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Research Article

Effective Energy Utilization in Non-Conventional Bakery Ovens (A case study of Adamawa State, Nigeria)

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Abstract

A study was conducted on fuel wood as energy source in non-conventional bakery ovens. Nine bakery ovens selected randomly were considered for the study. Three each from the study areas, namely Mubi, Yola and Numan Local Governments metropolis, Adamawa State, coded (A, B, and C), (D, E, and F), (G, H and I) respectively. Thermometer, spring balance, measuring scale pan and tape were used to measure the temperatures, masses of fuelwood, bread and dough, and the oven wall thickness respectively. Minimum and maximum energy utilization of 20.27% and 25.11% with corresponding minimum and maximum heat losses of 74.89% and 79.73% were obtained. Two main channels of energy losses were identified. First channel depends on the oven characteristics and the other is through the present practice that allows time for evacuating the oven chamber before the commence ment of the baking process. Estimated oven wall thickness of 0. 33m (33cm) (i.e, 5cm in excess of the present average of approximately 0.28m (28cm) obtained from the bakeries considered for the study) was found to reduced the rate and quantities of heat lost by 14% and the corresponding quantities of heat energy conserved, its Naira equivalent ranged from 6.66 x 10^4kJ to 2.80 x 10^5kJ and N67.00 to N283.21 respectively. Thus large proportion of energy obtained from fuelwood is wasted in non- conventional ovens. The paper, therefore recommends ways of possible improvement of efficient utilization of fuelwood in non-conventional bakery ovens.

Keywords: *Non-conventional Ovens, Energy Sources, Fuelwood, Energy Utilization, Bakery.*

Significance*: Optimization of bread baking using the non conventional method, energy conservation through reduction of excessive fuelwood and charcoal consumptions which will consequently reduce deforestation which will enhance environmental control.*

1. Introduction

Fuel wood energy is one of the most abundant and renewable natural resources of this planet. Trees are renewable resources which today covers over 30% of the earth's land surface (Earl, 1975). It is estimated that about 50% of the world annual wood production is utilized as fuel and of this 90% is used in developing countries (Earl, 1975). The use of wood for domestic purposes is projected to have began some 400,000 to 500,000 years ago and bio-fuels, especially wood, has remain the most widely used fuel both for domestic (cooking and heating) and industrial (bakery, suyaetc) purposes throughout the change of history (Openshaw, 1980) and (Foley, 1985). With over 80% of total fuelwood consumption in less developed countries, the demand for fuelwood from natural forest resources has greatly increased the world over due to increasing population growth (Oseneobo, 1992). The largest sources of fuelwood supply in Nigeria are the communal bushes and private farms. The most important controlling factors influencing the efficiency of wood as fuel is moisture content. Moisture in a very fresh wood may amount to more than 100% of the dry weight substance, which reduces its values as fuel because of the absorption of heat required in the evaporation of the water or moisture content. 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). Apart from being the major source of energy, it is used for commercial purposes in various forms as plywood, sawn wood, paper products etc. Nigeria is using 80 million cubic metresi.e 43.3 x l0^9kg 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). 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).

Fuelwood is the major source of energy used in non-conventional bakery ovens found in Nigeria. The non-

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conventional bakeries are similar to the early German ovens constructed with clay bricks mainly 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 the energy utilization of the ovens, hence 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). For this reason the paper recommends the possible ways of improving the efficient utilization of fuelwood in non-conventional bakery ovens in Adamawa State.

2. Materials and Method

For the purpose of this study, nine bakery ovens were selected randomly. Three bakeries each from the study areas of Mubi, Yola and Numan Local Government metropolis of Adamawa State coded (A, B and C), (D, E, and F), (G, H, and I) respectively. The fuelwood species used in the study were Acacia nilotica, BalamiteAegyptiaca and parkiabiglobosa with an approximated calorific value of 14.9 kJ/kg (Charles,1990). The fuelwood was weighed and introduced into the oven chamber and left to burn completely into charcoal for at least an hour for the wall to absorb heat. The charcoal was then removed using a long wooden handle spade. Thereafter, the oven was thoroughly cleaned and allowed to stabilize for 10 - 15 minutes to attain a steady state of heat distribution before loading. Prepared dough was then introduced into the ovens. The temperature of the oven was recorded at the beginning and at the end of the baking process by a MSZ 13950 Nitrogennel TOLTVES thermometer with a temperature range of 0°C -360°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 bakery

Q_{input} = mass of fuelwood x calorific value of fuelwood =Mx C.V (1)

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

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

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

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

= Surface areas of the cylindrical portion + ½ surface area of the spherical portion

$$= 2\pi r(h - r) + \tfrac{1}{2}\left(4\pi \times r^2\right) - (L \times b) \quad (4)$$

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

Where,

K = Thermal conductivity of the oven material (clay) (0.70 W/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

$$d\,Q_{11} + d\,Q_{12} MS(T_3 - T_4) + (T_5 - T_6) \quad (5)$$

$$d\,Q_{21} + d\,Q_{22}(M_2 - M_4) r_w \times 2 \quad (6)$$

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

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

$P.E.U_{index}$
= Total theoretical heat energy to bake a dough x 100
Total energy input of fuelwood expanded (8)

2.6 Quantity of heat loses

Is defined as total energy input of fuelwood expanded minus heat energy required t bake a specific mass of dough. Mathematically

$$Q_L = C.V = Q_m \quad (9)$$

Where,
Q_L = Quantity of heat lost (KJ)
C.V = Calorific value of fuelwood (KJ)
Q_m = Heat energy required to bake a specific mass of dough (KJ)

2.7 Percentage heat lost index

Is simply 100% minus percentage energy utilization index
= 100%- P.E.U (10)

2.8 The Naira equivalent values of heat losses

The computation was done by applying simple ratio

= Quantity of heat loss x cost price of a specified mass of fuelwood
Calorific value of fuelwood used (11)

2.9 Using estimated oven wall thicknesses of 32cm and 33cm

Assumption was made by using a wall thickness of 32cm and 33cm.

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

$$q = \frac{Q}{A} = \frac{K\left(T_2 - T_1\right)}{X} \quad (12)$$

2.10 Quantity of heat losses by using an estimated oven wall thickness of 33cm (0.33m), quantity of heat energysaved and the Naira equivalent of heat energy saved.

To compute the quantity of heat losses at an estimated oven wall thickness of 33cm (0.33m) 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 it 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 bakery A is presented as follows

Surface area (A) of oven for bakery A using equation 4
A= $2\pi r\left(h + 2r\right) - \left(L \times b\right)$
A= $2\pi \times 1.63\left(2.65 + 2 \times 1.63\right) - \left(0.50 \times 0.45\right) = 60.31m^2$
Total energy input of fuelwood (Q_{input}) using equation 1
$Q_{input} = M \times C.V$
Q_{input} = Mass of fuelwood x calorific value of fuelwood
$= 128.2 \times 1490 = 1.91 \times^{10^6} KJ$
Quantity of heat flow (Q) and heat transfer rate at the oven wall surface, using equation 2

i) $Q = \frac{KA\left(_{T_2} - T_1\right)}{X}$

$= \frac{0.7 \times 60.31\left(260 - 210\right)}{0.270} = 7.82kW$

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

$q = \frac{Q}{A} = \frac{7.82 \times 10^3}{60.31} = 0.129kW / m^2$

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

$dQ_{11} + dQ_{12} = 24150 + 2495562 = 3.87 \times 10^5 KJ$
$dQ_{21} + dQ_{22} = 16900032 + 1690032 = 33800032KJ$

$DQ = dQ_{11} + dQ_{12} + dQ_{21} + dQ_{22}$
$5910622KJ + 33800032KJ = 3.87 \times 10^5 KJ$

Therefore, the total heat energy required to bake 1 kg of dough

$= \frac{38710654}{536.68} = 721.29KJ$

Percentage energy utilization (PEU) index, using equation 8

$P.U.E_{input}$= Total heat energy to bake a dough x 100
Total energy input of fuelwood expended

$= \frac{3.87 \times 10^5}{1.91 \times 10^6} \times 100 = 20.27\%$

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

$= 1.91 \times 10^6 - 3.87 \times 10^5 = 1.52 \times 10^6 KJ$

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

$= 100 - 20.27 = 79.73\%$

The Naira equivalent value of heat loss using equation 11

= $\frac{l.52 \times 10^6 \text{ x N1923.00}}{1910180}$ = N1533.00

Table 1: Parameters Values for the Nine Bakeries (A to I)

S/No	Parameters Considered	Values for the Nine Bakeries (A to I)								
		A	B	C	D	E	F	G	H	I
I	M_T	128.2	141.3	*125.6*	150.5	135.1	126.2.	136.5	139.4	128.2
2	M_1	536.68	687.31	526.98	777.26	570.70	530.21	570.20	624.42	540.50
3	M_2	268.34	343.66	263.49	388.63	285.35	265.1	285.1	31221	270.25
4	C_0	274	351	269	397	291	271	291	319	276
5	T_0	0.270	0.285	0.315	0.295	0.280	0.275	0.275	0.300	0.278
6	R_0	1.63	1.97	1.57	2.05	1.76	1.58	1.75	1.86	1.62
7	H_0	2.65	2.69	2.58	2.70	2.68	2.64	2.66	2.72	2.70
8	T_3	240	260	230	260	255	245	245	250	248
9	T_4	210	220	200	230	220	210	215	210	218
10	T_5	195	200	190	218.	200	193	200	194	192
11	T_6	164	158	155	185	163	155	165	1 56	159
12	T_2	260	280	250	288	285	270	265	280	285
13	T_1	210	252	220	230	230	235	220	240	245
14	B_t	14	13	15	12	13	14	12	15	13
15.	M_3	383.6	491.4	376.6	555.8	407.4	379.4	407.4	446.6	386.4
16	M_4	191.8	245.7	188.3	277.9	203.7	189.7	203.7	223.3	l93.2
17	L_0	0.50	0.50	0.60	0.65	0.55	0.60	0.55	0.50	0.65
18	B_0	0.45	0.50	0.50	0.65	0.50	0.551	0.53	0.45	0.65

Table 2: Results of Oven Performance Characteristics for Bakeries (A to I)

S/N	Parameters Computed	Values For Respective Bakeries A to I								
		A	B	C	D	E	F	G	H	I
1	Q_m (k.J)	$3.87X\ 10^5$	$5.17X\ 10^5$	$3.83X\ 10^5$	$5.62X10^5$	$4.21X10^5$	$3.91X10^5$	$4.15X10^5$	$4.66X10^5$	$4.14X10^5$
2	Q_i	721.29	752.39	727.57	723.6	738.29	737	728	746	765
3	H_r(kWm^{-2})	0.129	0.069	0.067	0.138	0.138	0.089	0.115	0.093	0.100
4	P.E.U%	20.27	*24.56*	20.49	*25.11*	20.93	20.79	20.47	22.42	21.66
5	E_t (kJ)	$1.91X10^6$	$2.1\ 1X10^6$	$1.87X10^6$	$2.24X10^6$	$2.01X10^6$	$1.89X1\ 0^6$	$2.03X\ 10^6$	$2.08X1\ 0^6$	$1.91\ Xl\ 0^6$
6	Q_1 (kJ)	$1.52X10^6$	$1.52X10^6$	$1.49X10^6$	$1.68X10^6$	$1.59X10^6$	$1.49X10^6$	$l.61X10^6$	$l.61Xl0^6$	$1.50X10^6$
7	P.E.L (%)	79.73	75.44	79.51	74.89	79.07	79.21	79.53	77.58	78.34
8	A_t (m^2)	60.31	81.82	56.13	87.17	68.29	57.27	67.44	75.04	60.04
9	N_e (N)	1533	1599	1498	1691	1602	1499	1628	1622	1507

Keys

Q_m = Quantity of heat required to bake the mass of dough used

Q_i = Quantity of heat energy required to bake 1kg of dough

H_r = Rate of heat transfer to the oven surrounding

P.E.U.= Percentage energy utilization indices

E_t= Total energy input of Fuelwood expended

Q_1 = Quantity of heat loss

P.E.L = Percentage energy lost indices

A_t= Total surface area

Ne = Naira equivalent of heat lost

Table 3: Results of Estimated Oven Wall Thickness

S/N	Parameters Computed	Values For Respective Bakeries A to I								
		A	B	C	D	E	F	G	H	I
1	W_t (m)	0.33	0.33	0.33	0.33	0.33 •	0.33	0.33	0.33	0.33
2	H_r(kWm^{-2})	0.106	0.059	0.064	0.123	0.117	0.074	0.095	0.085	0.085
3.	P.E.U. (%)	34.48	35.50	24.05	33.25	32.96	33.97	34.30	29.09	34.07
4.	Q_1(kJ)	$1.25x10^6$	$1.36xl0^6$	$1.42x10^6$	$1.49x10^6$	$l.34x10^6$	$1.24x10^6$	$1.33x10^6$	$1.47x10^6$	$1.26x10^6$
5	Q_c(kJ)	$2.72x10^5$	$2.30x10^5$	$6.66x10^4$	$1.82x10^5$	$2.42x10^5$	$2.48x10^5$	$2.80x10^5$	$1.39x10^5$	$2.37xl0^5$
6	N_e(N)	273.38	231.72	67.00	183.75	243.83	249.33	283.21	139.54	238.67

Keys

W_t = Oven wall thickness

H_r =. Rate of heat transfer to the oven surrounding

P.E.U = Percentage energy utilization indices

Q_i = Quantity of heat lost

Q_c = Quantity of heat energy conserved

N_e = Naira equivalent of heat energy conserved

Estimated oven wall thickness using equation 12Using wall thickness (X) of 32cm

$$q = \frac{0.7(260-210)}{0.32} = 0.109 kW/m^2$$

Using wall thickness (X) of 33cm

$$q = \frac{0.7(260-210)}{0.33} = 0.106 kW/m^2$$

Quantity of heat loss by using an estimated oven wall thickness of 33cm (0.33m), quantity of heat energy saved and the Naira equivalent of heat energy saved

If at 0.270m wall thickness, the rate of heat transfer is $0.129 kW/m^2$ and the quantity of heat loss is $1.52\times10^6 KJ$, then at the rate of $0.16 kW/m^2$ will be,

$$\text{Quantity of heat loss} = \frac{152307346\times0.106}{0.129} = 1.25\times10^6 KJ$$

The quantity of heat energy saved by using a wall thickness of 0.33m (33cm) is, heat energy saved $= 152307346 - 125151773 = 2.72\times10^5 KJ$

The Naira equivalent of heat energy saved is expressed as.
If 128.2kg fuelwood gave out 19101.80kJ and cost N1923.00, then 271555.73kJ will cost

$$= \frac{271555.73 \times N1923.00}{1910180} = N\ 273.38$$

Quantity of heat energy that could have been utilized is

= Total quantity of fuelwood (expended) - heat loss
= 1910180-1251517.73 = 658662.27kJ

Percentage heat energy utilized

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

$$= \frac{65866227}{1910180}\times100 = 34.48\%$$

The parameter values, oven performance characteristics and the results of estimated oven wall thickness of 33cm (0.33m) are shown in tables 1, 2 and 3 respectively.

3. Results and Discussion

From table 2, it can be seen that utilization of heat energy generated in the ovens of the nine bakeries considered for the study ranges from a minimum of 20.27% to a maximum of 25.11%, corresponding to bakeries A and D respectively. This result is similar to 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.

This means that, out of the 128.2kg of fuelwood used for the experiment for bakery A, with energy content of 1.91 x 10^6kJ only 3.87 x10^5kJ of heat energy was actually utilized, the rest was wasted. Similarly, only 5.62 x 10^5kJ of the heat energy content of the 150.5kg of fuelwood used for bakery D was actually utilized while the remaining 1.68 x 10^6kJ had gone to waste. Also from table 2, maximum and minimum heat energy losses of 79.73% and 74.89% were obtained. In monetary terms, this means that for bakery A, using fuelwood cost of Nl5.00/ kg, of the Nl923.00 worth of fuelwood used for the study, N1533.00 worth of fuelwood was wasted, similarly, for bakery D, the N2257.5 (i.e 150.5kg x N15.00) worth of fuelwood used for the study, N1691.00 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. A close look at the data in table 1 revealed 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 20.27% for bakery A to 25.11% for bakery D as can be seen in table 2.

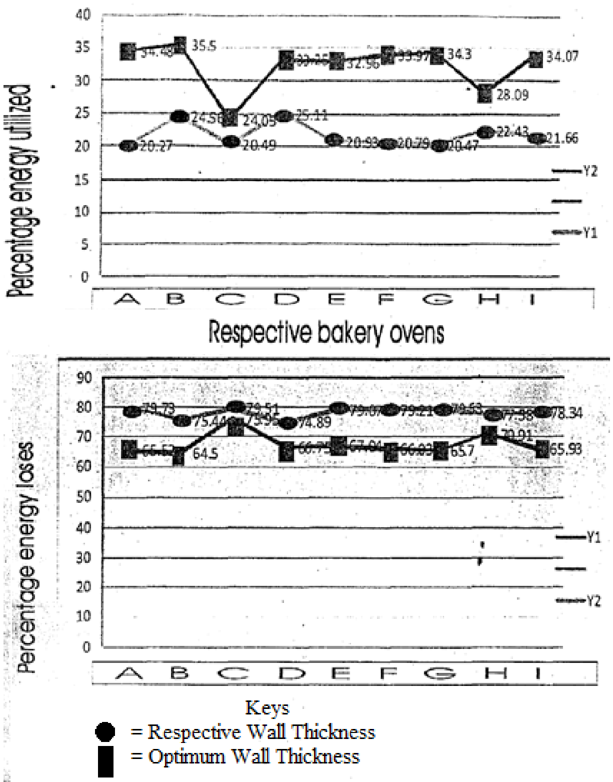

Fig.2 Percentage energy loses for the bakeries using the respective wall thicknesses and the estimated wall thickness.

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. 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.

4. Conclusion and Recommendation

The study was carried out to determine energy utilization in non-conventional bakery ovens used in bread baking. Based on the findings, the following conclusions are reached. Percentage heat energy utilization indices for bakeries considered for the study ranged from a minimum of 20.27% to a maximum of 25.11% and the percentage energy loss index ranged from a maximum of 79.73% to a minimum of 74.89%. 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 is that, there is an additional cost to consumers of bread, and also accelerated deforestation with subsequent environmental problems. Heat energy losses took 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 evaluating the oven chambers before the commencement of the baking process.

Recommendations

The following recommendations were made to improve energy utilization in the non-conventional bakery oven in Adamawa State Nigeria.
i. 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 0.33m, heat energy loss will be reduced by 14%.
ii. There is need for the modification of the non-conventional bakery ovens and the present baking process in order to reduce energy losses 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 fueldwoodvis-a-vis the oven capacity is also required.
iii. To reduce heat energy losses via the oven wall, additives like chromites, feldspar or kaolin, rice, millet and maize husks, sodium chloride and sawdust can be blended with the current constructional materials (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 (Mshelia et, al, 2002).

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