 1992).

In Nigeria, Omoluabi (1983) estimated the demand for fuelwood at 58.9 million cubic meters in 1987 and this is expected to increase due to increase in population and the use of more fuelwood by the urban dwellers. This leads to rapid deforestation and attendant environmental problems such as desertification and global warming. In developing countries, for example, fuel wood accounts for about 85% of the energy consumed (Ajibefun and Imoudu, 1995). However, in Nigeria, fuelwood would continue to be the dominant domestic energy source given the current fuelwood consumption of 79 million cubic meters per annum (Papka, 1997).

Bread bakeries commonly found in Nigeria have non-conventional ovens that use fuelwood and charcoal as the main fuels. They are called non-conventional because their design, construction and operation procedures do not conform to standard engineering practices, and hence they have no standard specifications for baking time and temperatures, construction procedures and guidelines, etc. These non-conventional ovens are also known as side flue or peel bricks ovens (Charles, 1990). The material of construction of the ovens is generally clay. They consist of large brick chambers and floors made of solely large rectangular refractory tiles. Generally, these non-conventional ovens are constructed without due consideration to standard design practices. Design parameters such as thermal conductivity, wall thickness and surface area directly affect energy utilization capacity of ovens and hence the question of heat energy utilization arises. Determination of heat energy use efficiency is necessary since excessive consumption of fuelwood and charcoal as energy resources leads to the low technical efficiency. For instance, out of the energy content of about 6.0×10^9 MJ for fuelwood used in Nigeria, only 5 – 10% is actually utilized (Sambo, 1992 and DanShehu et al, 1996). This low technical efficiency has stimulated research efforts that led to the development of improved wood burning stoves (Inegbenebor and Mshelia, 2000; Alkali *et al.*, 1989; Danshehu *et al.*, 1996). Presently, no work has been reported on energy use in non-conventional ovens used in bread baking in Nigeria today. There is therefore, the need to

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evaluate the energy utilization capacity of these ovens, which is necessary for energy conservation purposes. The objective of this study, therefore, was to carry out the evaluation of the energy utilization capacity of the non-conventional ovens used in bread baking in Maiduguri Metropolis.

2. Materials and Methods

The materials used in this study include industrial thermometer and thermocouple (Digital ALDA Multimeter, AVD 890C⁺ K type, with a temperature range of -50°C to 400°C), stopwatch, measuring tape, scale pan and spade. The tape was used for measuring the oven wall thickness whereas the industrial thermometer and thermocouples were used in obtaining the temperatures of the inner chambers and interior walls of ovens respectively. Weighing of the wood and unbaked bread were done using the scale pan, while the stopwatch was used for timing the baking process being experimented.

The study considered ten (10) ovens in bakery industries randomly selected within Maiduguri metropolis of Borno State, Nigeria. The fuelwood species used in the study were *Acacia nilotica*, *Balanite egyptica* and *parkia biglobos* with an approximate calorific value of 14.9 MJ/kg (Charles, 1990). The fuelwood was weighed and introduced into the oven chamber and left to burn completely into charcoal for an hour for the wall to absorb heat. The charcoal was then removed using a wooden handle spade. Thereafter, the oven was thoroughly cleaned and allowed to stabilize for 15 minutes (to attain steady state of heat distribution) before loading. Prepared dough was then introduced into the oven. The temperature of the oven was recorded at the beginning and end of the baking process.

The following assumptions were made in the study:

- (i) Complete combustion of the fuelwood
- (ii) All dough of the bakeries is made in the same way.

The following parameters were computed: total energy input of fuelwood used (Charles, 1990), quantity of heat flow and heat transfer rate at the oven wall surface (Rogers and Mayhew, 1992), amount of heat energy needed to bake a unit mass of bread (Charles, 1990), energy utilization (EU) indices for all the bakeries, quantity of heat energy loss index and its percentage.

- (1) Total energy input of the fuelwood used per bakery:

$$Q_{\text{input}} = \text{mass of fuelwood} \times \text{calorific value of fuelwood}$$

- (2) Quantity of heat flow (Q) and heat transfer rate at the oven wall surface:

$$Q = KA (T_2 - T_1)/X$$

Surface area of oven (A) = area of the dome shaped oven minus area of oven opening/door.

= surface area of the cylindrical portion + 2 surface area of the spherical portion.

$$= 2\pi r (h+r) + 2 (4\pi r^2) - (l \times b)$$

$$= 2\pi r (h + 2r) - (l \times b)$$

Where, K = thermal conductivity of the oven material (clay) (W/m°C)

A = Surface area of the oven (m²)

T_2 = maximum temperature of oven ($^{\circ}\text{C}$)
 T_1 = temperature at oven wall surface ($^{\circ}\text{C}$)
 X = thickness of the oven wall (m)
 Q = Quantity of heat flow (kW)
NB: Heat transfer rate is Q/A (kWm^{-2})

(3) Amount of heat energy needed to bake a unit mass of bread:

$$dQ_1 + dQ_2 = ms(T_3 - T_4) + (m_2 - m_1)r_w$$

Where, m = mass of dough (kg)

s = specific heat of dough (kJ/kg)

T_3 = temperature at which baking starts ($^{\circ}\text{C}$)

T_4 = temperature at which baking is completed ($^{\circ}\text{C}$)

$(m_2 - m_1)$ = difference in weight between dough piece and the baked loaf (kg)

r_w = heat of evaporation of water (i.e. 2208 kJ/kg)

dQ_1 = quantity of heat required to heat the dough pieces to the required baking temperature (kJ)

dQ_2 = quantity of heat required to evaporate excess water from the dough pieces (kJ).

(4) The energy utilization (EU) index of an oven is expressed as the ratio of the total theoretical heat energy required to bake a loaf of bread of a defined weight to the total energy input (Charles, 1990). Hence,

$$\text{EU index} = \frac{\text{Total theoretical heat energy to bake a loaf}}{\text{Total energy input of fuelwood expended}}$$

(5) Quantity of heat energy losses is defined as total energy input of fuelwood expended minus heat energy required to bake a specific mass of bread.

(6) Percentage heat lost index is simply 100% minus percentage energy utilization index per bakery.

The heat lost index is defined as:

$$\text{Heat lost index} = \frac{\text{Quantity of heat lost}}{\text{Total energy input of fuelwood expended}}$$

To show the detailed procedure of the computations carried out, the computations for bakery A are presented as follows;

a) surface area (A) of oven for bakery A:

$$A = 2\pi \times 1.10 (2.65 + 1.10) + 2 (4\pi \times 1.10^2) - 0.50 \times 0.45 = 33.37\text{m}^2$$

b) total energy input of fuelwood (Q_{input}):

$$Q_{\text{input}} = \text{mass of fuelwood} \times \text{calorific value of fuelwood} \\ = 78.20 \times 14,900 = 1.17 \times 10^6 \text{ kJ.}$$

c) Quantity of heat flow (Q) and heat transfer rate at the oven wall surface;

$$(i) Q = KA(T_2 - T_1) \times \\ = 0.70 (260 - 210) 10.27 = 4.31 \text{ KW}$$

(ii) Heat transfer rate at the oven wall surface;

$$Q/A = 4.31/33.27 = 0.129 \text{KW/m}^2.$$

d) Amount of heat energy needed to bake a specific mass of bread;

$$\begin{aligned} dQ_1 + dQ_2 &= ms (T_3 - T_4) \times (m_2 - m_1) r_w \\ &= 486.68 \times 3.0 (513 - 483) + (486.68 - 389.34) \times 2208, \\ &= 2.59 \times 10^5 \text{ kJ.} \end{aligned}$$

Therefore, the quantity of heat required to bake 1 kg of dough

$$= \frac{2.59 \times 10^5}{486.68} = 531.62 \text{ kJ.}$$

e) Percentage Energy Utilization (PEU) index;

$$\text{PEU}_{\text{index}} = \frac{\text{total heat energy to bake a loaf}}{\text{Total energy input of fuelwood expended}}$$

$$= \frac{2.59 \times 10^5}{1.17 \times 10^6} = 22.20\%$$

f) Quantity of heat loss is equal to the total energy input of fuelwood expended minus heat energy required to bake a specific mass of bread,

$$= 1.17 \times 10^6 - 2.59 \times 10^5 = 9.06 \times 10^5 \text{ kJ}$$

g) Percentage energy lost index (PEL) is 100% minus $\text{PEU}_{\text{index}}$

$$\begin{aligned} &= 100\% - \text{PEU}_{\text{index}} \\ &= 100 - 22.20\% = 77.80\%. \end{aligned}$$

4. Results and discussion

The summary of the results of the study is presented in Table 1.

Table 1: Result of oven performance characteristics for bakeries (A to J)

S/ N	Parameters Computed	A	B	C	D	E	F	G	H	I	J
1	Q_m (kJ)	2.59×10^5	3.58×10^5	2.44×10^5	3.87×10^5	3.20×10^5	2.92×10^5	2.48×10^5	3.32×10^5	2.61×10^5	3.07×10^5
2	Q_1 (kJ)	531.62	561.59	531.62	531.58	614.70	608.94	496.02	578.65	531.96	601.69
3	H_r (kWm ⁻²)	0.129	0.069	0.067	0.138	0.138	0.090	0.115	0.093	0.100	0.101
4	PEU (%)	22.20	29.50	22.50	31.07	26.68	25.76	20.95	28.05	22.39	25.34
5	E_t (kJ)	1.17×10^6	1.21×10^6	1.13×10^6	1.24×10^6	1.19×10^6	1.13×10^6	1.18×10^6	1.23×10^6	1.17×10^6	1.21×10^6
6	Q_1 (kJ)	9.06×10^5	8.54×10^5	8.73×10^5	8.58×10^5	8.70×10^5	8.38×10^5	9.32×10^5	8.98×10^5	9.09×10^5	9.03×10^5
7	PEL (%)	77.80	70.50	77.50	68.93	73.32	74.24	79.05	71.95	77.61	74.66

Q_m = Quantity of heat required to bake the mass of dough used
 Q_1 = Quantity of heat energy required to bake 1kg of dough
 H_r = Rate of heat transfer to the oven surroundings.
 PEU = Percentage energy utilization(PEU) indices
 E_t = Total energy input of fuel wood expended
 Q_1 = Quantity of heat loss
 PEL = Percentage energy lost (PEL) indices

Table 2: Parameter values for ten bakeries (A to J)

S/N	Parameters Considered	Values for ten bakeries (A to J)									
		A	B	C	D	E	F	G	H	I	J
1	Total mass of fuelwood used (kg)	78.20	81.30	75.60	83.50	80.10	76.20	79.50	82.40	78.20	81.30
2	Total mass of unbaked bread (kg)	486.68	637.31	476.98	727.26	520.70	480.21	500.20	574.42	490.50	510.20
3	Thickness of oven wall(m)	0.270	0.285	0.315	0.295	0.280	0.275	0.275	0.300	0.278	0.276
4	Height of oven (m)	2.65	2.65	2.58	2.70	2.68	2.64	2.66	2.72	2.70	2.65
5	Radius of oven (m)	1.10	1.20	1.21	1.25	1.22	1.41	1.22	1.24	1.20	1.26
6	Baking temperature begin T ₃ (°C)	240	260	230	260	255	245	245	250	248	253
7	Baking temperature finish T ₄ (°C)	210	220	200	230	220	210	215	210	218	215
8	Maximum temp. of oven T ₂ (°C)	260	280	250	288	285	270	265	280	285	290
9	Temp. at oven wall surface(°C)	210	252	220	230	230	235	220	240	245	250
10	Baking time (Min.)	14	13	15	12	13	14	12	15	13	14
11	Total mass of baked loaves (kg)	389.34	509.85	381.58	581.81	400.50	370.61	388.10	455.10	392.32	397.51
12	Length of oven l opening/door (m)	0.50	0.50	0.60	0.65	0.55	0.60	0.55	0.50	0.65	0.50
13	Breadth of oven opening/door (m)	0.45	0.50	0.50	0.65	0.50	0.50	0.50	0.45	0.60	0.45

From Table 1, it can be seen that utilization of the heat energy generated in the ovens of the four bakeries considered for the study ranges from a minimum of 20.95% to a maximum of 31.07%, corresponding to bakeries G and D respectively. This result is similar to those reported by Sambo (1992) and Danshehu *et al.* (1996). They reported that only 5-10% of the energy content of the fuelwood being used in Nigeria is actually being utilized. This means that out of the 79.50 kg used for the experiment for bakery G, with energy content of 1.18×10^6 kJ, only 2.48×10^5 kJ of heat energy was actually utilized, the rest was wasted. Similarly, only 3.87×10^5 kJ of the heat energy content of the 83.5kg of fuelwood used for bakery D was actually utilized, the remaining 8.58×10^5 kJ had gone to waste.

Also from Table 1, maximum and minimum heat energy losses of 79.05% and 68.93% were obtained. In monetary terms this means that for bakery G, using fuelwood cost of N5.00 /kg, of the N2501.00 worth of fuelwood used for the study, N1977.04 worth of the fuelwood was wasted. Similarly, for bakery D, the N3636.30 (i.e $727.26 \text{ kg} \times \text{N}5.00/\text{kg}$) worth of fuelwood used for the study, N2506.50 worth of it was wasted. These amounts when estimated annually are significant losses and hence there is need for optimizing the whole bread baking process using the conventional ovens.

A close look at the data in Table 2 reveals that bakery parameters like height, wall thickness, surface area, baking time and temperature are not standardized. The ovens were constructed without due consideration for standard design procedures. The differences in oven characteristics affect the heat energy utilization indices of the bakery ovens which vary from 20.95% for bakery G to 31.07% for bakery D as can be seen in Table 1.

From the analysis carried out, two possible channels of energy losses were identified. The first takes place via the oven wall and this is a function of the wall-thickness of the oven, surface area, ambient temperature and material of construction, while the other takes place due to practice in the present baking process. The time between evacuating the oven chambers and the commencement of the baking process allows energy losses. This means that there is the need for the urgent review of the present process of baking bread.

4. Conclusion and recommendations

4.1 Conclusion

The study was carried out to determine energy utilization in non-conventional ovens used in bread baking. Based on the finding of the study, the following conclusions are reached:

Percentage heat energy utilization indices for the bakeries considered for the study ranged from a minimum of 20.95% to a maximum of 31.07% and the percentage energy loss index ranged from a maximum of 79.05% to a minimum of 68.93%. The quantity of heat energy loss is significant and this means that unnecessarily large quantity of fuelwood is used during the baking process. The implications of this are that there is additional cost to consumers of bread, and also accelerated deforestation with subsequent environmental problems.

Heat energy losses take place via two main channels. The first channel is dependent on oven characteristics (wall thickness, surface area, ambient temperature and material of construction), and the other is through the present practice that allows time for evacuating the oven chambers before the commencement of the baking process.

4.2 Recommendations

The following recommendations can be made to improve energy utilization in the non-conventional bakery ovens in Maiduguri:

- (1) There is need for the modification of the non-conventional oven and the present baking process in order to reduce energy loss and subsequently fuelwood waste. This may include optimizing the process through sequential processing using at least two ovens. In addition, a method of estimating the appropriate quantity of fuelwood vis-à-vis the oven capacity is also required.
- (2) A wall thickness of 0.33m (5cm in excess of the present average of approximately 0.28m obtainable for the bakeries considered for the study) is recommended. This was found to be safe and feasible. By using a wall thickness of 0.33cm, heat energy loss will be reduced by 9%.
- (3) Because the heat loss from an oven is a function of the surface area, ovens of smaller surface areas are preferred.
- (4) To reduce heat energy loss via the oven wall, additives like chromite, feldspar or kaolin, rice, millet and maize husks and sawdust can be blended with the current construction material (clay). These materials burn away in the oven leaving plenty tiny holes in the clay body. These holes make the oven wall better heat insulators when they become part of the combustion chamber.

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