

DEVELOPMENT AND TESTING OF OVENS USING SAWDUST AS FUEL

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ABSTRACT

The development and laboratory testing of a prototype "hole-through - sawdust" type burner and oven is described. Four models of the oven were field tested to obtain socio-economic data on user reaction and its potential for future use. The oven produces temperatures comparable to standard electric and gas settings by appropriate loading of the sawdust burner and can maintain these ranges of temperatures to enable baking to be carried out. In field trials carried out in four homes the oven was generally accepted but efforts must be made to reduce the amount of smoke produced. The oven may be very useful to people who bake cakes at home for daily distribution to institutions. In such applications, there is substantial savings in the cost of fuel, compared to gas and electricity operated ovens. The oven's cost is less than one-fourth the cost of electric and gas ovens.

INTRODUCTION

Sawdust is one of several alternative sources of renewable energy. Bassey (1980) estimates the amount of sawdust available in Sierra Leone at about 2000 m³/month. The calorific value of the fuel depends on the moisture content and the species of tree from which the sawdust is obtained. But a generalised estimate is a calorific value of about 16,000 kJ/kg at a moisture content of about 20% (dry basis), which corresponds to open air drying under local conditions (Bassey 1980).

A method of burning sawdust in "hole-through sawdust burners" has been extensively studied by Bassey (1977, 1983). The purpose of this article is to describe the design, development and testing of two prototype ovens using sawdust as a fuel in "hole-through-sawdust" burners and that practical application in household baking.

OVEN DESIGN

The burner

The burner (Figure 1) consists of a container having a base area 40 x 40 cm² and 20 cm high, made of 0.06 cm thick galvanised iron sheet metal. Nine holes, 2 cm in diameter and situated about 10 cm apart in the base of the container serve as the air inlet holes. This configuration was derived from general equations developed by Bassey (1977, 1983), in order to achieve an oven size comparable to existing electric or gas ones and a burning time of more than two hours. The generalised equations for designing burner size are as follows:

$$d/D_B = C_1 \exp(C_2 t) \quad (1)$$

$$m_f/t_H = C_3 \exp(C_4 D_B) \quad (2)$$

where m_f is mass of sawdust consumed in t minutes in g; d and D_B are burner hole and air inlet hole diameters in cm; and C_1, C_2, C_3, C_4 are constants.

The burner is charged by placing cylindrical rods, with diameters slightly less than D_B , through the holes and packing the sawdust around them tightly by hand.

The rods are then carefully withdrawn leaving vertical holes through the sawdust which are lit to produce heat. Depending on the amount of heat needed, one to nine burner holes are lit.

Ovens I and II

Prototype I is shown in Figure 2. It is made from 0.06 cm thick galvanised iron plate with double walls, between which is placed 5 cm thick fibreglass wool insulation. An ash tray is situated below the burner and the door is insulated. The chimney passes through the baking space and exhaust gases also heat up this space. Upper and lower oven spaces are created by a removable shelf made of galvanised iron sheet. To shield the oven space from the burner compartment, an air gap (8 cm thick) sandwiched between two plates was created with a flap opening for air to enter. The chimney is 60 cm long and 8 cm in diameter. Dimensions of the oven space are about 40 x 40 x 30 cm³.

Prototype II is identical to prototype I, except that the bottom plate sandwiching the air gap between the burner and oven space was removed. Hot gases thus come into direct contact with the bottom of the plate separating the burner area from the baking space.

Instrumentation

Chromel-alumel (type K) thermocouples, connected to a thermo electric digital electronic temperature indicator, ELPH 4 model, were located at five points in the oven as shown in Figure 2. During tests the ovens were placed on a scale so as to measure the decrease in mass of the fuel due to combustion.

EXPERIMENTAL PROCEDURE

The first set of experiments were done using prototype I with 2cm diameter burner air inlet holes. Seven burner holes were packed to a height H . The whole burner was weighed and the holes were then lit by burning paper or wood shavings in the holes. When the sawdust was glowing uniformly throughout the height of the holes, the burner placed in the oven and the whole equipment weighed.

Temperatures and the weight of the oven were recorded at intervals of between 5 and 15 minutes until the sawdust was completely burned. This was indicated by a temperature drop in the combustion chamber and reduction in smoke from the chimney. In several tests, burner holes were loaded to a height of 8, 10, 12 and 14cm. The damper was usually fully open but some tests were carried out with the damper being 1/2 and 1/8 open.

The above procedure was repeated with oven II. In these experiments, the parameters used were 5 or 7 burner holes, $D_B=2$ cm and $H=6, 8, 10, 12$ cm. In each case the damper was fully open.

All the sawdust used during the tests had a moisture content of 23% (dry basis). The density of packing, about 200 kg/m^3 , was maintained during the experiments.

RESULTS AND DISCUSSION

Relative temperatures in Oven I

The amount of heat transferred from the combustion chamber to the oven space depends on the relative magnitudes of temperatures. Typical temperature variation with time are shown in Figure 3. Hot gases in the burner chamber attain maximum temperatures of around $300\text{--}320^\circ\text{C}$ and in the oven spaces up to 150°C . Temperatures are up to 40°C lower in the burner chamber owing to the metal shelf separating the lower and upper oven spaces. Temperatures in the chimney are generally higher than those in the oven space but drop below the values for the lower oven space as a result of heat losses during the final stages of combustion of the fuel. This indicates the ability of the oven to conserve useful heat in the baking space. Temperatures in the oven door typically range between 30 to 100°C during the operation of the oven.

Effect of height of packing on temperatures in Oven I

Results showing the effects of increasing the height of packing on the temporal variation of temperatures are shown in Figure 1. Combustion chamber temperatures are dependent on the value of H but the maximum temperature does not exceed 400°C . Similar trends are observed for the lower oven space temperatures, where working temperatures of between 150 and 160°C are possible after 40 to 180 minutes depending on the height of packing. During baking it is necessary to maintain a relatively constant temperature and it has been taken that a temperature 5°C below the maximum of the lower space is a working range of temperatures.

Temperatures in the upper oven space also depend strongly on the value of H but they are substantially lower. These results indicate that the shelf can be useful for baking foodstuff requiring different temperatures at the same time.

The time taken to reach the maximum range of temperatures are not unrealistic. Oven I has an air space sandwiched between two galvanised iron plates and temperatures in the baking space can be increased by removing the plate immediately above the burner.

Consumption of sawdust in oven I

The amounts of sawdust used in the burner during various tests are shown in Figure 5 for Oven I. The linear variation of M_f is consistent with results of Bassey (1983). For a burner with $N=7$, $D_B=2 \text{ cm}$, Bassey (1983) estimated the consumption to be: $M_f/H = 2.05 \text{ t}$. From our results we estimated $M_f/H = 1.47 \text{ t}$, or 28% lower than Bassey's estimate for sawdust consumption. This is possible as the oven has more flow resistances causing a slower combustion of the sawdust compared to the open burner used by Bassey (1983), in which the only flow resistance was due to the air inlet, D_B .

Temperature control in oven I

Setting the air inlet flap fully open, half open or one-eighth open had virtually no effect on the burner and the lower oven space temperatures and the inlet flap does not serve any significant purpose. The nature of the packed bed burner makes it difficult to control its burning rate by using flaps. It is proposed that control of temperatures should be achieved by a variation of H and N.

Development of oven II

Testing of oven I suggested that the galvanised plate between the gap and the burner might not be necessary as the temperatures, both in the combustion chamber and in the oven space, were not excessive. A second oven was therefore constructed and tested as mentioned earlier, with the modifications described above. The flap was left fully open during all tests.

Performance of oven II

Temperatures in oven II are shown in Figure 6 for N=7 and H=6, 10 and 12 cm. These results are similar to those discussed for oven I, the difference being that the temperatures in oven II are higher.

Typical comparisons between the oven temperatures and the amount of fuel used are shown in Figures 7a and b, and in Table 1 for the maximum temperatures.

Temperatures are up to 40°C higher in oven II compared to oven I because the removal of the plate above the burner permits the hot gas to come into direct contact with the base of the oven. Another factor increasing the temperatures in oven II is the slight increase in mass of fuel consumed with time (Figure 7b). The increase in fuel may be due to less restriction in the flow of combustion air as a result of removing the plate above the burner.

Performance data for oven II, similar to those for oven I are shown in Table 2. The maximum temperatures and the times taken to attain them are quite encouraging. There is clearly a possibility of controlling oven temperatures by a combination of H and N.

PRACTICAL APPLICATION

Baking temperatures and equivalent settings

Oven II performs better than oven I and was used in experiments relating the result obtained to real-life baking conditions. By manipulating values for H and N, temperatures equivalent to standard settings of household gas and electric ovens were determined (Table 3).

With the exception of the very cool range of temperatures for which data were not available, combinations of H and N could produce working temperatures equivalent to those in gas and electric ovens.

Use of oven II for baking cakes

Many households use gas to bake cakes on a daily basis for sale in various supermarkets and institutions. Table 4 gives burner configurations corresponding to recommended temperatures for baking a list of cakes.

FIELD TRIALS OF SAWDUST OVEN

Method

Four families were given a sawdust oven with several sacks of sawdust. Detailed instructions were given on the operation of the oven and on the adjustment of maximum attainable temperatures by a combination of H and N. The trials were carried out over a two week period at the end of which each participant was requested to complete a questionnaire. Frequent visits were made to the households during the field trial to help with any problems.

The backgrounds of each participant, identified by a number, were as follows:

1. Commercial user; daily baking; used gas oven costing 3000 Leones; had an energy problem; monthly fuel cost 30 Leones.
2. Commercial user; daily baking; used charcoal/wood; wood oven costs Le50; no fuel problem; monthly fuel cost Le32.
3. Domestic user (household of 10); baking once a week; electric oven costing Le3000; energy problem; monthly cost Le10.
4. Commercial; baking once a week; electric oven costing Le3000; energy problem; monthly cost Le15.

Results

The individuals involved with commercial baking used domestic ovens for baking small cakes and cookies for schools and other institutions. All of the participants used conventional gas or electric ovens except one who used wood in a crude oven consisting of a closed container heated over a three-stone-open-fire stove.

Responses to several questions were:

Oven operation

(a)	Is burner difficult to load?	Yes (0);	No (4)
(b)	Does lighting of burner take too long?	Yes (1);	No (3)
(c)	Is operation of oven messy?	Yes (2);	No (2)
(d)	Is smoke excessive?	Yes (4);	No (0)
(e)	Is the ash a problem?	Yes (0);	No (4)

Baking time and temperature

(f)	Is warming up time too long	Yes (4);	No (0)
(g)	Does oven cool down too quickly	Yes (0);	No (4)
(h)	Is oven temperature too high	Yes (0);	No (4)
(i)	Is oven temperature too low	Yes (0);	No (4)

Cake quality

(j)	Does product rise well?	Yes (4);	No (0)
(k)	Does product taste well?	Yes (4);	No (0)
(l)	Does product smell of smoke?	Yes (0);	No (4)
(m)	Did product get burnt?	Yes (4);	No (0)
(n)	Overall are you happy with product?	Yes (3);	No (1)

The oven performed satisfactorily, although there were problems such as excess smoke, and some complaints about the burning of the product which should be investigated further.

Users 1 to 4 made savings of 22, 24, 4 and 9 Leones per month respectively. (The only cost incurred for the sawdust was for transportation.) Participants 1 and 2, doing daily commercial baking made the highest savings. Considering that the estimated cost of the oven is 650 Leones, this appliance has a potential for use in the country. Further attempts should be made to assess the viability of using less expensive construction materials such as bricks, so as to lower the capital cost of the oven.

CONCLUSIONS

A study has been carried out in which sawdust has been used to produce heat energy in an oven for domestic use. The conclusions which can be made are:

- (a) An oven suitable for use in homes has been developed and fully tested.
- (b) The temperatures which can be obtained in the oven by using combinations of the height of packing and number of holes in the burner, are comparable to those specified for conventional gas and electric cookers.
- (c) Results of field tests indicate that the technical performance of the oven and product quality are acceptable to potential users, but the smoke produced during operation should be reduced.
- (d) The oven costs less than a quarter the price of a gas or electric oven and substantial fuel savings can be made with its use.
- (e) The sawdust oven is a technology which should be encouraged as it has a potential for use in small scale commercial baking.

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TABLE 1: Comparison of maximum temperatures for ovens I and II for various operating conditions ($D_B = 2$ cm, $N = 7$)

Height of packing H, cm	Oven	Temperature in Oven			
		$^{\circ}\text{C}$	Tmax Range ($^{\circ}\text{C}$)	Time taken to attain, (min)	Time spent in range, (min)
8	I	156	151-156	130	55
	II	176	171-176	95	30
10	I	195	190-195	146	45
	II	213	208-213	100	46
12	I	218	213-218	116	39
	II	250	245-250	135	40

TABLE 2: Maximum temperatures for oven II for various values of height of packing, H($D_B = 2$ cm)

Height of Packing, H, cm	No of Holes N	Temperature in Oven			
		$^{\circ}\text{C}$	Tmax range ($^{\circ}\text{C}$)	Time taken to attain, (min)	Time spent in range, (min)
6	5	156	151-156	130	45
6	7	169	164-169	100	35
8	5	162	157-162	100	25
8	7	176	171-176	85	35
10	5	200	195-200	105	40
10	7	213	208-213	73	46
12	5	210	205-210	105	50
12	7	250	245-250	135	40

TABLE 3: Equivalent temperature settings between gas, electric and sawdust oven II

Temperature Description	Electric Oven	Gas Thermostat	Oven II	
			H, cm	N
Very cool	110°C/225°F	1/4 - mark		
	120°C/250°F	1/2 - mark		
	140°C/275°F	1 - mark		
Cool	150°C/300°F	1-2 - mark	6	5
Warm	160°C/325°F	3 - mark	8	6
			6	7
Moderate	180°C/350°F	4 - mark	8	7
Fairly hot	190°C/375°F	5 - mark	10	5
	200°C/400°F	6 - mark	10	5
Hot	220°C/425°F	7 - mark	10	7
Very hot	230°C/450°F	8 - mark	12	5
	240°C/475°F	9 - mark	12	7

TABLE 4: Burner configurations for baking cakes in oven II

Type of cake	Burner for Oven		Time to wait before baking (min)	Baking time (min)	Comments
	H, (cm)	N			
Plain Cakes;					
Small	10	7	75	15-20	-
Large	8	7	85	25	not recommended for cakes larger than 0.25kg.
Rich Cakes:					
Small	10	5	105	15-20	-
Large (e.g. fruit)	8	7	85	25	not recommended for cakes larger than 0.125 kg.
Sponge Cakes:					
Large	8	7	85	25	"
Sandwich	10	7	75	9-12	-
Biscuits/ Cookies	8	7	85	25	-

FIGURE 1: Schematic diagram of the hole-through-sawdust type burner with a single hole

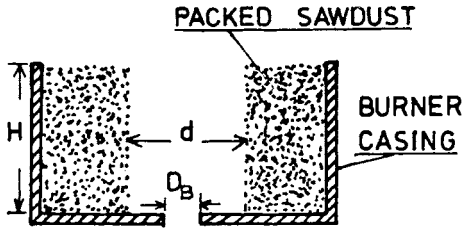


FIGURE 2: Cross-sectional view of oven I showing relative dimensions and location of thermocouples

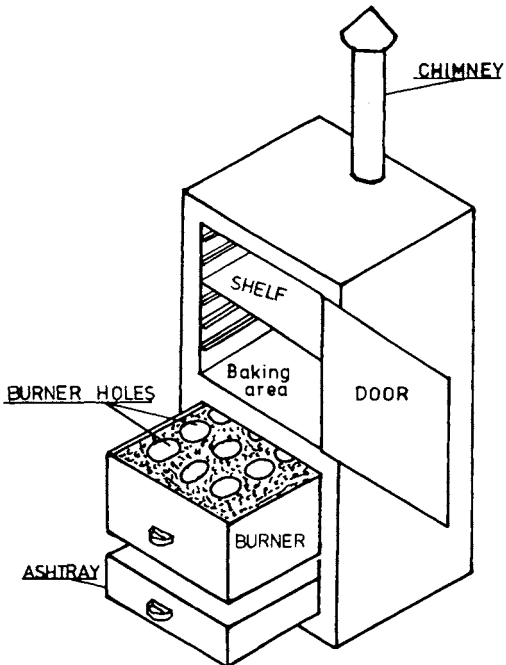


FIGURE 3: Cross sectional view of oven I

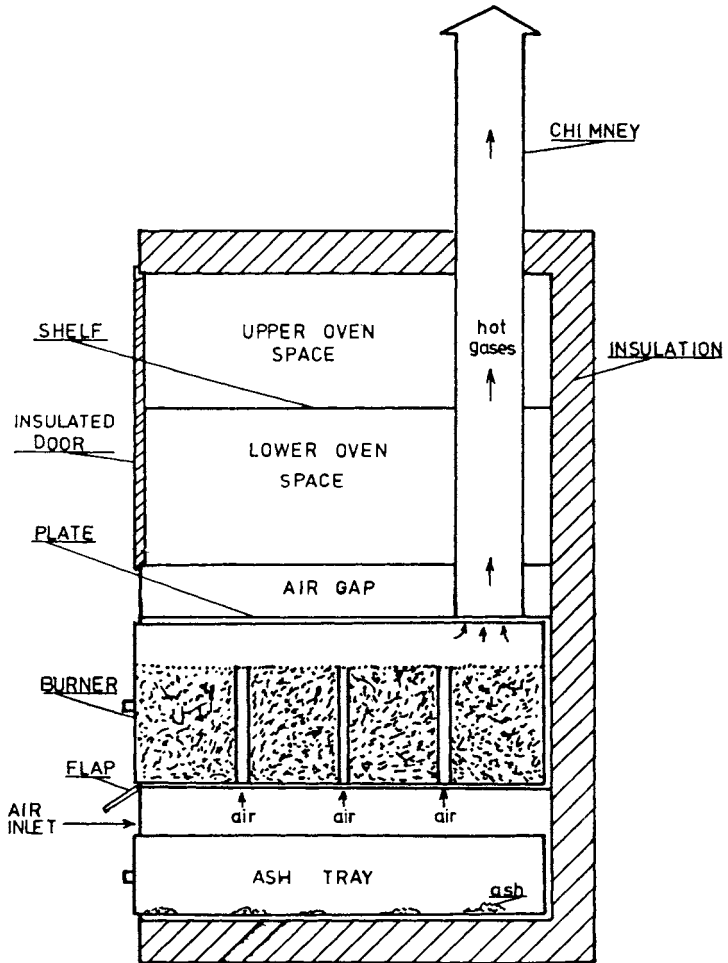


FIGURE 5: Variation of mass of sawdust used with time for oven I

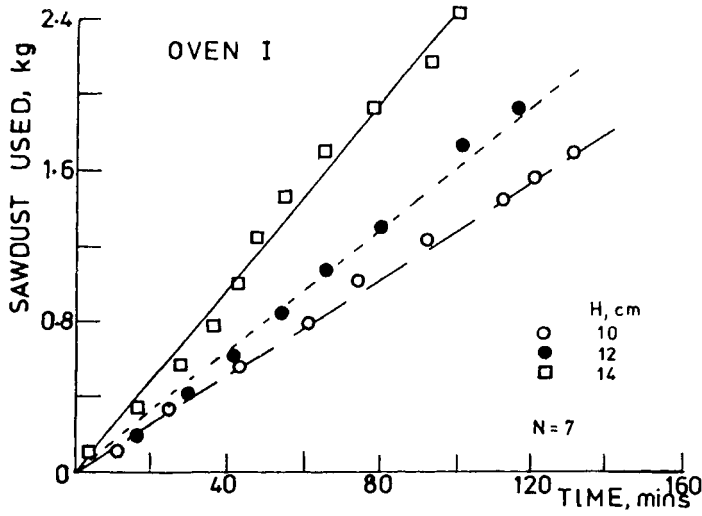


FIGURE 6: Effect of increasing sawdust packing height on the temperature in oven II

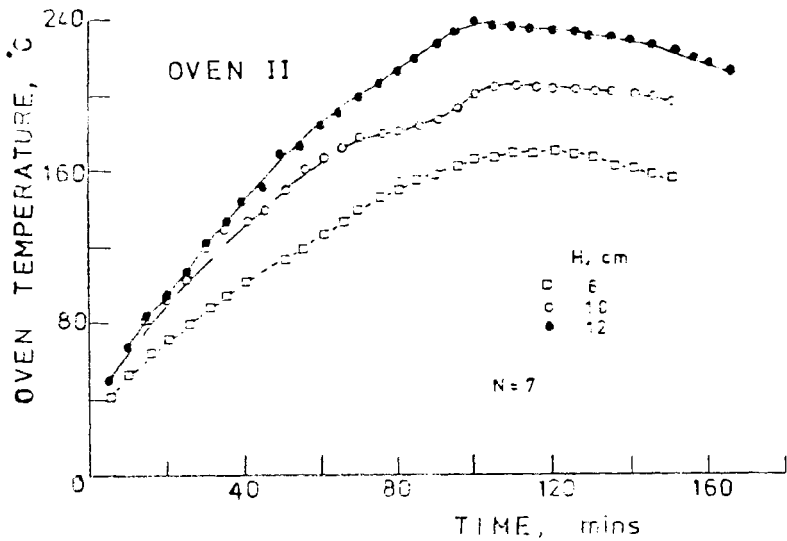


FIGURE 7: Comparison between (a) temperatures in ovens I and II and
(b) sawdust use over time

