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Comparative Analysis on the Performance of Four Selected Fuel Wood Stoves Using Water Boiling Test

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ABSTRACT

The comparative analysis of four selected wood stoves using Water Boiling Test was carried out in this study. The selected wood stoves were Save 80, Single Hole Improved (S.H.I.) Wood Stove, Locally Fabricated Metal (L.F.M.) Stove and Traditional Open Fire (T.O.F.) Stove. The Water Boiling Test adopted in this research is that of the Volunteers in Technical Assistance (VITA) 1985 which is currently accepted as standard for the performance evaluation of stoves (Ballard et al., 1996). The analysis showed that it took the Traditional Open Fire and Locally Fabricated metal Stoves an average of 40.66 min and 30.67 min to bring 2 liters of water to boiling point (100^0C) with 1.25 kg and 1.05 kg of wood respectively. However, for Single Hole Improved Wood Stove and Save 80, it took also an average of 28.00 min and 15.33 min to bring the same volume of water to boiling point with 0.75 kg and 0.30 kg of wood respectively. The results obtained further showed that the Save 80 Fuel Wood Stove has a Fuel Burning Rate of 0.79 kg/hr, Single Hole Improved Fuel Wood Stove, 1.20kg/hr, Local Fabricated Metal Stove, 1.24kg/hr, and Traditional Open Fire Stove (Three Stone Stove), 1.29kg/hr. Finally, the Percentage Heat Utilized (PHU) and Thermal Efficiencies of the Save 80 stove, the Single Hole Improved Wood Stoves, the Locally Fabricated Metal Stove and the Traditional Open Fire Type were found to be 39.39 (31.12%), 14.69 (17.62%), 11.25 (15.87%) and 7.78 (10.04%) respectively.

KEYWORDS: *Wood Stove, Traditional Open Fire, Locally Fabricated, Single Hole Improved, Save 80, Burning Rate, Specific Fuel Consumption, Efficiency.*

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I. INTRODUCTION

In rural areas of most developing countries like Nigeria, wood is the most readily available energy source for domestic cooking applications. This means that more than two billion people depend largely on various forms of biomass to meet their energy needs mainly for cooking (Pelinck, 1993). However, the frequent use of these woods leads to deforestation that affects our climatic conditions. Therefore, this woods needs to be properly managed. Therefore, the use of unsafe, inconvenient and inefficient wood stove will not help to solve our problems. A more efficient and saving cooking wood stove would indeed go a long way to saving resources and promoting good environmental conditions for most rural communities.The rate of deforestation in the past ten years has increased considerably due to the increase in wood fuel consumption, the expansion of agricultural land, desert encroachment and construction of new buildings (Obi *et al.*, 2002). At present, there is no real alternative to wood fuel for cooking particularly in the rural areas (Akinbode, 1991). Exposure to smoke has emerged as one of the major concerns in the rural areas of the developing countries (WHO, 1992). The increase in population will continue to increase the demand for firewood consumption whose supply is limited. Therefore, in order to balance the demand and supply of fuel wood for cooking, a more efficient use of this fuel is desirable by making use of more efficient and save cooking stoves (Akinbode, 1991).In Nigeria about 67% of the country's population depends on fuel wood for their daily cooking and often on the traditional open tires or inefficient cooking stoves with about one hundred million cubic meters of wood are consumed annually. Nigeria's forests are therefore under severe pressure from harvesting fuel wood for cooking (Okafor and Unachukwu, 2012). It was estimated that the number of people that will be affected worldwide by fuel wood shortage will increase from the current one billion to nearly 2.8 billion and those suffering an acute scarcity of fuel wood will increase from 100 million to over 350 million over that same period (Baldwin, 1986).

While the long term aspiration in respect of cooking energy is the complete substitution of fuel wood by other sources such as kerosene, electricity and solar, it is certainly obvious that this change will take a few decades to materialize and certainly not cheap for rural dweller to afford for their daily cooking (Garba and Atiku, 1996). It is therefore necessary for science researchers today to provide the rural communities with immediate means for absolute management of fire wood utilization.

II. THEORETICAL FRAMEWORK

The following characteristics of the stoves were determined from the water boiling test and controlled cooking test Based on the following approaches of some authors:

Burning Rate of the Stove

The burning rate R (kg/hr) which measures how economically the stove burns the fuel wood in its combustion chamber is determined using the equation below (Okafor and Unachukwu, 2012):

$$R = \left[\frac{100(W_i - W_f)}{(100+M)} + \frac{M_c \times C_c}{C_w}\right]\frac{1}{t} \tag{1}$$

Thermal Efficiency of the Stove

The thermal efficiency measures how the heat generated by the stove is utilized in boiling the water or in cooking the food. The thermal efficiency (n_{th}) of the stove can be determined using the equation (Ayo, 2009):

$$n_{th} = n_h - n_c \tag{2}$$

It is also related to the percentage heat utilized (PHU) by the stove which is given as

$$n_{th} = PHU \times R \tag{3}$$

The percentage heat utilized (PHU) is determined by equation below (Musa *et al*., 1997):

$$PHU = \frac{M_w C_{pw}(T_w - T_a) + M_p C_{pp}(T_p - T_a) + M_w L_w}{W_{wd} C_{wd} - W_c C_c} \times 100\% \tag{4}$$

Specific Fuel Consumption : In the controlled cooking test, the specific consumption (SFC) which expresses the amount of day wood required to obtain 1kg of cooked food is given by the equation (Garba and Atiku, 1996; Komolafe and Awogbemi, 2010)

$$SFC = \frac{M_{fc}}{M_{cf}} \tag{5}$$

III. METHODOLOGY

In this study, use was made of four different types of wood stove, they are: Traditional Open Fire Stove (the Traditional three stone), Locally Fabricated Metal Stove, Single Hole Improved Wood Stove and Save 80 Wood Stove (with Integrated Pot). The measuring instruments used are Weighing Balance, two Mercury-in-glass Thermometers, Measuring Cylinder Hygrometer and Multimeter (for measuring Ambient Temperature). Others are Aluminium Cooking Pot, Firewood (*Querasenegalensis*) and Match. A number of standard methods have been developed for evaluating the performance of cooking stoves. Such methods are the Constant Heat Output, Constant Temperature Rise, Constant Time and Water Boiling Test (Bhattacharge *et al*., 1984). Of all these, Water Boiling Test method is mostly used for its property of being short and also provides a simple simulation of standard cooking procedures. It measures the quantity of fuel consumed and time required for the simulated cooking. It is usually employed in investigating the performance of cooking stoves under different operating conditions. It also provides a quick method of comparing the performance of cooking stoves. The method is therefore, fits the purpose of this study. The water boiling test adopted here is that of VITA 1985 (Volunteers in Technical Assistance) which is currently accepted as standard for the performance evaluation of stove (Ballard and Jawurek, 1996). The procedure started with the pre-weighed 2 kg of fuel wood used to boil 2 L of water for the four different stoves. The pots with their lids were weighed and 2 L of water was poured into them and re-weighed to determine the weight of the water (Okafor and Unachukwu, 2012). The initial temperature of water in the pots was recorded. Some pieces of fuel wood from the weighed bundles were slotted into the combustion chamber, but that of stove 80 was chopped to smaller pieces to fit into the combustion chamber.

The fuel wood was then ignited. The cover pots were placed on the stove by and initial time noted. As the fuel wood started to burn, the temperatures of the water in the pots were measured and recorded at 2 minutes intervals until the moment the water get to its boiling point (100^0C). The two pots were then removed and the fire put out immediately with the help of dry sand. The remaining water was weighed by weighing the final weight of the pot and water. The unburned fuel woods removed from the stoves together with the remaining pre-weighed bundles were weighed. The loose charcoal knocked off from the ends of the fuel wood together with the ones removed from the stove was also weighed. The procedure was repeated five times in each case and average was calculated.

IV. RESULTS AND DISCUSSION

From the performance evaluation test that has been carried out on each stove to determine their water boiling capacity, the following results were obtained.

Table 1: Results of Performance Evaluation for the four selected Fuel Wood Stoves

Stove	**T.O.F. Stove**	**L.F.M. Stove**	**S.H.I. Stove**	**SAVE 80**
Relative humidity (%)	36.20	36.20	36.20	36.20
Initial water temperature (^0C)	31.50	31.50	31.50	31.50
Initial weight of fuel wood (kg)	2.00	2.00	2.00	2.00
Weight of fuel wood consumed (kg)	1.25	1.05	0.75	0.30
Weight of water evaporated (kg)	0.20	0.25	0.30	0.22
Weight of charcoal (kg) produced	0.28	0.15	0.10	0.08
Final water temp. (^0C)	100.00	100.00	100.00	100.00
Average time (min)	40.66	30.67	28.0	15.33
Burn rate (kg/hr)	1.29	1.24	1.20	0.79
Efficiency (%)	10.04	15.87	17.62	31.12
Fuel saving (%)	37.50	47.50	62.50	85.00
P.H.U (%)	7.78	11.25	14.69	39.39
Mass of charcoal produced (kg)	0.20	1.50	1.00	0.05

Table 1 shows the various results obtained from the analyses carried out in this study. In all the wood stoves under test, emphasis was laid on Burn Rate, Efficiency and PHU as the bases for comparison. It is observed from the table that, it took the Traditional Open Fire and Locally Fabricated Stove an average of 40.66 min and 30.67 min to bring 2 liters of water to boiling point (100^0C) with 1.25 kg and 1.05 kg of wood respectively. However, for Single Hole Improved Wood Stove and Save 80, it took also an average of 28 min and 15.33 min to bring the same volume of water to boiling point with 0.75 kg and 0.3 kg of wood respectively. The results obtained further showed that the Save 80 Fuel Wood Stove has a Fuel Burning Rate of 0.79 kg/hr, Single Hole Improved Fuel Wood Stove, 1.20kg/hr, Local Fabricated Metal Stove, 1.24kg/hr, and Traditional Three Stone Stove, 1.29kg/hr. Finally, the PHU and Thermal Efficiencies of the Save 80 stove, the Single Hole Improved Wood Stoves, the Locally Fabricated Metal Stove and the Traditional Open Fire Type were found to be 39.39 (31.12%), 14.69 (17.62%), 11.25 (15.87%) and 7.78 (10.04%) respectively.

V. CONCLUSION

Large percentage of the population in developing countries relies on biomass fuels and traditional technologies for cooking and heating. Therefore, the burning of biomass fuels in the traditional and inefficient cook stoves has a negative impact on the health of household members. In this research work, Save 80 fuel wood stove thermal performance was compared to single improved wood stove, local fabricated metal stove and the popular traditional open fire type, using the water boiling. The result obtained showed that the Save 80 fuel wood stove with fuel burning rate of 0.79 $kghr^{-1}$, Single Hole Improved Fuel Wood Stove 1.20$kghr^{-1}$, local fabricated metal stove 1.24$kghr^{-1}$, and traditional three stone type with 1.29$kghr^{-1}$. It can therefore be concluded that the Save 80 Wood Stove utilizes wood fuel more efficiently than the other three (3) stoves. Finally, the Percentage Heat Utilized (PHU) and Thermal Efficiencies of the Save 80 Stove, Single Hole Improved Wood Stoves, Local Fabricated Metal Stove and Traditional Open Fire type were found to be 39.39 (31.12%), 14.69 (17.6%), 11.25 (16.8%) and 7.78 (10.0%) respectively. The Save 80 Burning Fuel Stove is therefore recommended for use by Nigerians especially in rural areas where alternative fuels for cooking such as kerosene and cooking gas are lacking.

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Nomenclature:

W_i = initial mass of wood (kg)
W_f = Final mass of wood remaining (kg)
M= moisture content of wood used for
M_c = mass of charcoal produced (kg)
C_c = calorific value of charcoal remaining after test.
C_w = calorific value of the wood used
t= total time taken for the test(s)
C_c = calorific value of charcoal remaining after test
C_w = calorific value of the wood used
M_w = initial mass of water (kg)
C_{pw} = Specific heat capacity of water (4180 J/kgK)
T_w = final water temperature (^oC)
T_a = initial temperature of (^oC)
M_p = mass of the pot (kg)
T_p = Final temperature of pot body (^oC)
T_a = Ambient temperature (^oC)
C_{pp} = Specific heat capacity of pot material
M_w = Mass of water Evaporated (kg)
L_w = Latent heat of vaporization of water (2260 x 10^8 J/kg)
W_{wd} = Mass of wood burned (kg)
M_{fc} = mass of consumed fire wood (kg)
M_{cf} = mass of cooked food (kg)

Appendix

Figure 1: Single Hole Improved Wood Stove

Figure 2: Local Fabricated Metal stove

Figure 4a: The Save 80 Wood Stove

Figure 4b: Heat Retention (Wonder) Box