Advances in Science and Technology, Vol. 9, No. 1&2, September / October, 2015, pp 43 - 47

Construction of an Improved Fuel-Efficient Woodstove for Nigeria

Chidi E. Akujor, Oluwasogo A. Ogungbenro, Chibuike K. Njoku, Innocent W. Onyekwere, I.M. Mejeha, Greg A. Alozie, Alvan C. Chinaka and Ikechukwu C.E. Irechukwu
Department of Physics, Federal University of Technology, Owerri
(Submitted: October 14, 2015; Accepted: October 31, 2015)

Abstract

We have undertaken the design, construction and testing of an improved woodstove. The design improvement focused on; the provision of insulation around the combustion chamber in order to reduce conduction heat loss across the walls of the chamber and the provision of sizable and adjustable air inlet to ensure the availability of sufficient air for the complete combustion of the fuelwood. We have compared the performance of our woodstove (stove 3) with earlier versions (stove 1 and stove 2) using thermal efficiency, burning rate and portability. Standard water boiling tests were carried out and the results showed that stove 3 has a maximum thermal efficiency of 43.69% and burning rate of 1.03 x 10^{-3} $kghr^{-1}$. This indicates a better performance when compared to the other stoves (stove 1 and stove 2) with thermal efficiencies and burning rate of 22.49% and 1.25 x 10^{-3} $kghr^{-1}$, 16.09% and 2.33 x 10^{-3} $kghr^{-1}$ respectively.

Keywords: woodstove, water boiling test, thermal efficiency, burning rate.

1.0 Introduction

There has been several calls for harnessing the diverse available energy resources for optimum power generation in Nigeria (see Nwofor *et al*., 2007; Agba, *et al*., 2010; Akujor, *et al*., 2011). Among them is the need for optimizing the fuelwood resources abundant across the country. We have in the past advocated the usage of improved woodstoves for domestic cooking as opposed to the current trend which depends on the conventional tripods with very low efficiency and associated health and environmental hazards (see Akujor *et al*., 2012). In this paper, we report on our effort towards building an improved fuel-efficient woodstove for the rural Nigerian populace. The currently built version of the woodstove is labelled stove 3 and is compared with our earlier versions (1 and 2).

2.0 Design and Construction

The woodstove is circular in section (Figures 1-3) and generally consists of a combustion chamber, a top section and a base. The hearth of the combustion chamber is made of an insulating material and encased in a mild steel casing. The grate or fuel bed is at the base of the combustion chamber. The base of the stove consists of a door for loading fuelwood into the combustion chamber, and opening(s) which serve as combustion air inlet(s) to the chamber. A drawer is incorporated at the base to facilitate the removal of ash which would have collected at the tray. The top of the stove consists of the pot seat, three refractory rings of different diameters to accommodate different sizes of pots.

The combustion chamber should be made in such a way that heat generated within it is not lost through radiation to the environment. Consequently, materials used for the construction of the combustion chamber should have poor thermal conductivity. Locally made durable ceramic can be used as walls for a combustion chamber as in the Winiarski design. Insulative ceramics such as mixtures of sawdust and clay, charcoal and clay, vermiculite and clay, etc. (Bryden *et al*., 2002a; 2002b) are good for constructing an efficient combustion chamber. The combustion chamber should also be lagged with insulative materials in order to ensure zero percent heat loss to the environment through radiation. The radial conduction heat flow Q_r across a composite cylinder with known inside and outside surface temperatures and having n layers of different materials is given by (Ayo, 2009):

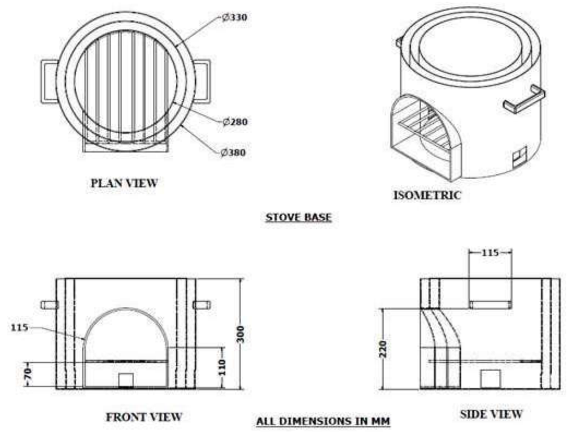

Figure 1: Sectional view and dimension of the woodstove.

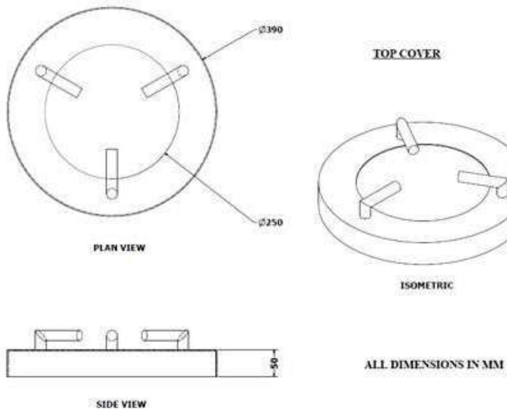

Figure 2: Sectional view of the top cover

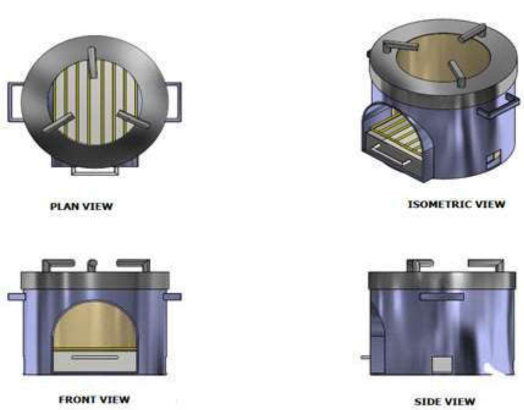

Figure 3: Woodstove fully assembled.

$$Q_r = \frac{T_1 - T_{n+1}}{\frac{1}{2\pi H}\sum_{i=1}^{n}\frac{1}{K_i}\ln\left(\frac{r_i+1}{r_i}\right)} \quad ...1$$

where K is thermal conductivity of the cylindrical material; T_1 and r_1 are the temperature and radius of the innermost layer of the combustion chamber; H is the height of the combustion chamber.

An improved combustion efficiency does not appreciably translate into a usage of less quantity or amount of fuel. Improving the combustion efficiency is necessary to reduce smoke and harmful emissions that affect human health. Improving heat transfer efficiency to the pot makes a large difference; it can significantly reduce fuel use. To achieve maximum heat transfer, the fuelbed-to-pot distance should be kept as close as possible so as to minimize heat loss. The thermal efficiency, n_{th} of a stove is given by:

$$n_{th} = \frac{W_{wi}\, C\,(T_f - T_i) + (W_{wi} - W_{wf})\, L}{R \times t \times Q_{net}} \times 100 \quad ...2$$

The lifespan of the fuelwood in the combustion chamber, i.e. the burning rate (R), is given by:

$$R(kghr^{-1}) = \frac{100(W_i - W_f)}{(100 + M)t} \quad ...3$$

where W_i is the initial weight of fuel at start of test (standard water boiling test), W_f is the final weight of fuel at end of test, M is the moisture content of fuel, Q_{net} is the net calorific value of fuel, t is the total time taken for burning fuel, W_{wi} is the initial weight of water in the pot, W_{wf} is the final weight of water in the pot, T_i is the initial temperature of water, T_f is the final temperature of water, C is the specific heat capacity of water, and L is the latent heat of vaporization of water at 100°C. In order to improve heat transfer efficiency, n_{th} and combustion efficiency, Q_r, and at the same time minimize heat loss to the environment, materials with low thermal conductivity K are used to construct the combustion chamber and effort was made to maintain a good height H for the combustion chamber.

We currently have three (3) designs of woodstoves which we have labelled stove 1, stove 2 and stove 3. Stove 1 is constructed using mild steel and clay. It consist of a combustion chamber, a top section, a grate and one layer. The layer is filled with clay which serves as the insulator preventing heat loss by conduction. In constructing stove 2, mild steel, clay and polyeurethene are used. This stove consist of two layers. The first layer was filled with a mixture of clay and cement. The second layer was filled with polyeurethene material which ensures that the user does not feel the effect of heat emitted by the stove, by this heat loss to the environment is greatly reduced. The component parts of stove 2 are; combustion chamber, ash tray, pot seat and fuel bed. Stove 3 is made with mild steel, mixture of clay and saw dust and polyeurethene material. It comprises of two layers, the first layer was filled with a 1:1 ratio mixture of clay and sawdust which serves as an insulator preventing heat loss by conduction. The second layer was filled with a polyeurethene material. There was also an introduction of a sizable air inlet to ensure the availability of sufficient air for the complete combustion of the fuelwood. The procedure employed in the design is based on the approach used by Ahuja *et al*. (1987), Danshehu, Sambo and Musa (1992) and Olorunsola (1999). The weight of stoves 3 and 2 are significantly reduced considering the materials used when compared to stove 1; stove 3 is the most moveable, followed by stove 2.

3.0 Testing and Result

Performance evaluation of these stoves were carried out using a standard water boiling test; the test is a simplified version of the University of California Berkeley (UCB) / Shell Foundation revision of the 1985 International Standard Water Boiling Test. The test was conducted in a kitchen environment. A measured amount of fuelwood was weighed out for each test. The same type of wood was used for the series of tests, it was therefore ensured that there was sufficient fuel available for the tests, stored in the same experimental condition so as to ensure uniform moisture content. The pot, lid were weighed, and then a measured amount of water by volume (about two-thirds the pot capacity) was added to the pot and weighed again to determine the weight of the water. This was repeated for each test.

The already weighed fuelwood was introduced into the combustion chamber and about 15ml of kerosene was sprinkled on it to initiate burning. The pot was placed on the stove immediately burning was initiated. The time of the day, the environmental conditions (ambient temperature) and the initial temperature of the water were recorded. After the commencement of the test the temperature of the water was recorded at consecutive intervals until the maximum attainable boiling point of water (100^{o}C). 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 on the 6th and 7th of October, 2015 starting at about 11am. This test is used to evaluate the three stoves we have made so far. The constant parameters noted and used during the experiment are given in Table 1. The results of the water boiling tests are presented in Tables 2 and 3.

Table 1: Constant parameters noted and used during the experiment.

Parameter	Value
Weight of wood	1.15kg
Weight of pot and lid	0.5kg
Weight of pot and lid with water	2.0kg
Initial Temperature (Water)	28^{o}C
Atmospheric temperature	30^{o}C
Weight of water	1.5kg
Amount of Kerosene added	~ 15cl
Thermal conductivity of clay, dry to moist	0.15 - 1.8$W/(mK)$
Thermal conductivity of sawdust	0.08$W/(mK)$

Table 2: Temperature readings of stoves 1, 2 and 3 from the water boiling test.

Time (Sec)	Temperature of Stove 1 (°C)	Temperature of Stove 2 (°C)	Temperature of Stove 3 (°C)
30	31	32	32
60	52	60	62
90	-	-	71
120	68	72	78
180	74	82	84
240	82	86	91
270	-	92	95
300	85	95	99
360	91	99	
420	95		
480	99		

The thermal efficiency, n_{th} and the burning rate, R (i.e. the lifespan of the fuelwood) are obtained using equations 2 and 3. Constants used in estimating the thermal efficiency and the burning rates are presented in Table 4. The estimated values of the thermal efficiencies and the burning rates are presented in Table 5.

Table 3: Fuel consumption of stoves 1, 2 and 3 from the water boiling test.

	Stove 1	Stove 2	Stove 3
Weight of wood (fuel) before use.	1.15kg	1.15kg	1.15kg
Weight of the wood recovered.	0.47kg	0.20kg	0.80kg
Weight of ash and ash tray.	0.55kg	1.02kg	0.50kg
Weight of ash tray.	0.40kg	0.50kg	0.45kg
Weight of ash recovered	0.15kg	0.52kg	0.05kg

Table 4: Constants used in our calculations.

Parameter	Value
Moisture content of fuelwood (bamboo)	13%
Net calorific value of fuelwood (bamboo)	1.6 x 10^7 *J/kg*
Specific heat capacity of water	4186 $Jkg^{-1}K^{-1}$
Latent heat of vaporization of water at 100ºC	2.3 x 10^6 $Jkg^{-1}K^{-1}$

Table 5: Estimated burning rate and thermal efficiency of stoves 1, 2 and 3.

Stoves	Burning Rate, *R* ($kg\ hr^{-1}$)	Thermal Efficiency, n_{th} (%)
1	1.25 x 10^{-3}	22.49
2	2.33 x 10^{-3}	16.09
3	1.03 x 10^{-3}	43.69

4.0 Discussion and Conclusion

The result shows that stove 2 has a higher burning rate than the other stoves (i.e. stove 1, and 3). The higher the burning rate the shorter the life span of the fuelwood, therefore, burning rate determines the life span of the fuel during combustion. It is disadvantageous to have a very high burning rate, because a very high burning rate implies that the flames will be scattered and thus resulting to a lower flame efficiency. Hence the lower burning rates obtained for stove 3 is good as it shows that it has high economy for fuel utilization.

The highest thermal efficiency was obtained for stove 3. This is due to:

- The minimal loss of convective and conductive heat in stove 3. This is an indicator that the clay-sawdust mixture in the ratio 1:1 is a good insulator.
- The introduction of other air inlets in stove 3 which helped to achieve complete burning in the combustion chamber.

The higher burning rate of fuel in stove 2 lowers the thermal efficiency of the stove since both parameters are inversely proportional to each other.

We have been able to reduce the weight of the stove; stove 1 is heavier than stove 2, while stove 2 is heavier than stove 3. This can be traced to the introduction of a mixture of clay and sawdust as insulators (both having low thermal conductivity). The mixture of clay and sawdust can serve as a good insulator between two metal surfaces where heat is to be conserved within a certain area and heat loss by conduction is prevented.

Materials used for construction of a woodstove are of great significance in determining the efficiency of the woodstove. We proposed the use of insulating material with very low thermal conductivity (high thermal resistivity) for the construction of woodstove. In Nigeria, clay and sawdust mixture - a good insulating material, is among the readily available and accessible materials for the construction of fuel efficient woodstoves. This will help in addressing some of the critical challenges associated with fuelwood cooking.

References

Agba, A.M.O., Ushie, M.E., Abam, F.I., Agba, M.S. and Okoro, J. 2010, "Developing the biofuel industry for effective rural transformation in Nigeria", European Journal of Scientific Research **40 (3),** 441-449.

Ahuja, D.R., Joshi, V., Smith, K.R., and Venkataraman, C. 1987. Thermal performance and emission characteristics of unvented biomass-burning cookstoves: A proposed standard method for evaluation. Biomass **12(4),** 247-70.

Akujor, C.E., Ogungbenro, O.A., Alozie, G.A., Mejeha, I.M., Nwofor, O. and Efurumibe, E.L. 2012, "Improved woodstoves for domestic cooking in Nigeria", in Renewable energy for national industrial growth, Akujor, C.E. and

Mejeha, I.M. eds, pp144-146.

Akujor, C.E., Ogungbenro, O.A., Mejeha, I.M., Nwofor, O. and Alozie, G.A. 2011, "The state of energy supply in Nigeria: need for more efficient utilization of fuelwood resources", Advances in Science and Technology **5 (1S),** 1-4.

Ayo, S.A. 2009, "Design, Construction and Testing of an Improved Wood Stove", AU J. T., **13(1),** 12-18.

Bryden M., Still, D., Scott, P., Hoffa, G., Ogle, D., Bailis, R. and Goyer K. 2002a, "Design Principles for Wood Burning Cook Stoves", A publication of Aprovecho Research Centre, Shell Foundation and United States Environmental Protection Agency in Partnership for Clean Indoor Air.

Bryden M., Still, D., Ogle, D. and Macarty, N. 2002b, "Designing Improved Wood Burning Heating Stoves", A publication of Aprovecho Research Centre and Shell Foundation.

Danshehu, B.G., Sambo, A.S. and Musa, M. 1992, "Comparative performance of sawdust and wood-burning stoves", Nigerian Journal of Renewable Energy **3(1 & 2),** 50-55.

Nwofor, O.K., Chineke, T.C., Akujor, C.E. and Okoro, U.E. 2007, "Energy diversification choices for Nigeria", Energy and Environment **18 (5),** 577-589.

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