Characterization of Three Conventional Cookstoves in South Eastern Nigeria

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Abstract: Performance characterization of some selected conventional cook stoves in South Eastern Nigeria had been carried out. Three conventional cook stoves (3-stone wood stove, charcoal stove and sawdust stove) were selected and evaluated. Their performances were compared with those of improved stove using stove test standards. The results show that the time spent in cooking 1 kg of rice/(yam) is significantly different in all the conventional stoves under test; (maximum 0.75 (0.44) kg/hr for 3-stone stove and minimum 0.61 (0.35) hr/kg for charcoal). Fuel utilization also differs for instance lesser quantity of charcoal would be required to cook the same quantity of food on the charcoal stove than the open fire stove. Also the specific fuel consumption value of charcoal stove is lesser than all other stoves. The 3-stone wood stove have higher specific fuel consumption values indicative of more fuel consumption but lower thermal efficiency. This indicates a poor performance when compared to other improved stoves with higher thermal efficiencies.

Keywords: Cookstove, fuel consumption, thermal efficiency, burn rate

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1 Introduction

Over 60% of Nigeria's population depends on fuelwood and charcoal for cooking and other domestic energy needs (Olorunnisola, 1999)**.** The energy consumed per capita was in the past used as an indicator of progress in stove development. In countries in Africa, charcoal is widely available and is thus used to almost the same extent as wood fuels. However, it was recognized in the nineties that it is not necessarily the amount of energy provided that mattered but the quality of the energy services needed at a certain development stage and its distribution. While better stoves may save energy, they will not by themselves prevent deforestation, though they may help slow it.

Cookstove technology and development have been studied on a continuing basis for over 35 years; unfortunately, there exist today no clear-cut internationally accepted design standards for biomass burning stove (Stout and Best, 2001; George, 2007, Bello *et al*., 2013). Worse still, the currently available local stoves do not usually represent the best designs that modern engineering can offer. However, the increasing interest on climate change and global warming issues has created awareness on the environmental and social costs of using traditional stoves.

The challenge of cook stove design is not only a technical issue but a social issue as well. How and what we cook greatly depends on our culture, lifestyle and resources. A good stove should be able to boil water quickly, simmer foods and cook an almost infinite variety of foods in different ways depending on the culture while minimizing fuel use and emissions produced. Research results so far show that one stove may be efficient, another may heat faster, another safer, and each of them

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pollutes more or less than the other. It therefore depends on the stove designer to pick out a design that will best suit the locality and food types for which it is intended. Lack of access to appropriate energy sources is undoubtedly one of the roots of poverty which hinders economic and social development.

Many rural household in South Eastern Nigeria use traditional cooking stoves often, the use of firewood, agro-residues and cow-dung as fuel, have certain inherent defects in the environment (Bouttete, 1981). This paper presents performance characteristics of some tested traditional cooking stoves in South Eastern Nigeria and a comparison with improved stove.

2 Materials and methods

Among several designs off cookstoves identified in the local market, majority of which utilizes fuelwood, sawdust/rice husk, charcoal and kerosene as fuel, three models (3-stone stove, charcoal and sawdust) were chosen based on the following criteria:

- Type of fuel burn
- Widespread coverage and acceptability among household users
- Unit price at the local market
- Availability and in common use for cooking

Fuel materials were sourced locally; firewood from nearby fields, sawdust from the carpentry workshop, charcoal from the open market and the rice husk from the rice processing centers. The sawdust and charcoal were screened for impurities and metals and dried under sun to remove the moisture content for proper combustion and also the elimination of smoke emission during burning.

2.1 Materials description

Cook stoves

Three types of traditional stoves; 3-stones wood stove charcoal and sawdust/rice husk metal stoves (Figure 1). Description of each stove is presented below.

3-stone wood stove: This stove comprises of three set of stone/brick block arranged such that it could accommodate any specific size of pot. The stove supports the cooking pot over the centre of the fire; the stove was arranged so that the pot sits partly down between them.

Charcoal metal stove: The stove consists of an upper combustion chamber that opens to the atmosphere but separated from the ash chamber by a set of metal strips for charcoal support and allow ash drop to the base of the lower chamber. The base chamber consists of an opening for removing ashes and also serves as air-inlets chamber. The top of the stove consist of 4 finger seating of the same chamber to accommodate different size of pot. The combustion chamber is 15cm wide and 23cm high.

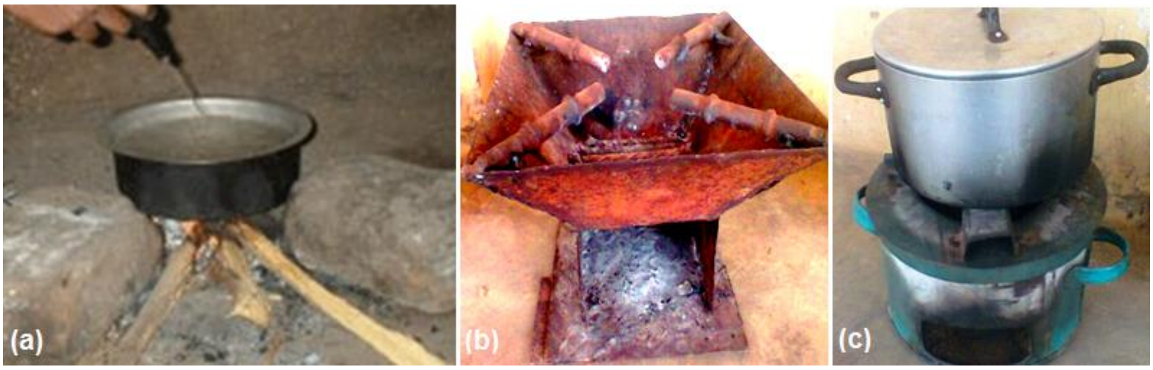

Figure 1: Test stoves: a) 3-stone fire stove b) Charcoal, c) Sawdust / rice husk

Sawdust/rice husk stove: The sawdust or rice husk stove is circular in shape, and is made of light metal and consists of the combustion chamber, the top and base section. There is an opening at the top for loading sawdust into the combustion chamber and another opening at the base which serves as air inlets and for ashes removal. There are 3 pot rest of the same size to accommodate different pot sizes. The diameter of the combustion chamber is 14cm and its height is 16cm.

Fuel material description

Fuel material selection were informed by material availability (the commonly used materials) in domestic cooking In order to minimize the variation that is potentially introduced by fuel characteristics, VITA's precautionary recommendations of 1985 was considered; the use of only wood (or other fuel) that has been thoroughly air-dried and an assumption of solid fuels fuel having different burning characteristics (VITA, 1985).

The firewood of 5cm average diameter range and approx. 60cm long was gathered from around the College farm, and sun dried to reduce their moisture content to below 10%.The charcoal fuel used for the water boiling test was bought in the open market and sorted to obtain a uniform size, so as to get the same weight at 6% moisture content. The sawdust was collected at the carpentry dump site and dried under exclusive environment to 8-10% moisture content dry basis.

Instrumentation

Test materials utilized include a flat bottom aluminum cooking pot 21cm in diameter and 12cm high. A glass tube 100^0C range thermometer was used to determine variation in temperature; it is graduated in 76mm immersion. A stopwatch was used to measure time taken by each stove to boil a measured quantity of water at different intervals. A Salter electronics weighing balance of 5kg capacity and ±1g accuracy was used for material weighing. The experimental setups were conducted under open environment and closed environment. Where necessary, the stoves were aspirated /supplemented with a hand fan to provide enough air support for combustion especially under closed environment, but under open environment, minimal aspiration was required due to air flow.

2.2 Methodology

The tests were conducted under two varying atmospheric conditions; open and closed environments. The first test was carried out in an open shed environment after taking the measurement of the materials used such as, the initial weight of the stoves, the quantities of fuels introduced into their combustion chambers, 10ml of kerosene were sprinkled to initiate ignition, stopwatch was used to monitor the time taken per cycle of operation.

Second test was conducted in an enclosed environment, where wind does not affect the burning of the fuels, measurement were also taken, as done in the first test. The time taken by the fuels to burn last more than the one conducted in an open environment. Two methods of stove test according to Stewart (1987); water boiling test (WBT) and controlled cooking test (CCT) was implemented to simulate cooking conditions because materials utilized in the test. In conducting the water boiling tests, the following procedures were taken:

1. Dry weights of experimental materials like pot and stove were taken and recorded.
2. The pot was filled with an initial known weight of water and the same weight was maintained throughout the course of the experiment.
3. All test procedures utilized in WBT test was adopted in the test for the briquettes in each of the stoves.
4. Data was collected and analyzed.

Water boiling test (WBT): The time of the day, the environmental conditions (ambient temperature) and the initial temperature of the water were noted. Thereafter the commencement of the test the temperature of the water was recorded at intervals of five (5) minutes until the moment the water came to a vigorous boil.

The pot was then removed from the stove and the fire immediately put out with the help of dry sand. The final weight of the remaining water, charcoal and the final temperature of water were then measured and recorded. The tests were carried out between 24th of November and 7th of December, 2011 starting at about 10am each day.

Controlled cooking test (CCT): Controlled cooking test (CCT) was carried out using food items such as rice and yam (Discorea*rotundata*). The performance characteristics of traditional stoves were compared with that of 3- stone wood stove and sawdust stove. Mass of the fuel was measured, and stacked inside the internally lined stove and ignited. The first experiment was carried out using yam the pot containing water and yam was placed on the glowing fuel and left to cook. When the cooking was properly done, the mass of the cooked yam and time to achieve cooking were recorded with the aid of a stopwatch. Also, the mass of the fuel remaining after cooking was also recorded. The process was repeated using rice and beans respectively.

2.3 Methods of data analysis

The procedure and formulae employed in the calculation of parameters were based on FAO (1990), Ahuja *et al.,* (1997), Olorunisola (1999), and Kuti (2003) approaches.

Performance test indicators: The following performance indicators were used in determining stove characteristics;

a. *Burn rate (R_{cb}):* This determines the rate at which a certain mass of fuel is combusted in air. This is a measure of the rate of wood consumption while bringing water to a boil. It is calculated by dividing the equivalent dry wood consumed by the time of the test. This is also used to calculate heat transfer efficiency, η_{th} (%).

$$r_{cb} = f_{cd}/(t_{cd} - t_{cd}) .. (1)$$

The burn rate in (Kg/hr) can also be calculated using equation stated below (Ahuja *et al.,* (1997)

$$F = \eta_{th} = \frac{1}{t} * 100 \frac{W_i - W_f}{100 + m} .. (2)$$

b. *Thermal efficiency (η_{th}):* Thermal efficiency is a measure of the proportion of the total energy which is gainfully employed in any thermodynamic system. This is a ratio of the work done by heating and evaporating water to the energy consumed by burning wood. According to Clarke (1985) the thermal efficiency of a cooking stove depends largely on how well the heat generated is transferred from the hot gas of the fuel line to the pot or vessel on the stove (convective heat transfer). It is calculated as follows:

$$\eta_{th}(100\%) = \frac{(P_{ci} - P_f) * (T_{cl} - T_{ci}) + 2260 * W_{cv}}{f_{cd} * LHV} . (3)$$

The thermal efficiency is also related to the percentage heat utilized (PHU) given by:

$$\eta_{th}(100\%) = BurnRate * PHU . (4)$$

Where PHU is defined by

$$PHU = \frac{m_w C_p (T_b - T_o) + m_c L}{m_f E_f} 100\% . (5)$$

The numerator gives the net heat supplied to the water while the denominator gives the net heat liberated by the fuel.

Where

m_w= Mass of water in the pot (kg);

C_p= Specific heat of water (kJ/kg K);

T_o= Initial temperature of water (K);

T_b= Boiling Temperature of the water (K);

m_c= Mass of water evaporated (kg);

L = Latent heat of evaporation (kg);

m_f= mass of fuel burnt (kg);

E_f= Calorific value of the fuel (kJ/kg);

c. *Specific fuel consumption:* This is defined as the amount of solid fuel equivalent used in achieving a defined task divided by the weight of the task. It can be expressed as:

$$SFC = \frac{Mass\ of\ Consumed\ Fuel(f_{cd})}{Total\ mass\ of\ cooked\ food(P_{cf-P})} . (6)$$

According to Olorunnisola (1999), the specific fuel consumption (SFC) and the time (T) spent to cook 1kg of food were examined from the data.

d. *Time spent in cooking per kilogram of cook food:*

$$T_s = \frac{Total\ time\ spent\ in\ cooking(T_{ts})}{Total\ Weight\ of\ cooked\ food(T_{wc})} (hr/kg)...$$

(7)

3 Results and discussions

The mean of results of the water boiling test and the controlled cooking tests under varying environmental conditions were presented below.

3.1 Results of water boiling tests (WBT)

Table 1 shows the results of time variation for WBT under varying conditions. The values within the closed bracket represent the results obtained under closed environment.

Table 1Time variation for WBT under open environment and closed environment

Time taken (min)	Rice husk stove	Charcoal stove	Three stand stove
Time spent before fuel reaches steady burn rate	2.32 (2.43)	3.25(7.23)	2.40 (3.35)
Time spent by each stove to boil 1.30kg of water at 100^0C	8.32(8.32)	5.17(5.17)	10.03(10.03)
Total time spent to consume fuel in combustion	54.22(122)	87(105)	41.32(48.22)

The stoves were used for water boiling test (WBT) and controlled cooking test (CCT) under closed and open environment in order to determine the time variation to raise water temperature to 100^0C and time taken for each stove to boil specific quantity of food. It was found that in a closed environment, it takes a shorter time to boil 1.30kg of water and cook some quantity of food, and consumes little quantity of fuels, while in open air it consumes a lot of fuel and more time to cook the food and boil 1.20kg of water due to uncontrolled conventional air influence on setup.

3.2 Results of control cooking tests (CCT)

The controlled cooking tests (CCT) conducted under varying conditions for two varieties of food; rice and yam were presented in Tables 3 and 4. Measured quantities of food used in CCT tests (rice and yam) were boiled in each stove and the respective weight measurements (0.88Kg). The weight of material use and consumed by each stove are represented in Table 2.

Table 2 Quantity of fuel consumed in boiling rice (yam) in each stove

Quantities measured (Kg)	Sawdust stove	Charcoal stove	3- Stone wood stove
Initial mass of raw food	0.88	0.88	0.88
Final mass of cooked food + water	2.38(2.45)	2.40(2.35)	2.39(2.33)
Initial fuel mass at start of cooking	1.09	1.05	2.6
Final fuel mass at the end of cooking	0.4 (0.4)	0.71(0.43)	0.6(1.04)
Mass of consumed fuel	0.69(0.69)	0.34(0.62)	2.0(1.56)

Higher fuel consumption is evident in 3-stone wood stove because of uncontrolled air movement while it is minimal in charcoal stove because of controlled atmospheric burning, high thermal capacity and high temperature differentials (Bello et al., 2010). The result of controlled cooking test (CCT) under controlled atmosphere provides the time variation for each stove in CCT under the close environment. From the table, the sawdust stove takes more time (7.23 min) to reach steady burn rate while charcoal stove spent lesser time to reach steady burn rates. Total time spent in burning off the fuel varies for each stove but maintain time range of 32-39min. time spent in cooking rice and yam were as indicated in each operation.

Table 3 Time variation for CCT under closed environment

Time taken (min)	Sawdust stove	Charcoal stove	3-stone stove
Time spent before fuel reaches steady burn rate	7.23	2.43	3.35
Total time spent for cooking rice	37.22	32.10	39.30
Total time spent cooking yam	20.15	18. 4	23.31

Table 4 indicates test results for cooking of rice and yam under enclosed environment. From the test results, charcoal burns more rapidly than sawdust and hence heated up the water/food faster due to the passage of conventional airflow within the loosely packed materials in the combustion chamber (Bello et al., 2010). The rate of sawdust combustion is generally slow and produces a lot of smoke because of inadequate air for complete combustion.

Table 4 CCT for rice and yam (in brackets) under enclosed environment

Measured quantities	Sawdust stove (Kg)	Charcoal stove (Kg)	3- Stone stove (Kg)
Initial weight of the stove	1.51	4.10	-
Initial weight of fuel	1.09	1.05	2.6
Initial weight of the pot	1.08	1.08	1.08
Initial weight of stove + fuel	2.6(2.6)	5.15(5.15)	2.6(2.6)
Quantity of water added to pot	0.9(0.6)	0.9(0.6)	0.9(0.6)
Initial mass of raw rice (kg)	0.88(0.88)	0.88(0.88)	0.88(0.88)
Weight of the pots + rice	1.96(2.33)	1.96(2.33)	1.96(2.33)
Weight of rice after boiling	2.38(2.45)	2.40(2.35)	2.39(2.33)
Stove weight after combustion	2.20(2.20)	4.72(4.44)	1.56(2.00)
Fuel weight after combustion	0.4(0.4)	0.43(0.71)	1.04(0.6)
Weight of fuel consumed	0.69(0.69)	0.62(0.34)	1.56(2.0)

The result of time spent in cooking per kilogram of food is presented in Table 5 below. Relatively, the time spent in cooking 1 Kg of food; rice (yam) is not significantly different in all the stoves (maximum 0.44kg/hr for 3-stone stove, 0.35 hr/kg for charcoal and 0.39 kg/hr). The practical implication of this result is that lesser quantity of charcoal would be required to cook the same quantity of food on the charcoal stove than the 3-stone stove because of uncontrolled air movement.

Table 5 Performance evaluation of each stove

Cooking duration for rice (yam)	Sawdust stove	Charcoal stove	3- Stone wood stove
Total time spent in cooking rice (min)	37.22	32.10	39.30
Total time spent in cooking yam (min)	20.15	18.40	23.31
Time spent/kg of cooked food (hr/Kg)	0.39	0.35	0.44
Ave. time spent/kg of cooked food	0.55	0.48	0.60

3.3 Stove characteristics

The data collected were used in calculating the specific fuel consumption (SFC) and thermal efficiency presented in Table 6 below. The results show varying thermal efficiencies of 52.64%, 64.38%, and 34.56 % for sawdust stove, charcoal stove, and three-stone respectively and average specific fuel consumptions of 0.54, 0.48, and 0.60 respectively. Thermal heat transfer efficiency is higher for a charcoal stove and very low specific fuel consumption value. 3-stone wood stove thermal efficiency is lesser than all other stoves with higher specific fuel consumption. Charcoal stove have lower specific fuel consumption value and higher thermal efficiency. This indicates a better performance comparable to other biomass stove such as sawdust stove which has thermal efficiency of 52.64%.

Table 6 Performance evaluation of each stove

Parameters	Sawdust stove	Charcoal stove	3- Stone wood stove
Specific fuel consumption (SFC)	0.54	0.48	0.60
Thermal efficiency (%)	52.64	64.38	34.56

Stove researchers like Krämer and Karhagomba, (2009) reported that published data (Goldemberg and Johansson, (1995); Anozie *et al*. 2007) on three-stone wood stove shows a wide range of variation in efficiency of between 5% and 25% consequent on some neglected factors (such as pot material, thickness etc) contribution in the WBT protocols, however, under controlled atmosphere, the efficiency could be higher.

4 Conclusion

From the test results, the time spent in cooking 1 Kg of rice/ (yam) is significantly different in all the stoves (maximum 0.75 (0.44) kg/hr for 3-stone wood stove and minimum 0.61 (0.35) hr/kg for charcoal). The quantity of fuel utilization also differs for instance lesser quantity of charcoal would be required to cook the same quantity of food on the charcoal stove than the open fire stove. The results indicates that charcoal burns more rapidly than other stoves indicating a higher thermal value due to the passage of conventional airflow within the loosely packed fuel in the combustion chamber (Bello et al., 2010). The rate of combustion of sawdust is generally slow and produces a lot of smoke because of inadequate air for complete combustion. The results equally show that the specific fuel consumption value of the charcoal stove is lesser than all other stoves. The 3-stone stove have higher specific fuel consumption values indicating more fuel consumption and lower thermal efficiency. The practical implication of this result is that the stoves have differing SFC value for different foods. However, when compared to other stoves charcoal stove has a better performance. Sawdust has advantage of low fuel consumption and high thermal capacity but produces excessive smoke; if densified under high pressure into briquettes will be a better fuel (Bello et al., 2012).

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