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Evaluation of Energy Utilization in Traditional Baking Ovens (A case study of Small Scale Bakeries in Kano City-Nigeria)

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Abstract

A study on the use of fuel wood for baking ovens of traditional bread in Kano Nigeria is carried out. Seven household bakery ovens are selected randomly in the baking quarters of the town and coded B1 to B7. Thermometer, spring balance, measuring scale pan and tape were used to measure the temperatures, masses of fuel wood, bread and dough, and the oven wall thickness respectively. Minimum and maximum energy utilization of 11.66% and 13.08% with corresponding minimum and maximum heat losses of 88.34% and 86.92% were obtained. Two channels of energy losses were identified. The first depends on the oven characteristics and the other on the baking practice that allows time lapse between oven chamber evacuation and the commencement of the baking process. Estimated oven wall thickness of 0.06m (2cm in excess of the present average of approximately 0.04m (4cm) obtained from the ovens considered for the study) was found to reduce the rate and quantities of heat lost by 33.3%. The corresponding quantities of heat energy conserved and its Naira equivalent ranged from 6.3 x 10^7kJ to 8.6 x 10^7kJ and N69.51.00 to N90.75 respectively. Thus large proportion of energy obtained from fuelwood is wasted in traditional ovens. Recommendations of possible improvement of efficient utilization of fuelwood in the traditional bakery ovens were made.

Keywords: *Traditional Ovens, Fuelwood, Energy Utilization, Bakery*

1. Introduction

Traditional bread 'gurasa' is locally made bread in Kano from plain flour and baked in oval shaped earthenware pot known as 'tanderu', after it has been heated from within with firewood or cornstalk fire. Gurasa is widely accepted by people in the north-west and north-east regions, though its preparation has remained the special preserve of people in Jakara Quarters in Kano. Sections of households there are reserved as mini bakeries. This thriving industry is energy intensive. The demand is on fuelwood and cornstalk to drive it.

Between 1962 and the early 1980s the urban population of Kano increased from a quarter of a million to about a million, according to unofficial estimates. The increasing population has led a number of observers to predict the elimination of trees, in time, from the Kano close-settled zone, the immediate hinterland of Metropolitan Kano. Indeed Eckholm *et al*. (1984) have stated that 'over the last 25 years commercial wood demands have led to severe deforestation and the collapse of a sustainable agricultural system ... now farmland within a 40 km radius of the city (of Kano) has been largely stripped of trees'. A survey of households was carried out to assess the demand for firewood. The results of this survey indicated a mean monthly consumption of firewood of 332 kg, however, this figure disguises a wide variation between households of different economic and social status (Moss and Morgan, 1980). Surveys of traffic in wood fuel from the local hinterland, conducted in the 1960s and 1983, show that this traffic has declined dramatically during the last two decades. However, recorded imports from the distant hinterland have increased, with some consignments of wood coming from up to 600 km away. The outward shift of Kano's wood fuel hinterland has negative implications as pressure on natural woodland in the distant hinterland is increasing without adequate conservationary safeguards. (Cline-Cole *et al*, 1988)

The hinterland Nigeria is using 80 million cubic metres i.e 43.3 x $l0^9$kg of fuelwood with an energy content of 6.0 x 10^9MJ annually for cooking and domestic purposes, out of which only 5-10% that is been utilized (Sambo, 1992). Burning is the crudest form of energy conversion, must of the energy that is been produced tends to be wasted or vented to the atmosphere (Manas, 1981).

Although the biomass availability as at 1973 was put at 9.1 x 10^2MJ, it is expected that, the overall biomass resources availability at present is lower than the 1973 figures, this is largely due to the demand of wood for construction and furniture industries in addition to its use as an energy source (Sambo, 1992). Apart from being the major source of energy, it is used for commercial purposes in various forms as plywood, sawn wood, paper products etc.

Fuelwood is the major source of energy used in bakery ovens found in Nigeria. The bakeries are similar to the early German ovens constructed with clay bricks, called heat storage ovens. They depend on direct heating principle. After heating up, the temperature in the tiles and bricks wall is been utilized during production and because of the high initial temperature and the oven heat energy transfer, they are ideal for bread baking. It was observed that, the energy obtained from fuel wood is not efficiently been utilized. This is because of the poor design, construction and operational procedures of the ovens which directly affect their energy utilization. Therefore the question of energy utilization arises since excessive consumption of fuelwood as energy source leads to low technical efficiency of the ovens (Mshelia et, al, 2002). Duvuna and Abur (2014) have determined the efficiency of such ovens in Adamawa Nigeria to be around 20-25% with slight increment of oven wall thickness.

2. Materials and Method

Seven ovens were selected randomly in Jakara Quarters in Kano metrolitan and coded B1 to B7 respectively. The fuelwood species used in the study were Acacia albida and Parkia biglobosa with an approximated calorific value of 19.741 MJ/kg. The fuelwood was weighed and introduced into the oven chamber and left to burn completely into charcoal for 30-45 minutes for the chamber to absorb heat. The charcoal was then removed. Thereafter, the oven was thoroughly cleaned and allowed to stabilize for 5 minutes to attain a 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 at the end of the baking process by a Taylor 3506 Oven thermometer with a temperature range of 0°C -320°C. Stopwatch, measuring tape, scale pan, recording chart and spade were also employed. The tape was used for measuring the oven wall thickness, the thermometer was used in obtaining the temperature of the inner chambers and interior walls of the ovens respectively. Weighing of the fuelwood, dough and bread were done using scale pan and stopwatch was used for timing the baking process being experimented... This procedure was equally repeated for the second batch of production. The following assumptions were made in the study:

(i) Complete combustion of the fuelwood
(ii) All dough of the bakeries are 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 *et al*, 1992), amount of heat energy needed to bake a unit mass of dough (Charles, 1990), energy utilization (EU) indices for all the bakeries, quantity of heat energy losses and its percentages, Naira equivalent values and estimated wall thickness

2.1 Total energy input of the fuelwood used per oven

$$Q_{input} = mass\ of\ fuelwood \times calorific\ value = M \times CV \quad (1)$$

2.2 Quantity of heat flow (Q) and heat transfer at the oven wall surface

$$Q = \frac{KA(T_2 - T_1)}{X} \quad (2)$$

$$q = \frac{Q}{A} \quad (3)$$

2.3 Surface area of oven (A) = Area of the oval shape oven minus area of the oven opening/door

= surface area of cylindrical section + surface area of conical sections (modeled as cylindrical middle and two conical ends of 2/3 surface area).

$$= 2\pi rh + \frac{4}{3}(\pi rs) \quad (4)$$

where
K = Thermal conductivity of the oven material (clay) (0.70W/m)
A = Surface area of the oven (m^2)
T_1 = Temperature at oven wall surface (0^c)
T_2 = Maximum temperature of oven (0^c)
X = Thickness of the oven wall (m)
M = Mass of fuelwood (kg)
C.V = Calorific value of fuelwood
Q = Quantity of heat flow (kW)
q = Heat transfer rate (kWm^{-2})

2.4 Amount of heat energy needed to bake a specified mass of dough

$$dQ_{11} + dQ_{12} = MS[(T_3 - T_4) + (T_5 - T_6)] \quad (5)$$

$$dQ_{21} + dQ_{22} = (M_2 - M_4)r_w \times 2 \quad (6)$$

Therefore, total amount of heat energy needed to bake a specified mass of dough

$$DQ_T = dQ_{11} + dQ_{12} + dQ_{21} + dQ_{22} \quad (7)$$

where
M = Mass of dough (kg)
S = Specific heat of dough (3.0kJ/kg)
T_3 = Temperature at which baking started (°C) for the first batch
T_4 = Temperature at which baking was completed (°C) for the first batch
T_5 = Temperature at which baking started for the second batch (°C)
T_6 = Temperature at which baking was completed for the second batch (°C)

$M_2 - M_4$ = Difference in weight between dough piece and the baked loaf (kg)
r_w = Heat of evaporation of water (i.e 2208kJ/kg)
$dQ_{11} + dQ_{12}$ = Quantity of heat energy required to raise the dough to baking temperature (kJ)
$dQ_{21} + dQ_{22}$ = Quantity of heat energy required to evaporate excess dough water (KJ)

2.5 The percentage energy utilization (P.E.U) index of an oven

This is expressed as the ratio of total theoretical heat energy required to bake a dough of a defined weight to the total energy input (Charles, 1990). Hence

$$P.E.U = \frac{Total\ theoretical\ heat\ energy\ to\ bake\ a\ dough}{Total\ energy\ input\ of\ fuelwood\ expanded} \times 100 \qquad (8)$$

2.6 Quantity of heat loses

Defined as total energy input of fuelwood expanded minus heat energy required to bake a specific mass of dough.

$$Q_L = CV - Q_m \qquad (9)$$

where
Q_L = Quantity of heat lost (kJ)
CV = Calorific value of fuelwood (KJ)
Q_m = Heat energy required to bake a specific mass of dough (kJ)

2.7 Percentage heat lost index

This is defined as 100% minus percentage energy utilization index

$$= 100\% - P.E.U \qquad (10)$$

2.8 The Naira equivalent values of heat losses
This is calculated as

$$= \frac{Quantity\ of\ heat\ loss\ x\ cost\ price\ of\ a\ specified\ mass\ of\ fuelwood}{Calorific\ value\ of\ fuelwood\ used} \qquad (11)$$

2.9 Quantity of heat losses by using an estimated oven wall thickness of 4cm (0.04m), quantity of heat energy saved and the Naira equivalent of heat energy saved

To compute the quantity of heat losses at an estimated oven wall thickness of 4cm (0.04m) i.e at the above computed rate of heat dissipation, we obtained this by comparing this rate of heat transfer with the existing rate of heat transfer at the oven wall surface computed in equations 2 and 3 and its associated heat losses.

To show the detailed procedure on how the energy obtained from the fuelwood was utilized for the bakeries considered for study. The computation for oven B1 is presented as follows:

Surface area A for oven B1 from equation (4)

$$A = 2\pi rh + \frac{4}{3}(\pi rs)$$
$$= 2\pi \times 0.15 \times 0.7 + \frac{4}{3}(\pi \times 0.15 \times 0.16) = 0.76\text{m}^2$$

Total energy input of fuelwood (Q_{input}) using equation (1)

$$Q_{input} = mass\ of\ fuelwood\ \times calorific\ value$$
$$= M \times CV$$
$$= 15\ \times 19.471 \times 10^6 = 292000000.07\text{kJ}$$

Quantity of heat flow (Q) and heat transfer rate at the oven wall surface, using equation (2)

$$Q = \frac{KA(T_2 - T_1)}{X}$$

$$= \frac{0.7 \times 0.76 \times (240 - 220)}{0.04} = 266\text{ kW}$$

Heat transfer rate at the oven wall surface using equation (3)

$$q = \frac{Q}{A} = \frac{266}{0.76} = 350\text{ kW/m}^2$$

Amount of heat energy needed to bake a specific mass of dough using equations 5, 6 and 7

$$dQ_{11} + dQ_{12} = 2414 + 249556 = 251970\text{ kJ}$$
$$dQ_{21} + dQ_{22} = 16900004 + 16900004 = 33800008\text{ kJ}$$
$$DQ_T = dQ_{11} + dQ_{12} + dQ_{21} + dQ_{22} = 251970 + 33800008 = 3.38 \times 10^7\text{ kJ}$$

Therefore, the total heat energy required to bake 1 kg of dough = $3.38 \times \frac{10^7}{24590} = 1376$kJ

Percentage energy utilization (PEU) index, using equation (8)

$$P.E.U = \frac{Total\ theoretical\ heat\ energy\ to\ bake\ a\ dough}{Total\ energy\ input\ of\ fuelwood\ expanded} \times 100$$
$$= \frac{3.38 \times 10^7}{2.92 \times 10^8} \times 100 = 11.66\%$$

Quantity of heat lost is equal to the total energy input of fuelwood expended minus heat energy required to bake a specific mass of dough. Using equation (9)

$$= 2.92 \times 10^8 - 3.38 \times 10^7 = 2.58 \times 10^8\text{kJ}$$

Percentage energy lost index (P.E.L) is 100% minus P.E.U index. Using equation (10)

$$100 - 11.66 = 88.34\%$$

Naira equivalent value of heat loss using equation (11)

$$2.58 \times 10^8 \times 20 \times 15 / 2.92 \times 10^8 = 265.07\ \text{Naira}$$

Quantity of heat loss by using an estimated oven wall thickness using equation (12):

With original thickness of 4cm, heat flow and transfer rates Q and q were calculated from equations 2 and 3 as 266kW and 350kW/m^2 respectively. If thickness assumed to be 6cm,

$$q = \frac{0.7\times(240-220)}{0.06} = 233.33\text{kW/m}^2$$

So, if at thickness of 4cm, rate of heat transfer is 350kW/m^2 and heat lost by oven is 2.58×10^8kJ, then for increment of wall thickness to 6cm with less heat transfer rate of 233.33kW/m^2, heat loss is calculated as

$$\frac{233.33}{350} \times 2.58 \times 10^8 = 1.72 \times 10^8\text{kJ}$$

Quantity of heat saved by wall thickness increment = $2.58 \times 10^8 - 1.72 \times 10^8 = 8.6 \times 10^7$kJ

The Naira equivalent of heat energy saved is expressed as:

If 15kg fuelwood gave 2.92×10^8 kJ and cost N300, then 8.6×10^7kJ will cost

$8.6 \times 10^7 / 2.92 \times 10^8 \times 300 = 88.36$ Naira

Quantity of heat energy that could have been utilized is

= Total quantity of fuelwood (expended) - heat loss
$= 2.92 \times 10^8 - 1.72 \times 10^8 = 1.2 \times 10^8$kJ

Percentage heat energy utilized:

$$\frac{\text{Total heat energy utilized}}{\text{Net heat supplied}}$$

$1.2 \times 10^8 / 2.92 \times 10^8 = 41.1\%$

The parameter values, oven performance characteristics and the results of estimated oven wall thickness of 6cm (0.06m) are shown in tables 1, 2 and 3 respectively.

Table 1: Parameter Values for the Seven Ovens (B1 to B7)

S/N	Parameters considered	Values for Seven Ovens						
		B1	B2	B3	B4	B5	B6	B7
1	M_T	15	18	16	16	17	15	15
2	M_1	245.9	251.1	247.0	247.0	245.0	244.6	243.8
3	M_2	122.9	125.5	123.5	123.5	122.5	122.2	121.7
4	C_0	124	126	123	124	123	124	122
5	T_0	0.04	0.04	0.03	0.03	0.03	0.05	0.04
6	R_0	0.25	0.22	0.26	0.23	0.26	0.24	0.22
7	H_0	1.03	1.08	0.97	1.05	2.60	1.10	1.01
8	T_3	240	245	243	245	240	242	241
9	T_4	220	218	226	226	220	228	219
10	T_5	198	195	197	195	193	195	195
11	T_6	165	159	167	164	164	167	164
12	T_2	235	230	233	235	235	233	233
13	T_1	220	244	230	220	220	215	210
14	B_t	14	13	12	11	14	15	14
15	M_3	210.0	215.0	212.0	218.0	216.5	210.1	205.0
16	M_4	105.0	107.0	105.5	108.5	108.0	204.0	203.0
17	L_0	0.45	0.50	0.50	0.60	0.50	0.45	0.40
18	B_0	0.40	0.43	0.45	0.45	0.40	0.43	0.42

Table 2: Results of Oven Performance Characteristics

S/N	Parameters computed	Values for Respective Ovens						
		B1	B2	B3	B4	B5	B6	B7
1	Q_m ($\times 10^7$kJ)	3.38	3.53	3.41	3.62	3.88	3.80	3.67
2	Q_i (kJ)	1376	1473	1602	1488	1420	1312	1410
3	H_r (kWm^2)	0.129	0.107	0.084	0.117	0.124	0.118	0.132
4	P.E.U. (%)	11.66	12.48	13.57	12.60	13.08	12.01	11.72
5	E_t ($\times 10^8$kJ)	2.92	3.01	2.88	2.85	2.95	2.81	2.98
6	Q_1 ($\times 10^8$kJ)	2.58	2.66	2.55	3.52	2.61	2.84	2.63
7	P.E.L. (%)	88.34	87.52	86.43	87.40	86.92	87.99	88.28
8	A_t (m^2)	0.76	0.78	0.84	0.74	0.90	0.78	0.78
9	Ne (Naira)	265.07	271.54	249.07	250.66	255.90	260.01	243.63

Table 3: Results of Estimated Oven Wall Thickness

S/N	Parameters computed	Values for Respective Ovens						
		B1	B2	B3	B4	B5	B6	B7
1	W_t (m)	0.06	0.06	0.05	0.05	0.05	.0.07	0.06
2	H_r (kWm^{-2})	0.106	0.094	0.094	0.123	0.095	0.107	0.096
3	P.E.U. (%)	41.10	34.50	36.95	32.67	41.50	33.02	32.22
4	Q_1($\times10^8$kJ)	1.72	1.75	1.43	1.74	1.57	1.48	1.37
5	Q_c ($\times10^7$kJ)	8.6	7.7	6.8	6.3	7.2	7.5	6.4
6	Ne (Naira)	88.36	69.51	75.71	90.75	80.36	87.69	70.82

3. Results and Discussion

It can be seen from Table 2 that utilization of heat energy generated in the ovens in the study ranges from a minimum of 11.66% to a maximum of 13.08%, corresponding to oven B1 and B5 respectively. The average of 12% utilization is close to the range of those reported by Sambo (1992), Danshehu et, al (1996) and Mshelia et, al, (2002). They reported that only 5-10% of the energy content of fuelwood being used in Nigeria is actually being utilized. It varied from the report of Duvuna and Abur (2014), with minimum utilization of over 21%. Possible variation could arise from different wood species and calorific value consideration.

This implies that out of the 15kg of fuelwood used for the experiment for oven B1, with energy content of 2.92 x 10^8kJ only 3.38 x10^7kJ of heat energy was actually utilized, the rest getting wasted. Similarly, only 3.88 x 10^7kJ of the heat energy content of the 15.2kg of fuelwood used for oven B5 was actually utilized while the remaining 2.95 x 10^8kJ had gone to waste. Table 2 shows maximum and minimum heat energy losses of 88.34% and 86.92% were obtained. In monetary terms, this means that for oven B1, using fuelwood cost of N20.00/ kg, of the N300.00 worth of fuelwood used for the study, N265.07 worth was wasted. Similarly, for oven B5, the N300.00 worth of fuelwood used for the study, N255.90 worth of it was wasted. These amounts when estimated annually at 5-day work week amount to about N9,657.00 waste on fuel, which are significant losses. Hence, there is need for optimizing the whole traditional bread baking process. Looking at the data in Table 1, it can be seen that oven parameters like height, wall thickness, baking time and temperature are not uniform or standardized. The ovens were constructed based on artisanship without due consideration for standard design procedures. Thus, differences in oven parametric characteristics affect the heat energy utilization indices of the ovens which vary from 11.66% for oven B1 to 13.08 for oven B5, as can be seen in the Table 2.

The study identified two main channels of energy losses. The first is through the oven wall and is a function of the wall thickness of the oven, surface area, ambient temperature and material of construction while the other took place due to practice in the present baking process. In table 3, theoretical increment of wall thickness of 2cm has indicated increment of energy utilization of 32-41.5% across the oven with corresponding Naira savings. Practically this could be achieved by further lagging with the pot material or clay during assembly. Also the time between evacuating the oven chambers and the commencement of the baking process allows energy losses. This means that there is a need for the urgent review of the present process of baking bread.

Conclusion and Recommendation

The study on fuelwood energy utilization in traditional bread making in Kano was carried out. It discovered low utilization ranging from a minimum of 11.66% to a maximum of 13.08%, and corresponding heat energy losses of 88.34% and 86.92%. Energy utilization in the ovens in the study is close to the range of those reported by other studies on fuelwood in Nigeria. The report concluded that the low utilization plays significant financial loss in the low income sector of the industry. The energy losses were as caused by inherent oven material and geometry properties as well as baking practices.

Recommendation

The following recommendations are made:

1) Study can be carried out on the optimal lagging thickness of such ovens, so that standard thickness is incorporated in the design of the ovens.
2) Comparative study of the use of other viable fuels such as kerosene and cooking gas as energy sources can be made for the traditional ovens.

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