Fabrication and Performance Evaluation of an Improved Charcoal Cooking Stove.

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ABSTRACT

In this study, an improved charcoal cooking stove was designed, fabricated, and evaluated, along with a traditional metal stove using charcoal as fuel. Evaluation of the two stoves was based on two different test conditions, namely vent completely/fully opened and vent half way opened. Water boiling tests and cooking tests were used to evaluate the improved stove fabricated. A thermal efficiency value of 34% was obtained for the improved stove and 11% for the traditional metal stove. Values obtained for burn rates, specific fuel consumption and cooking durations were 0.34 kg/hr, 0.52 kg/kg, and 38 min, respectively for the improved stove and 0.1 kg/hr, 1.23 kg/kg, and 52 min, respectively for the traditional metal stove. The improved cooking stove fabricated proved to be more efficient and effective than traditional metal stove.

(Keywords: stove, charcoal, fuel, burn rate, thermal efficiency)

INTRODUCTION

A number of people in the rural and urban areas as well still uses firewood for cooking despite the discomfort posed on the user as a result of smoke that accompanies or precedes its usage. Other commercial fuels such as cooking gas and kerosene mostly relied upon by African countries for cooking are not only scarce but rather expensive. Also, electric stoves and boiling rings in our homes had been rendered useless as a result of epileptic power supplies by the Power Holding Company (PHCN). Thus, the perennial fuel crisis in Nigeria has drawn attention to the need for energy experts to further concentrate on producing viable alternatives or complements to electric power, kerosene and cooking gas for domestic cooking. The relative abundance of agricultural and wood conversion residues in many parts of the country all years round recommends them as possible viable alternative energy sources, Olorunisola, (1999) stated.

Charcoal, as an alternative to other cooking fuels, has twice the energy content of wood and this is one of the principal attractions for consumers (Foley et al., 1986). A small amount of it provides an intense steady heat. Thus, this paper presents a report on the fabrication and performance evaluation of an improved charcoal cooking stove which can efficiently and effectively conserve heat for cooking practices in comparison with a traditional metal stove.

DESIGN CONSIDERATIONS

The following factors were considered in the stove design.

Fuel: The type of fuel to be burned in the combustion chamber determines the type and configuration of such combustor. Availability, cost, convenience of use, storage, cleanliness, and moisture content were all considered. According to Foley et al. (1994), the moisture content of the fuel used in a test is one important variable as the energy yield of a newly cut wood may be less than half that of dried wood. Wereko-Brobby and Hagen (2000) stated that the calorific value plays a crucial role in knowing the amount of energy (heat) given off by a particular fuel. Foley et al [2] stated that the net calorific value of 1kg charcoal is 30MJ.

Cost of Production and Maintenance: Consideration was given to keep both costs as low as possible to enhance affordability by low-income earners.

Ease of Manufacture and Subsequent Maintenance: The design of the stove was such that minimal technical skills are possessed by road-side artisan welder which would be required in fabricating and subsequent replacing component parts of the stove.

Portability: The stove was designed to be relatively small in size to allow for easy movement and also to minimize heat losses.

Moisture Content: The moisture content of the fuel used in a test is one important variable, as the energy yield of newly cut wood may be less than half that of dried wood, as stated by Foley et al, (1984).

DATA ANALYSIS

The procedure and formulae employed in the calculation of parameters were based on the approach used by Ahuja et al. (1997), FAO (1990), and Olorunisola,(1999).

Burn Rate (F): The burn rate was calculated using equation (1):

$$F(kg/hr) = \frac{1}{t}\ x\ \frac{100(w_i - w_f)}{100 + m} \quad (Ahuja\ et\ \ al\,[1997]) \qquad \textbf{(1)}$$

Thermal Efficiency (η): Efficiency, which is a measure of the proportion of the total energy which is usefully employed in a thermodynamic system. According to Clarke (1985) the thermal efficiency of a cooking stove depends largely on how gas of the fuel line to the pot or vessel on the stove (convective heat transfer). The burn rate and the net calorific value of the fuel were used in the calculation of this parameter as stated in equation (2):

$$\eta th(\%) = \left(\frac{W_{wi}\ x\ a(T_f - T_i) + (W_{wi} - W_{wf})L}{f_{th}\ x\ t}\right)\ x\ 100 \quad (FAO,\ [1990]) \qquad \textbf{(2)}$$

Specific Fuel Consumption:

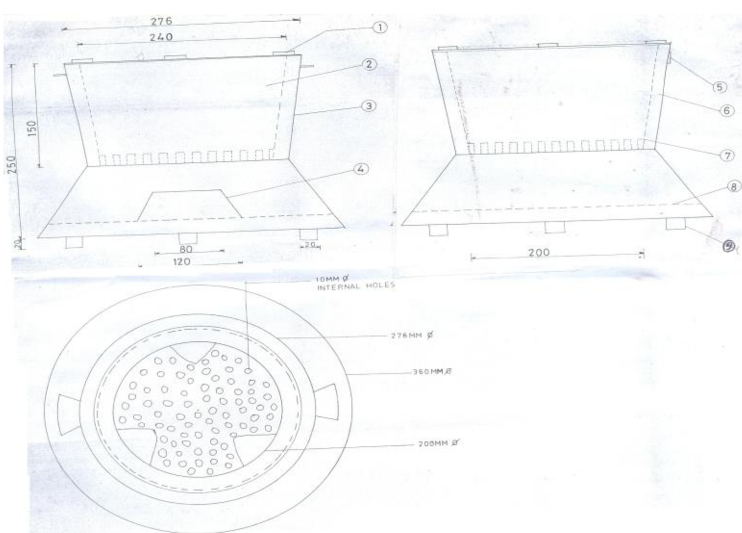
$$SFC = \frac{Mass\ of\ Consumed\ \ Fuel(M_{fu})}{Total\ mass\ of\ cooked\ \ food(M_{cf})} \quad (Olounisola[1999]) \qquad \textbf{(3)}$$

MATERIALS AND METHODS

<u>A Brief Description of the Stove Fabrication Methods</u>

The improved charcoal cooking stove consists of two internal compartments namely, a combustion chamber (fire box) and an air-inlet chamber (vent). These and other components parts of the stove are described below.

Figure 1 shows the orthographic drawing of the improved cooking stove, while plate 1 shows the pictorial view of the stove.



Legend

1. Pot Stand
2. Combustion chamber
3. Metal Sheet
4. Air intake Vent
5. Stove Handle
6. Clay lining
7. Grate
8. Ash tray
9. Stove stand

Figure 1: Orthographic Drawing of the Improved Charcoal Cooking Stove.

(i) The Pot Stand: There are three pot stands situated at equal distance around the circumstance of the fuel bed.

(ii) The Combustion Chamber: This consists of 518.6cm^3 capacity of insulating clay surrounded by a mild steel plate enclosure designed to accommodate charcoal or fire wood or any biomass material as fuel. A screen 200mm diameter is provided at its base to allow for free air intake by updraft and the passage of ashes produced during combustion.

(iii) The air inlet Compartment: For proper combustion of fuel (charcoal or firewood), provision was made for adequate ventilation within the stove. A 120x60mm air inlet with adjustable cover was provided beneath the combustion chamber.

(iv) Ash Collection Tray: This is a light metal pan into which ashes are expected to drop during fuel combustion for immediate disposal even when the fire is on. Light weight material was chosen for its construction to minimize the overall weight of the stove. This tray is located at the inner base of the air inlet chamber.

(v) The Stove Stand: These are three 20mm high metallic structures located at equal distances around the circumference of the bottom part of the stove. These were provided to prevent rusting and heat losses through leakage occasioned by direct contact between the stove bottom and the ground surface. A prototype of the stove was fabricated at a total cost of ₦450.00.

Time Spent in Cooking per kilogram of Cooked Food:

$$T_s = \frac{Total\ time\ spent\ in\ cooking(T_{ts})}{Total\ Weight\ of\ cooked\ food(T_{wc})}\ (hr/kg) \ldots\ldots\ldots [1999]. \quad \mathbf{(4)}$$

Plate 1: Pictorial View of the Improved Charcoal Cooking Stove.

Experimental Procedure and Performance Evaluation

The tests carried out to evaluate the improved cooking stove were: water boiling test (WBT) and controlled cooking test (CCT) or comparative cooking test CCT. The performance of the improved stove was evaluated and compared with the traditional metal stove of the same design consideration using charcoal as fuel material. The charcoal which is a product of de-oxygenated burning of wood has a 6% moisture content. The apparatus were two big size aluminum pots, a weighing balance, two mercury-in-glass thermometers a weighing balance, a stopwatch, water, rice and matches. The improved charcoal cooking stove was designated 'Stove A' and the traditional metal skinned as 'Stove B'.

The stoves were assembled and tested simultaneously in the open air at the Federal University of Technology, Akure with the atmosphere conditions being 32^{0}C dry bulb and relative humidity of 55%. These test were carried out to simulate or match the cooking method commonly adopted in rural committees in Africa.

Water Boiling Test

Water Boiling Test (WBT) was conducted to compare the efficiency and burning rate of the two stoves under the following conditions:

(i) Vent is completely/fully opened.

(ii) Vent half way opened.

Each stove was loaded with equal amounts of fuel charge charcoal per stove. Two pre-weighed aluminum pots designated as pot A and B were each filled with the same quantity of water. The initial temperature of the water was recorded using a mercury-in-glass thermometer before the pots were placed on the stove. The charcoal was sprinkled with 10ml of kerosene and then ignited with a match. The subsequent changed in temperature up to the boiling point were recorded at 2-minute intervals with the two thermometers permanently inserted in the two opened pots. At boiling the pots were removed from the stoves and weighed. Also the fire was put out immediately and the remaining fuel was weighed.

Controlled Cooking Test (CCT)

Controlled Cooking Test (CCT) was conducted out-doors on a cool morning to simulate traditional approach to cooking in rural areas of African and to compare the fuel consumption rate and time spent in cooking a meal of rice on the two stoves. Equal quantities (0.2kg) of rice were placed in the two aluminum pots procured each containing 2 liters of water. The stoves were charged with the same quantity of fuel and the pots were placed on the lit stove. Stopwatches were set to monitor cooking duration and at the end of cooking, the time taken as well as quantity of fuel were noted and recorded.

Table 1: Changes in Temperature up to Boiling Point.

Time (Min)	VFO Temp. of water (^{0}C)		VHO Temp. of water (^{0}C)	
	Stove A	Stove B	Stove A	Stove B
00	29	29	33	33
02	33	30	36	34
04	37	32	39	35
06	42	35	41	37
08	51	38	44	39
10	60	42	47	41
12	73	45	50	42
14	86	49	53	44
16	92	51	56	46
18	100	56	60	48
20	100	60	65	50
22	100	63	71	52
24	100	67	76	55
26	100	71	80	57
28	100	74	86	60
30	100	76	92	64
32	100	80	97	69
34	100	83	100	73
36	100	87	100	78
38	100	90	100	81
40	100	94	100	86
42	100	97	100	90
44	100	100	100	94
46	100	100	100	96
48	100	100	100	100
50	100	100	100	100
52	100	100	100	100

Legend: VFO-Vent fully opened, VHO-Vent Half-way opened

RESULT AND DISCUSSION

Burning Rate - Vent Fully Opened

The burn rates obtained in Table 2 were 0.34 kg/hr and 0.11 kg/hr for stoves A and B, respectively, using Equation 1. These results showed that the fuel in an improved stove (Stove A) had a higher burn rate than fuel in traditional metal stove (Stove B). Olorunisola (1999) stated that the advantage of a high burn rate during the combustion of an solid fuel is the enhancement of the self-sustenance of the fire. Kaoma and Kasali (1994) in the research jointly carried out on coal briquettes Zambian stove, concluded that burn rate is a function of the supply of air (oxygen) to the fuel bed (firebox).

By design, the improved cooking stove (Stove A) had higher ability to sustain the burn rate of the fuel due to the insulating clay-lining which reduced heat loss, retaining more of the heat provided by the fuel as against the traditional metal stove (Stove B) which looses heat from the fuel bed to the surrounding at a faster rate (Komolafe [10]). Stove A boiled water faster (18 min.) as compared with Stove B which boiled the same quantity of water at 34 mins as shown in Figure 2.

Burning Rate - Vent Half-way Opened

The burn rate obtained were 0.13 kg/hr and 0.07 kg/hr for stoves A and B 34 mins and 48 mins on stove B as shown Table 2. The result in Table 2 revealed that there is a proportionality of burning rate to the air supply, as there is a decrease in burn rate values as compared to when the vent was fully opened.

Efficiency - Vent Full Opened

The thermal efficiency values obtained from the boiling of water on stove A and B were 34% and 11% respectively as represented in Table 2. The thermal efficiency value of 34% of the improved stove according to (Foley et al, 1986) falls within the range of 34-36% obtained for UMEME stove developed in Nairobi, Kenya by UNICEF and 30-36% reported by Karekezi and Ranja (1997), in their research for clay lined stove and a range of 10-20% for unlined metal cook stove developed in Africa and Asia countries.

Efficiency - Vent Half Way Opened

The efficiencies of 21% and 8% were obtained in test for both the improved and traditional metal stoves respectively as against 34% and 11% obtained when the vent is fully opened. Water spent 34 minutes to boil on stove A as against 48 minutes on stove B. This result showed that the rate of burning of fuel in a cook stove determines the efficiency of such stove.

Controlled Cooking Test

The data collected from this experiment were used in calculating the specific fuel consumption (SFC) and time spent in cooking per kilogram of cook food**.**

Table 2: Water Boiling Test Results (Efficiency and Burn Rate)

	VFO		**VHO**	
	Stove A	**Stove B**	**Stove A**	**Stove B**
Initial mass of water (kg)	2	2	2	2
Final mass of water (kg)	1.86	1.74	1.84	1.76
Initial mass of fuel (kg)	1.6	1.6	1.6	1.6
Final mass of fuel (kg)	1.05	1.25	1.40	1.35
Total time taken for burning fuel (min)	18	44	34	48
Burn rate (kg/hr)	0.36	0.11	0.13	0.07
Efficiency (%)	34	11	21	8

Legend: VFO-Vent Fully Opened, VHO-Vent Half way Opened

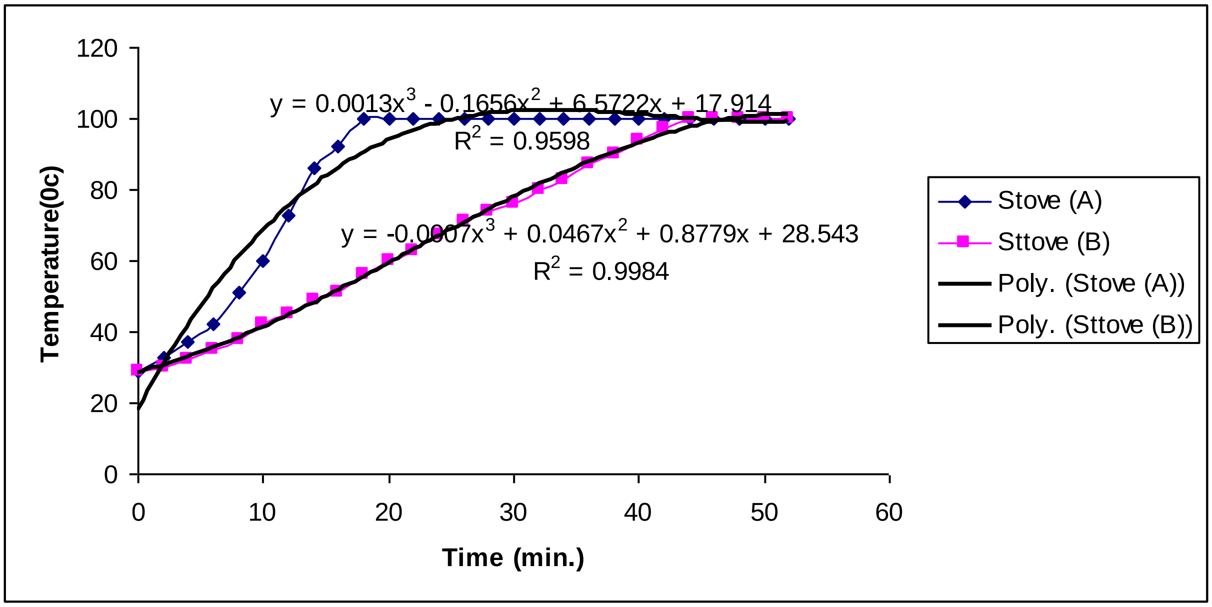


Figure 2: Changes in Temperature up to Boiling Point.

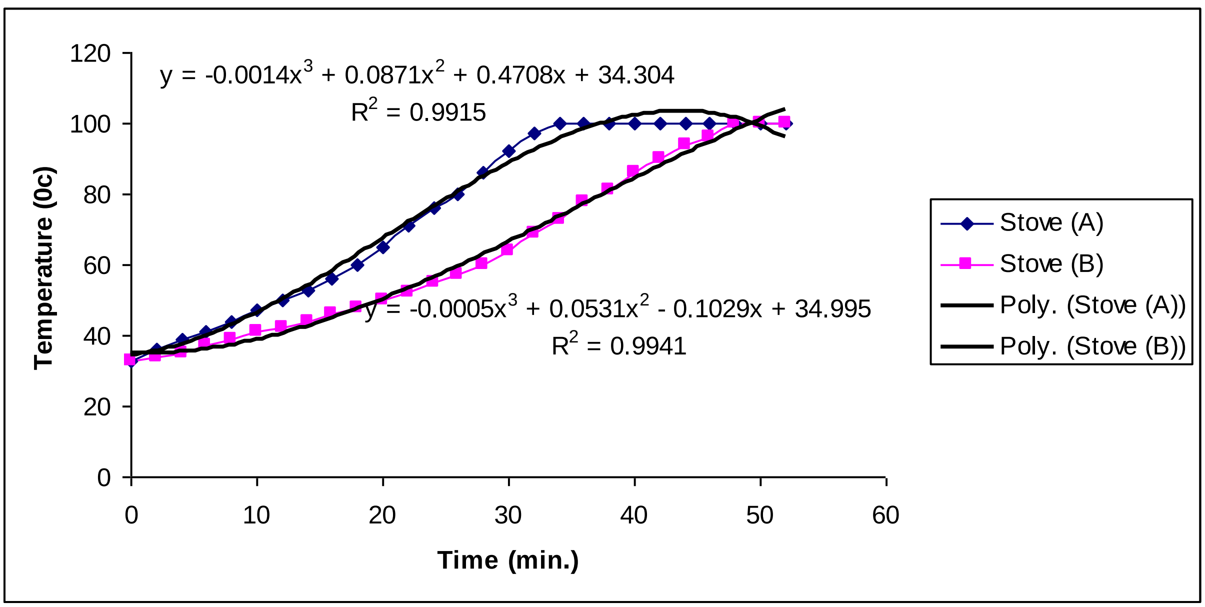


Figure 3: Changes in Temperature up to Boiling Point.

Table 3: Specific Fuel Consumption and Cooking Duration for Stoves.

Parameters	Improved cooking Stove (Stove A)	Traditional metal stove (Stove B)
Initial mass of raw food (rice kg)	0.20	0.20
Total mass of cooked food (kg)	0.628	0.630
Initial mass of fuel at start (kg)	0.436	0.80
Final mass of fuel at the end (kg)	0.112	0.025
Mass of consumed fuel(kg)	0.324	0.775
Cooking duration (mins)	38	52
Time spent in cooking rice kg of cooked food (hr/kg)	0.317	0.433
Specific fuel consumption (SFC)	0.52	1.23

Specific Fuel Consumption

The specific fuel consumption value of the improved stove was less than that of the traditional metal stove. The superiority of the improved stove to traditional metal stove was demonstrated. The practical implication of this result according to (Komolafe, 2000) is that lesser quantity of charcoal would be required to cook the same quantity of food on the improved stove than on a traditional metal stove. Hence stove A would be more economical than stove B if the two were to attract the same market price.

CONCLUSION

An improved charcoal fuel cooking stove was fabricated and compared with a traditional metal stove of the same design specifications. The performances of the two stoves were evaluated and from the evaluation, the improved stove fabricated, has an efficiency of 34% which falls with the range of values of thermal efficiency of several works all over the world.

NOMECLATURE

a- Specific heat capacity of water (Mj/kg/^{0}k)
F- Burning Rate (kg/hr)
F_{th}- Burn rate x Calorific value (Mj/kg)
L- Latent heat of vapourisation of water at 100^{0}C (Mj/kg)
M- Moiture Content (%)
M_{fu}- Mass of fuel used
M_{cf}- Mass of cooked food
t- Total time taken for burning fuel (hr)
T_f- Final temperature of water (^{0}K)
T_i-Initial temperature of water (^{0}K)
T_{ts}- Total time spent in cooking
T_{wc}- Total weight of cooked food
W_f- Mass of fuel after burning (kg)
W_i- Initial mass of the fuel before burning (kg)
W_{wf}- Final mass of the water in the pot (kg)
W_{wi}- Initial mass of the water in the pot (kg)

REFERENCES

1. Ahuja, D.F., Joshi, V., Smith, K.R., and Venkataranman, C. 1997. "Thermal Performance and Emission Characteristic of Unvented Biomass-Burning Cookstove". *Standard Methods for Evaluation*. Biomass. 10:12.

2. Clarke, R. 1985. "Wood-Stove Dissemination". Proceeding of the Conference held at Wolfheze, The Netherlands. Intermediate Technology Publications. London, UK. 97-102.

3. FAO. 1990. "The Briquetting of Agricultural Waste for Fuel". *Environment and Energy*. 1(2):25-31.

4. Foley, G., Moses, P., and Timberlake, L. 1986. *Stove and Trees*. International Institute for Environment and Development: Washington, DC. 1-87.

5. Foley, G., Barnard, G., Belieres, J.F., and Joncker, J. 1984. *Energy for the People: A Dossier on Woodfuel in the Developing World*. Commission of the European Communities, Panos Institute: London, UK. 45.

6. Kaomali, J. and Kasali, G. 1994. *Efficiency and Emission Characteristic and Briquettes*. Stockholm Environment Institute: Stockholm, Sweden. 25.

7. Karekezi, S. and Ranja, T. 1997. *Renewable Energy Technologies in Africa*. African Energy Policy Research Network. Zed Book: London, UK.

8. Komolafe, C.A. 2000. *Design and Construction of a High Efficiency Stove*. PGD Research Work. Mechanical Engineering Department, Federal University of Technology: Akure, Nigeria.

9. Olorunisola, A.O. 1999. "The Development and Performance Evaluation of a Briquettee Burning Stove". *Nigerian Journal of Renewable Energy*. 7(1 & 2):91-95.

10. Olorunisola, A.O. 1999. "Efficiency of two Nigerian Cooking Stoves in Handling Corn-Cob Briquettes". *Nigerian Journal of Renewable Energy*. 7(1 & 2):31-34.

11. Wereko-Brobby, C.Y. and Hagen E.B. 2000. "Biomass Conversion and Technology". UNESCO Energy Engineering Series, John Wiley and Sons: New York, NY. 99-115.

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