COMPARATIVE PERFORMANCE EVALUATION OF IMPROVED WOOD MUD STOVES

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ABSTRACT
In this study, a performance evaluation was carried out on three models of improved wood mud stoves respectively developed by Sokoto Energy Research Centre (SERC), Centre for Renewable Energy Research (CeRER) and OXFARM, in comparison with a traditional three stone stove. The three models of the stove - SERC, CeRER and OXFARM were subjected to water boiling and cooking tests using a biomass fuel (wood – fueled heating system). Though the results have indicated a good performance values in terms of percentage heat utilization of the stoves relative to the traditional three stone model of cooking and water heating. However, a lot of improvements needs to be considered. The models can be one pot model or multiple pot model. In this study, a single pot model is considered for the design for SERC, CeRER and OXFAM models. The results showed that ONE-POT OXFARM model has the lowest thermal efficiency values for both water boiling and cooking tests compared to other models.

Keywords: woodstove; model; performance; water boiling; controlled cooking; testing.

INTRODUCTION

Global energy demand for industrial and domestic application has been on increase annually due to exponential growth in world population. While most educated people know that there are 8 billion people, very few know how much energy the world uses (Seger, 2016). The major sources of this energy have been predominately from fossil fuel. The continual exploitation of these resources of energy need to be check as they have finite supply. More also, their utilization is a major cause of climate change and global warming being experienced at present, as extra-emission of greenhouse gases, GHG results from burning of fossil fuels (like coal, oil and gas) is expected to raise the temperature from as low as 3^0C to as high as 8 or 10^0C in next 100 years (Anjali & Ranjana, 2012). Hence the reinvigorated global interest in renewable energy resources and conservation as well as efficiency campaign.

In rural Africa and Nigeria in particular, the most predominant energy need is for domestic cooking and several sources indicate that wood is the most widely used domestic fuel. Hall et al. (1993) reported that about half of the world's population cooks with biomass fuel for all or some of their meals. The dependence on fuel wood by the rural dwellers of most developing countries including Nigeria is estimated at about 70 million cubic meters (Samuel 2009). It is estimated that about two million people around the world use wood stove for their domestic cooking and for keeping their surroundings warm. The large preference for wood as fuel is predicated upon the fact that apart from wood and coal, the other primary non-renewable sources of energy such as petroleum, natural gas and liquefied natural gas are no longer easy to come by in terms of cost and availability.

The improved wood mud clay stove is a traditional method of cooking on three stones or sometimes enclosed metallic, clay or brick stoves has been practiced for a long time. However, these have found to be inefficient even though simple and cheap, the energy requirement or fuel wood and time for cooking are found to be higher. The method is also hazardous and unhealthy with smoke becoming nuisance and polluting the environment. Moreover, only a pot at a time can be mounted on the stove. With introduction of improved mud stove, researchers have shown that up 50% cooking time and fuel wood can be saved, with smoke channeled to one direction. Using double hole improved wood mud stoves, two pots can be mounted at a time using the same energy, therefore killing two birds with one stone.

A report compiled by Mark et al. (1991) on design principles for wood burning cook stoves comprehensively discusses the stove theory, design principles, options for combustion chambers and in-field water boiling test. In another related document published in 1993, a developmental manual on improved solid biomass burning cook stoves discusses the system from basics/cruel to most technical or advance stage.

In 2009, Samuel conducted a study on design, construction and testing of an improved wood stove with focused on improvement on insulations around the combustion chamber, incorporation of smoke rings, provision of sizeable and adjustable air inlet and incorporation of chimney for the conveyance of flue gases. The study only addresses a single model with the maximum thermal efficiency of 64.4% with p0wer delivery of 2,52kW.

In another study carried out by Eric et al. (2000), the improved wood-burning stove developed for use in rural Guatemala is reported to substantially reduce levels of indoor air pollution with plancha consuming more fuel and took longer time than open fire but with modification of the plancha combustion chamber by inclusion of a baffle, 12% increment was reported in the overall thermal efficiency. It was reported that for five-day continuous cooking with plancha, the consumption of fuel wood was reduced by about 39% compared to open fire.

This study is intended to investigate the performances three different models which were respectively developed by SERC, CeRER and OXFAM with the aim of the improve wood stove developers to be able to draw some conclusive deductions on some the features and material properties responsible to their varied performances.

MATERIALS

The materials used were classified under the construction and performance measurement/testing materials. Clay, flat iron sheets, moulder and welding machine were some of the construction materials that were utilized. The performance measurement facilities used were chosen in accordance with the measured parameters. These performance parameters include Percentage Heat Utilization (PHU) and Specific Fuelwood Consumption (SFC). Determining PHU and SFC would require the measurements of the mass of the specimens (water, pot, etc.), the specific heat capacity (SHC) of the specimens, temperature values, and time. The variables were measure using thermometers/thermocouples, weighing balances, and stop watches. Other items/facilities are anemometer, stoves, cooking pots, rice and beans, buckets, and bowl.

METHOD

The experiment was setup with all the three models of the stoves, SERC, CeRER and OXFARM been subjected to the same microclimatic condition of the area. Both Water Boiling Test (WBT) and Controlled Cooking Test (CCT) were performed at separate time, on all the three models of the stove.

Water Boiling Test (WBT)

Some quantity of fuelwoods was weighed and recorded for each model of the stove. In addition, cooking pots and lids were weighed and filled up to 2/3 level with a known quantity of water. The pots were appropriately placed on each models of mud stoves and the environmental variables – ambient temperature and wind speed, were measured and recorded. Thermometers were inserted through the top end of pot lids and initial temperatures of the water is measures and recorded
The wood was set on fire with two spoons of kerosene and allowed to burn at a low level. Respective temperatures of water were recorded at a time interval of two minutes until the water attained it boiling point. The lids were removed at water boiling points and water in the pots was allowed to boil and evaporate for fifteen minutes. The remaining water after evaporation were taken. Charcoals from respective stoves were removed; and the same procedures were followed for the other two models of the stove. However, it should be noted that the data were collected simultaneously, just as the experiments were conducted under the same environmental conditions. Outlet chimney temperatures were also recorded. Wood was allowed to burn under the second pot

Controlled Cooking Test (CCT)

In the same vein, some quantity of wood was weighed and recorded for each model of the stove. Some quantity of rice and beans to be cooked were measured; their masses were noted, for each model of the stove. Cooking pots and lids were weighed and filled with some quantity of water that could cook the rice and beans. Respective weights of pot and food items to be cooked were weighed and recorded. The pots were appropriately placed on the top of the models of mud stoves and the ambient temperature and wind speed were measured and recorded.

Thermometers were inserted through the lids for recording the temperature of the water in the pot with initial temperatures of the water noted. The wood set for all the three models of the stove were simultaneously set on fire with two spoons of kerosene and allowed to burn at a low level. The stop watches were set to start running until when the rice and beans were done. The time taken to get food were removed and weighed. The pots were removed from the wood stoves and fire was put off.

Charcoal from respective stoves were removed, allowed to dry and weighed. Outlet chimney temperatures were also recorded. Both WBT and CCT were conducted thrice following the procedures above. Performance analysis of improved fuel wood mud stove were conducted to determine the thermal efficiency of the three models of the wood mud stove. PHU and SFC performance parameters were determined. The PHU and SFC were from:

$$\text{PHU} = \frac{\text{Total Heat Energy Utilised}}{Net\ Heat\ Supplied} \times 100\% \quad (1)$$

$$\text{PHU} = \frac{(M_W C_{PW}(T_W - T_a) + M_P C_P)T_W - T_a) + ML)}{M_{fnet}} \quad (2)$$

Where $M_w is$ Initial mass of water, C_{PW} is Specific heat capacity of water, $T_W is$ Final temperature of water, $T_a\ is$ Initial temperature of water, $M_P\ is$ Mass of Pot, $C_p is$ Specific heat capacity of Pot, M is Mass of evaporated water, L is Latent Heat of Evaporation of water (2,260kj/kg), $M_{fnet}\ is$ Net mass of fuel wood burnt including recovered charcoal and $C_j is$ Calorific value of fuel wood burnt.

$$SFC = \frac{W(1-M)-1.5C}{W_f} \quad (3)$$

Where W is the mass of the fuel wood burnt, M is the moisture content of the wood, C is the mass of the remaining charcoal after test and $W_f is$ mass of the cooked food .

The time spent in cooking 1Kg of cooked food is defined by the expression:

$$\text{Time Spend} = \frac{T}{W_f} \quad (4)$$

Where T is the total time spent in cooking, and $W_f is\ t$otal weight of cooked food.

The different models of the stoves are shown in Figure 1 (a, b, c, d & e).

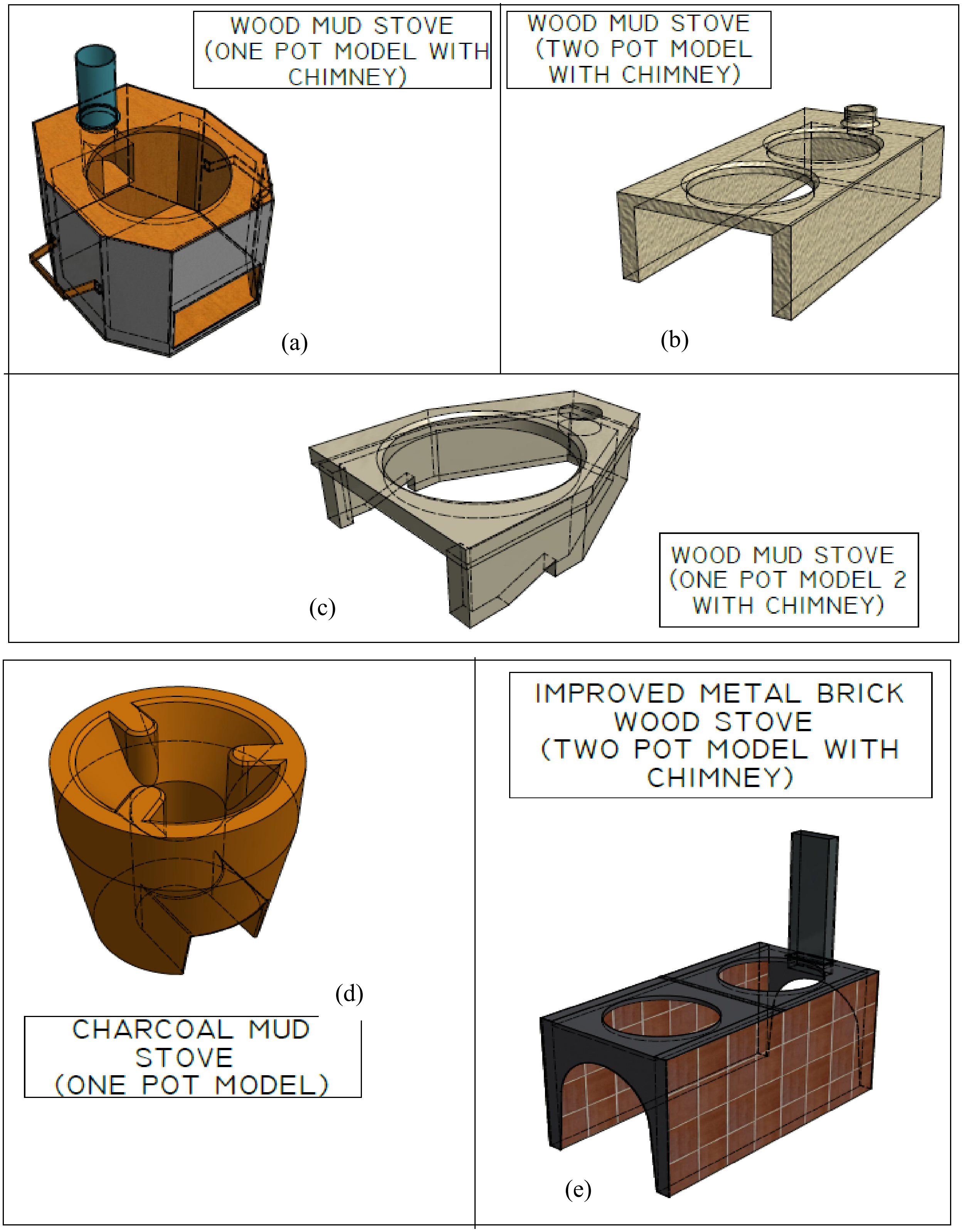


Figure1: Different models of the cooking stove

RESULTS AND DISCUSSION

The mean data obtained for the five models of the stove are presented in the form of charts.

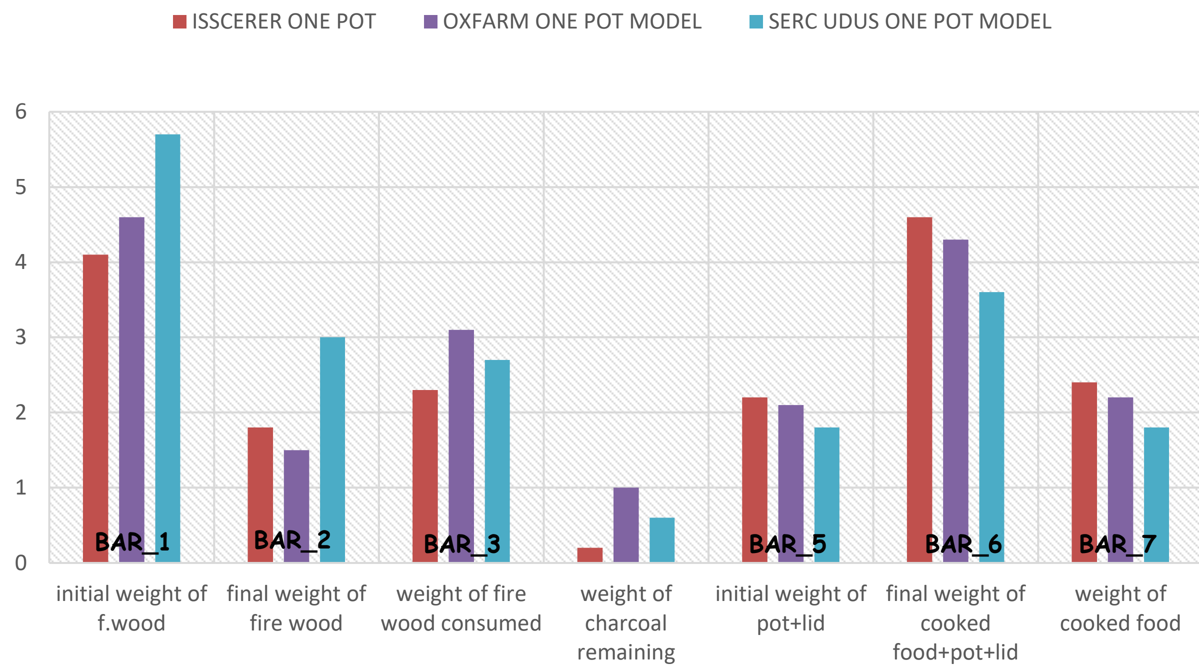


Figure2: Control Cooking Test (CCT) for models of the stove

It is obvious from the result presented in Figure 2 that for CCT, the initial weight of firewood (in kg) is greater for SERC UDUS ONE POT MODEL, compared with other models; then followed by OXFARM one pot model. CeRER one pot model weighs least. This could be used as a measure to determine the capacity or the size of the model for the stove. One may conclude that the greater the amount of initial weight of the firewood, the larger the capacity of the stove.

Comparing the first and second sets of bars from figure 2 (i.e. initial and final weight of firewood), it can be observed that almost all the stove models consumed more than half of the initial weight of the firewood. In summary therefore, all the stove models consumed half of the initial weight of the firewood.

It is also obvious that on average, the weight of firewood consumed for all the stove model superseded the final weight of the firewood.

Finally, the weights of the charcoals remaining are insignificant compared to both initial and final weight of firewood. However, OXFARM one pot model produced larger amount of charcoal (which can also be utilized for either cooking or water boiling).

Furthermore, BAR_5 shows the result for initial weight of pot for the respective stove models. The highest value there goes for CeRER one pot model. The next is OXFAM one pot model; whereas the least is SERC UDUS one pot model. This may also be link to the size of the stove and the amount or the quantity of the food that it may cooked at a time. BAR_6 and BAR_7 translated into that. That is, both final weight of the cooked food+pot+lid and weight of cooked food are maximum for CeRER, then followed by OXFARM. The least for both final weight of the cooked food+pot+lid and weight of cooked food is SERC UDUS one pot model.

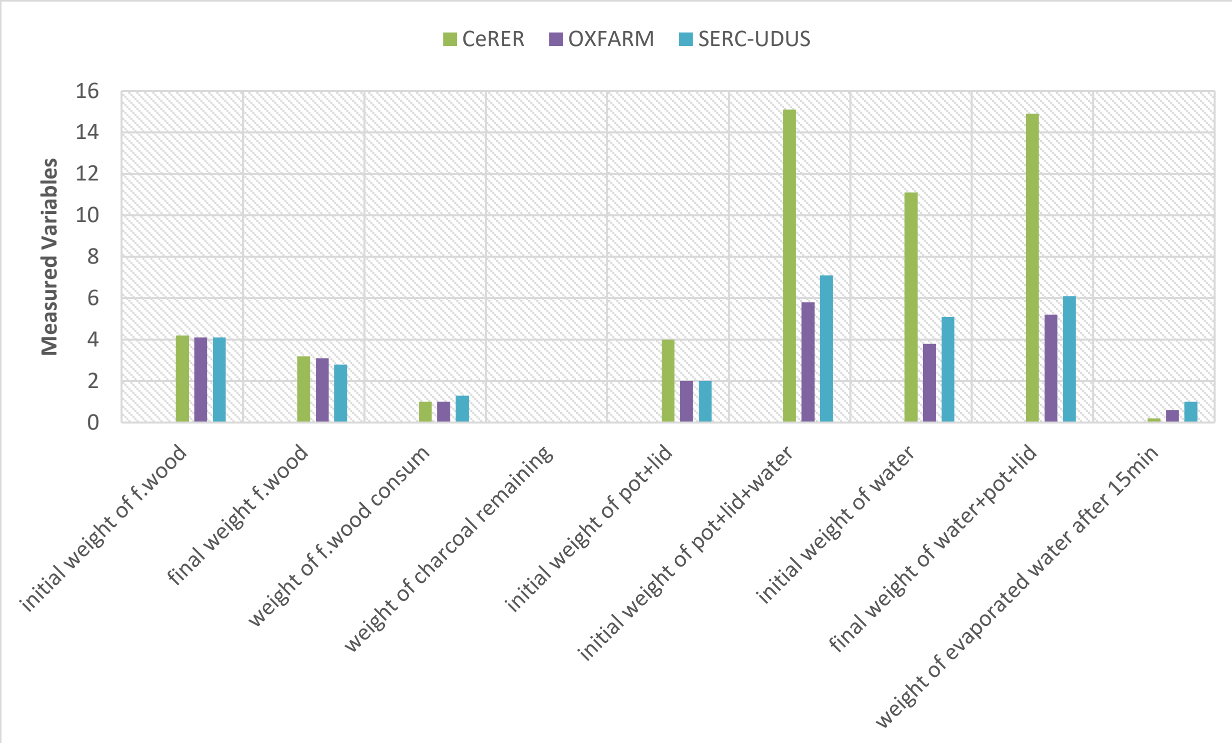
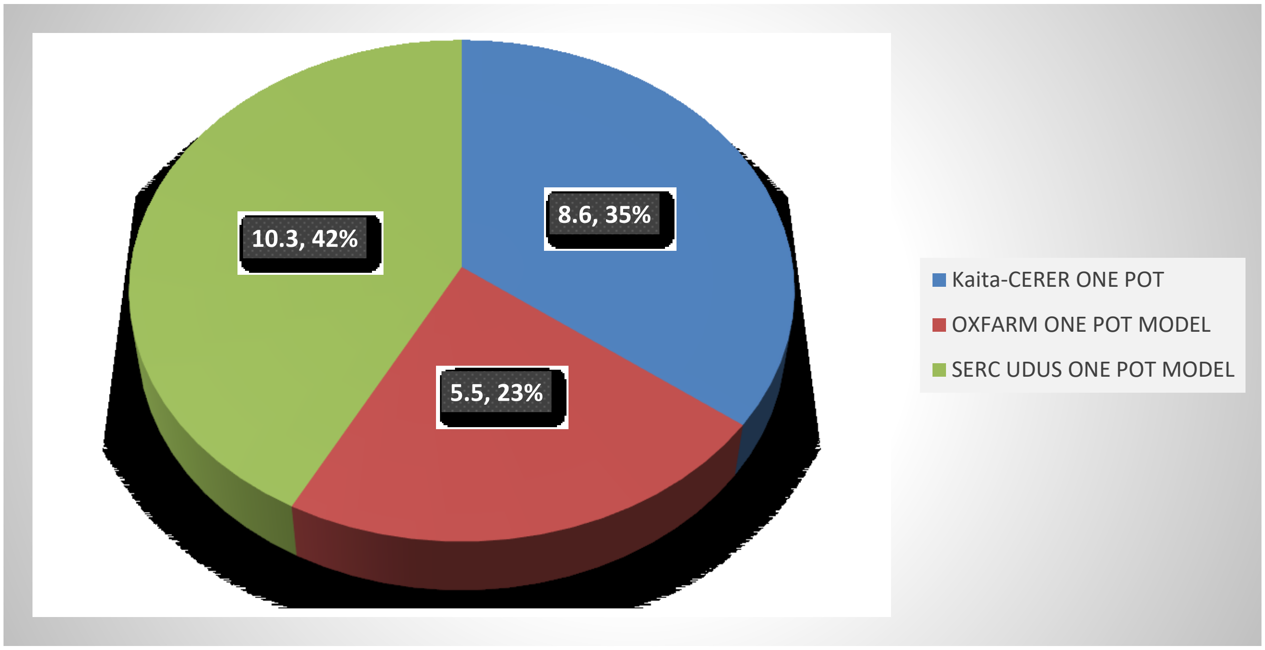


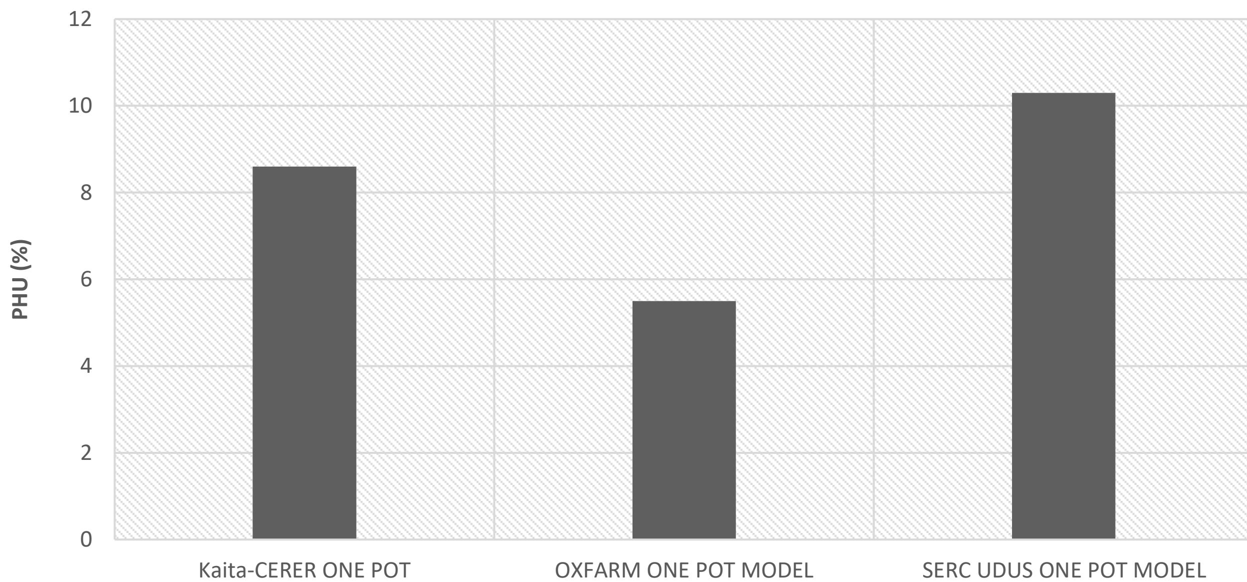
Figure3: Water Boiling Test (WBT) performed on models of stove

The results for WBT is similar to that of CCT except for slight change in initial weights of firewood. This may be attributed to errors due to the weighing instrument that were employed. However, the amount of charcoal produced by WBT is smaller compared with that CCT. In other words, the longer the duration of cooking, the larger the amount of charcoal that would be produced.

Figures 4 and 5 present the same result for percentage heat utilization, PHU on bar chart and pie chart. It could be observed that OXFARM one pot model has the least PHU, whereas SERC UDUS one pot model has the highest. This may translate to the losses associated with the three models of the stoves.



(a)



(b)

Figure 4: Percentage Heat Utilization for different models of stoves

Inspite of the small amount of PHU presented by OXFARM one pot model, the specific fuelwood consumption (SFC) is relatively high, i.e. 0.76, compared to SERC UDUS one pot model with least SFC value of 0.72. The highest SFC is presented by CeRER one pot model.

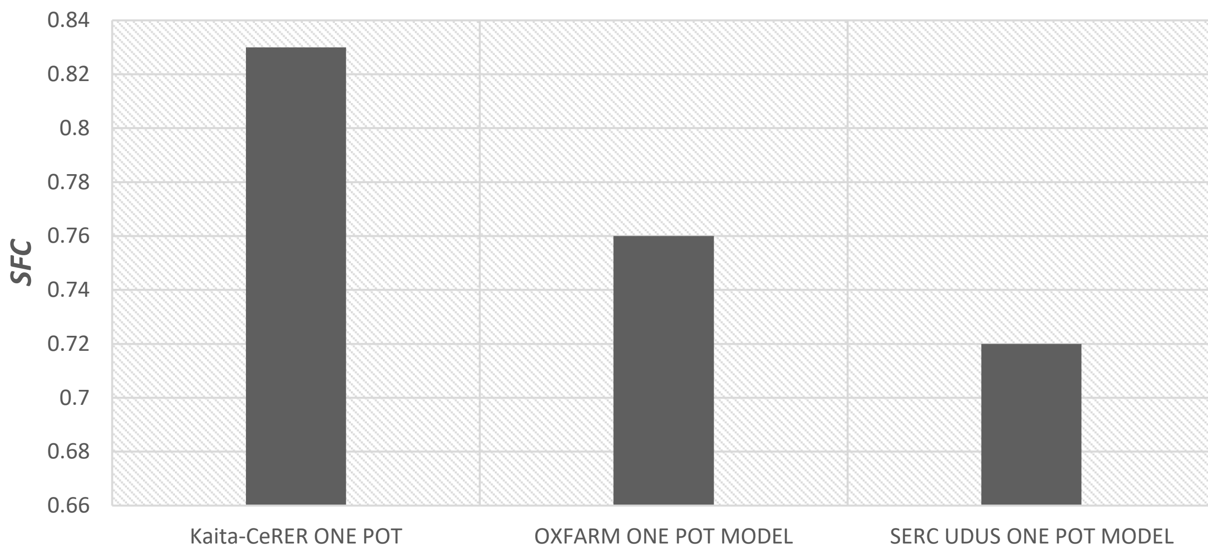


Figure 5: Specifc Fuelwood Consumption for different models of stoves

Though the results shown above indicate good performance value in terms of percentage heat utilization by the stoves, however a lot of improvements needs to consider. OXFARM model in particular, though more robust showed lowest thermal efficiency values for both WBT and CCT. The larger mass of mud that form the stove structure which incorporates the combustion chamber and means of escape of flue gases absorbs a substantial fraction of the useful heat generated during the combustion process that could rather be used in heating the cooking pot and the food item. Also, the pot seating is unsuitable for round bottom type that was used for the tests. In addition, was observed during the test that OXFARM model exhibits higher combustion rate which is desirable but it is an indication more excess than normal supply of air was supply in the combustion process. The effect excessive supply of air is that the content of oxygen takes significant of heat generated thus lowering the heat gain by the cooking pot. Also, there is better air draft was exhibited by the OXFARM model; tremendous amount of heat was lost through unguarded outlet surrounding the periphery of the pot.

It was observed that fire magazine of the OXFARM model is a bit below the required as it can only few number of fuel wood at a time. The same was observed with the model of CeRER with the low PHU. Models with relatively bigger magazine chamber but moderate has exhibits higher PHU and lower SFC. It was generally observed that non – uniform and unsteady rate of combustion process was partly due to non – homogeneous type, shape and size of the fuel wood used for tests.

CONCLUSION

It is shown that the modifications made in providing insulation around the combustion chamber and sizable air inlet to admit adequate quantity of air for combustion, incorporating smoke rings to seal the annulus between the pot and the pot hole, and redesigning the configuration of the pot seat and the position of the flue gas exit port, have served to increase the thermal efficiency and therefore the percentage heat utilization of the stove. There has also been a drastic reduction in the smokiness of the stove, making it to be more user friendly in health, comfort and convenience.

RECOMMENDATIONS

The paper recommends that, further modification on the OXFARM model be focused at redesigning the pot seat vis-à-vis the flue gas exit port in such a way that will minimize heat loss by radiation and convention ensuring maximum heat transfer to the base of the pot can be pursed in future.

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