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Research Paper

Effects of Some Critical Parameters on the Performance of Efficient Wood-Burning Stoves

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ABSTRACT
An investigation on the effects of some critical parameters on the performance of efficient wood-burning stove is carried out in this study.A light weighted pot with a making of Aluminum of about 3.3kg andbase diameter of 30cm was consider for the design of wood-burning stove. The stove diameter was designed to approximately match the diameter of the base diameter of the cooking pot, with chosen length of 28cm, but with its vertical height to be 27cm. The developed system was taken to air-controlled laboratoryof mechanical engineering department of Umaru Ali Shinkafi Polytechnic Sokoto and the tests were conducted.The regulation of airflow by damper has shown its effect on the cookers performance with improved efficiency of the stove and less consumption of the fuelwood for a moderately opened damper. In terms of performance index, the percentage heat utilization, and specific fuelwood consumption of 36.3% and 0.23kg were obtained for stove with baffle. The chimney height integrated stove recorded 37.2% and 0.19kg respectively in terms of percentage heat utilization and specific fuelwood consumption, while the damper – type stove wood consumption stood at 0.2kg with its percentage heat utilization of 39.1%.
KEYWORDS: *fuelwood, stove, damper, energy, biomass*

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I. INTRODUCTION

Sustainable Development Goals (SDGs) agenda is considered as one of the approaches to achieving economic prosperity and social well-being, while simultaneously protecting the environment. The goals seven (7) and thirteen (13) are specifically targeted at: affordable and clean energy and climate change, see Figure 1 (UNDP, ND). Goal 7 is aimed at ensuring access to affordable, reliable, sustainable and modern energy for all. Basically goal 7 is for cheap clean energy supply for home/residential and street lighting, phone charging and computers, and everyday businesses. In addition, electrical energy supply can also be utilized for cooking, water heating and warming.

Figure 1. Sustainable Development Goals

As a result of damages being done to the climate, goal 13 is aimed at taking urgent action to combat climate change and its impacts. The release of greenhouse gases (GHG) is known to be one of the major causes of global warming. Notably, utilization of fossil fuels for energy production is reported to have contributed 72% of share of GHGs emission globally (Oliver and Peters, 2020). Fossil fuels are popularly use for electricity generation (Ken, 2017), which in turn is use for variants of industrial, residential, transport, and agriculture applications. According to Oleg and Ralph (1999), the household sector consumption of primary energy use in the developed nations is between 15 – 25%, and much higher for developing countries. Considering a developed country like United Kingdom, report has indicated that kitchen activities (air handling, lighting, cooking equipment, refrigeration, hot storage, warewashing) accounted for 63% of energy consumption by business area, with about 42% for cooking of food with respect to energy-using activities (Mudie*et al.*, 2013).

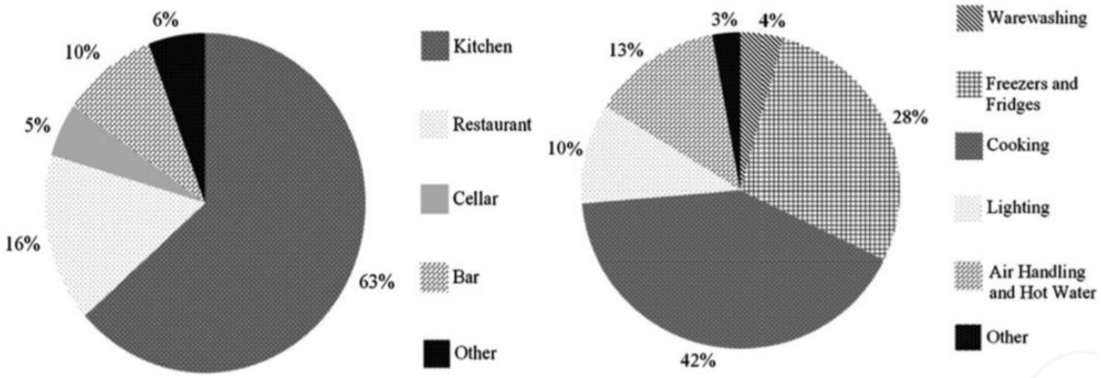

Figure 2. Monitored energy consumption by: business area and function (UK model)

With the established information and the concern for the climate change, especially for developing countries that are much vulnerable to some adverse effects of climate change such as flooding, elevated atmospheric temperature, coupled with the fact that most of these developing nations are ravaged by poverty, no doubt the development of cheap, effective and efficient, environmental friendly system that could serve the purpose of cooking while keeping the environment safe would go a long way in making positive change. Traditionally, cooking is done by burning of fuelwood and crops residues in a fire place known as three-stone stove. This practice has serious limitations in terms of efficiency and unhealthy to the users.

The convenient and efficient improved wood-burning stoves have been developed by many researchers and they have reported significant savings of both fuelwood and time, coupled with the advantages of being less hazardous. In an effort to optimize the efficiency of the wood-burning stoves developed, the effect of some design parameters such as baffle, chimney height on the stove performance have been examined previously. This paper investigates the effect of damper on the overall stove performance.

II. LITERATURE REVIEW

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 cookstoves 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 power delivery of 2,52kW.

I 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.

In an attempt to investigate the energy performance of wood-burning cookstoves in Michoacan, Mexico, three standard protocols were adopted by Victor et al. (2007). These standard protocol include Water Boiling Test (WBT), Controlled Cooking Test (CCT) and Kitchen Performance Test (KPT). The WBT, CCT and KPT results translate to quantifying the thermal efficiency and firepower, measuring the specific energy consumption associated with local cooking task and evaluating the behavior of the stoves in-field conditions and estimates fuels savings.

In 2000, Strehler categorized technical characteristics of wood stoves and wood boliers under furnaces with discontinuous fuel charging and furnaces with automatic fuel charging for wood chips and pellets. Each of the category is further sub-divided into two, that is, stoves and boilers for short logs, briquettes and coarse wood chips & boilers for long wood-logs and small straw bales, and pre-furnace system & boilers integrated wood chips furnaces. This categorization is essential in wood burning stove design as the nature of the biomass materials or its by-product would determine the technicalities of the stove.

Other related work includestudies conducted by Ballard-Tremeer and Jawurek (1996); and McCracken and Smith (1998). Their various studies investigated comparison of five rural, wood-burning cooking devices: efficiencies and emission; and emissions and efficiency of improved woodburning cookstoves in highland Guatemala. Ballard-Tremeer and Jawurek (1996) reported in their study that out of the five stoves (an open fire built on ground; an “improved” open fire built on a raised grate; a one-pot metal stove, a two-pot ceramic stove and a two-pot metal stove) used, average emissions of smoke were lowest for the improved open fire and the two-pot ceramic stove. Emissions of CO and SO_2 were lowest for the two open fires. Average efficiencies were 14% for the open fire, 21% for the improved open fire and 20 – 24% for the stoves.

III. METHODOLOGY

The experiment was setup under the same microclimatic condition for an air controlled environment. Both Water Boiling Test (WBT) and Controlled Cooking Test (CCT) were performed for the different configurations of the cooking stove, that is: baffle, chimney height and damper.

3.1 Water Boiling Test

Thefuelwoods to be used, and the cooking pot with its lidwere weighed and recorded for each configurations (in term of damper, baffle and chimney height) of the stove. The pot is then filled up to 2/3 level with a known quantity of water. The pots werethen tested on eachconfigurations and the environmental variables – ambienttemperature and wind speed, were measured and recorded. Thermometers were inserted through the top end of pot lids and the initial temperature of the water is measured and recorded

The wood was set on fire and allowed to burn at a low level. The 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 procedure was repeated for other configurations.

3.2 Controlled Cooking Test (CCT)

Similar to WBT, some quantity of wood was weighed and recorded for each configuration of the stove. Some quantity of rice to be cooked was measured; their masses were noted, for each configuration of the stove. Cooking pots and lids were weighed and filled with some quantity of water that could cook the rice. Respective weights of pot and food items to be cooked were weighed and recorded. The pots were appropriately placed on the top of the 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 was 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. PHU and SFC performance parameters were determined. The PHU and SFC were from:

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

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

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 thetotal time spent in cooking, and $W_f is\ t$otal weight of cooked food.

IV. RESULTS AND DISCUSSIONS

The performance index evaluation in term of percentage heat utilization for the features: chimney height, damper and baffle for the efficient wood stove is presented in Figure 3

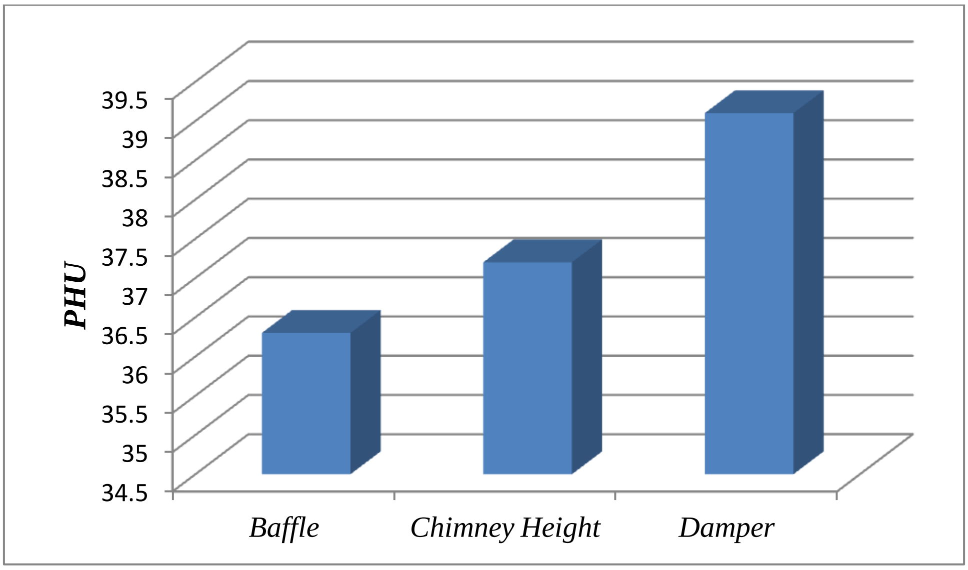

Figure 3. PHU for three different features for the constructed wood stove

The features included in the wood stove have shown different effects on the performance of the woodstove with damper opening at optimum position exhibiting the highest performance heat of utilization and the baffle showing the least with just 36.3% PHU. Figure 4 is a result showing specific fuelwood consumption for features earlier listed

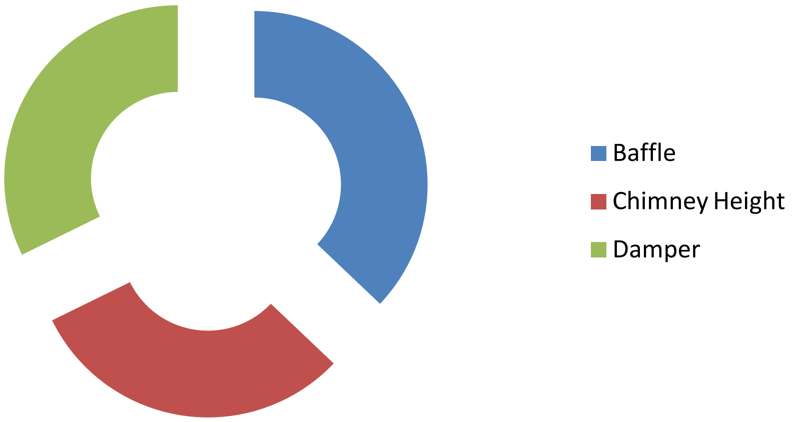

Figure 4. SFC as a function of integrated features in the woodstove

In summary, 0.19kg fuelwood consumption representing 31% of the total fuelwood for the cooking was utilized while the chimney height is integrated. The largest fuelwood was consumed while baffle was integrated, with about 230grams of fuelwood consumption; this represent 37% of the total quantity. Damper-type fuelwood woodstove consumes only 32% of its woodstove. Hence, for more fuelwood to be conserved, the preferred feature to be integrated in the woodstove is chimney height. Figure 5 is a side by side comparison for PHU and SFC.

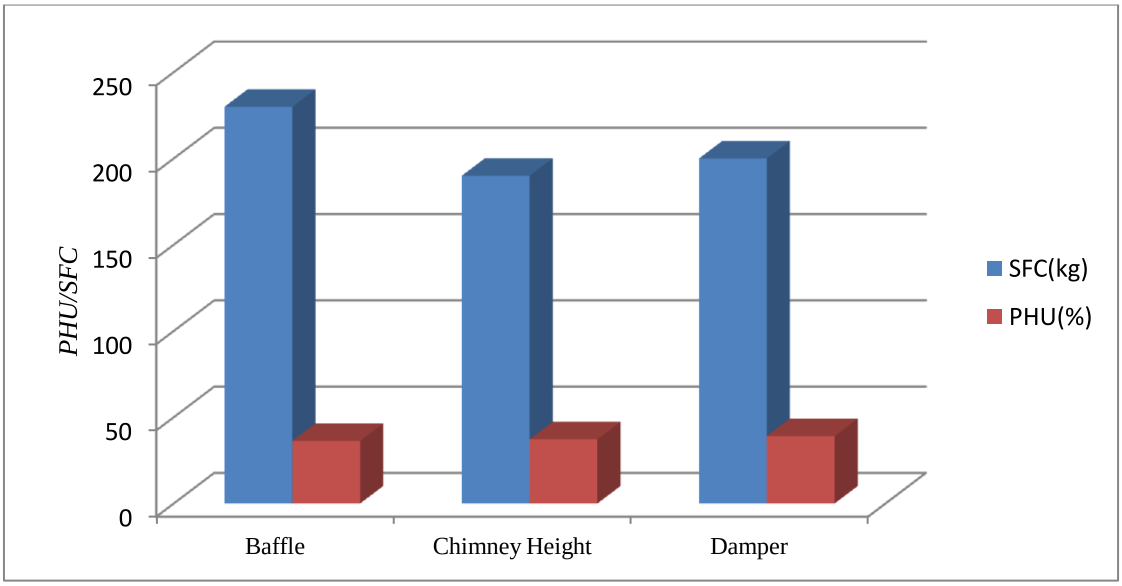

Figure 5. Side by side comparison of PHU and SFC

The given result in figure 5 can be best use to decide on the type of the feature that conserves fuelwood while simultaneously gives the optimum efficiency. The woodstove with baffle is the most effective in terms of heat utilization and fuelwood consumption as it present the highest PHU yet with least SFC.

V. CONCLUSION

The integration of features such as chimney height, baffle and damper is a way of improving on the systems performance in terms of heat utilization and fuelwood consumption. The woodstove with baffle presented the least SFC and highest PHU, indicating the optimum performances in terms of PHU and SFC. The combination of these features can also go a long way to showcase how the combination can influence the performance of the stove.

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