# Evaluation of powered charcoal stove by using different biomass

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**Abstract:** A powered stove was designed to utilized biomass effectively, easy ignition and maintain uniform fire, and reduce cooking time. The stove consists of a blower with hand winder and a fuel carrier. Performance evaluation carried out show that boiling time decreased with increased volumetric air flow rate. For air flow rates of 0.13 $m^3/s$, 0.14 $m^3/s$, and 0.16 $m^3/s$, the time to bring 4.5 L of water to boiling point decreased correspondingly from 14 to 12 and to 10 min. This trend was observed for all the biomass used namely wood, corn cobs and charcoal. However in comparing the three biomasses, it took longer time to bring water to boiling point by using charcoal followed by wood and corn cobs in above mentioned order. The percentage heat utilized and fuel efficiency increased with increase in the volumetric air flow rate. There was no significant difference ($P \geq 0.05$) in the heat utilization and fuel efficiency of wood, corn cobs and charcoal. The results also show that the specific fuel consumption decreased with air flow rate when yam, rice and beans were cooked. On the other hand, time spent for cooking the items increased significantly ($P \leq 0.05$). Also in comparison, the specific charcoal consumption for cooking yam, rice and beans was less followed by wood and corncobs. On the other hand the time spent for cooking the food items was longer by using charcoal followed by wood and corncobs. The results show that when powered the stove performed much better than under natural air flow condition and its efficiency increased with increase in volumetric air flow rate. Corncobs were found to be more suitable replacer of wood for domestic cooking followed by charcoal. The popularization of this stove will alleviate the problem of starting and maintaining fire and reduce over dependence on wood.

**Keywords:** charcoal, stove, biomass, wood fuel, corncobs, airflow rate

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## 1 Introduction

The Food and Agricultural Organization, in the United Nations conference on New and Renewable sources of energy held in Nairobi[1], reported that nearly one billion people are living in regions with acute scarcity or deficit wood supply either by way of monetary out lays on fuel for the urban poor or by way of labour on part of energy gatherers in the rural areas. In developing countries, such as Nigeria, cooking energy accounts for over 2/3 of all the energy used in the rural communities. For the poor developing countries, both urban as well as rural, most of the wood consumed is used for cooking. For the rural people, the dependence on wood is almost total. In India, domestic cooking accounts for 80% of the fuel wood consumption which is 35% of all energy consumed, 80% households use firewood and agricultural wastes for cooking[2]. In Ethiopia, about 93% of the energy consumed is derived from biomass mostly wood and cow dung resources[3].

The demand for fuel wood, which is the most popular source of traditional energy for domestic cooking, is growing much more than supply. The traditional method of cooking which has been used for centuries with little modification involves burning wood in an open fire sometimes enclosed by metallic, clay or bricks to act as wind shield. In most cases, three stones are placed around the fire to act as support for the cooking pots. This method of cooking is very inefficient and a source of health hazard to the users. The performance efficiency of this traditional method is only about 5%-10%[4]. The fire

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wood consumption and the energy cooking requirement are thus relatively high.

Therefore concerted efforts must be made in order to change or modify the traditional methods of cooking with the view to reduce wood consumption, for the sake of protecting the environment with specific reference to desert encroachment, soil erosion and pressure on already depleted forests. This forms the motivation behind the development of domestic stoves. Many designs, styles and sizes of domestic stoves are commercially available in the developing countries. Many countries have made significant progress in developing and disseminating improved wood stoves. Kenya has disseminated over one million improved stoves[5]. Globally, India, China and Kenya are world leaders in the development and use of this technology.

The increasing domestic energy prices for electricity, gas and kerosene coupled with their scarcity have fueled increase in the use of wood fuel in many parts of the world. This in turn has led to much more research interest in biomass burning stoves. The traditional designs are now being improved upon with increase efficiency, less pollution and more full–proof operation[6]. There are also the possibilities of new developments which could be extended into high grade energy supply through domestic scale cogeneration of electricity[7].

The motivation of this research is born from the desire to produce a stove that will efficiently use agricultural wastes as substitute for wood fuel for domestic cooking. Agricultural wastes such as corn cobs, millet stalks, cassava sticks are known to require a long time to decompose in the soil; when left to rot in the fields, they harbour pests and diseases and when burnt on the field they generate a lot of heat which destroys existing microbes in the soil[8,9]. The improved stove is also designed to reduce the difficulty encountered in starting and maintaining fire in the most wood stoves, which usually poses a problem to users by prolonging the time spent in cooking as well as enhance heat utilization. Enhancing the heat utilization capability has directed benefit of drastically reducing biomass consumption; time spent in cooking, increased productivity and provides alternative way for agricultural waste disposal. In this light, the performance evaluation of the powered stove by using different biomass is desirable.

The objectives of this work are: To determine the percentage heat utilized of a fabricated powered stove by using different biomasses and airflow rates; To determine the specific fuel consumption and the time spent in cooking three food items by using different biomasses and air flow rate.

## 2 Materials and methods

In order to investigate the performance of the powered charcoal stove, experimental tests were carried out on water boiling and controlled cooking of certain locally eaten dishes such as rice, beans and yam. The two sets of tests; water boiling and controlled cooking, were based on the provisional international standards in comparing and evaluating the performance of the stove.

### 2.1 Materials and apparatus

The materials and apparatus included in the performance tests are listed below: Pot, water, fuels (wood, charcoal, corn cobs and saw dust), food items (rice, yam and beans), weighing balance, mercury- in- glass thermometer, stop watch, measuring cylinder, matches

### 2.2 Experimental methods and procedures

The performance of the powered charcoal stove was evaluated by using the following methods: Water Boiling Test (WBT), Controlled Cooking Test (CCT).

#### 2.2.1 Water Boiling Test (WBT)

This is a short and simple laboratory simulation of standard cooking procedures recommended to stove designers, research organizations and field workers[10]. It is used for quick investigation of the performance of stoves under different operating conditions. It is equally possible to use WBT results to judge the suitability of a stove for various cooking tasks. The test is made up of two major segments or phases.

The first segment which is usually referred to as the high power phase involves recording the temperature of a measured quantity of water at regular interval of time as it is from ambient temperature to boiling at the same high power for 15 min. The lower phase follows in which power is reduced to the lowest level needed to keep the water simmering within 2℃ of boiling over a 30 min period.

Detail of the procedures followed in carrying out the water boiling test was as follows:

Specific amount of fuel was weighed. The pot and lid was weighed and filled with water to about 75% of its volumetric capacity. The thermometer was inserted through the lid. Small quantity of saw dust was poured on the charcoal carrier and the fuel to be used was poured on top and ignited using matches. The power was switched on and the temperature of the water was monitored after every two minutes interval until the water boiled to 98℃. Fire was reduced and maintained at a level just sufficient to keep the water simmering for 30 min. Fire was put out. The weight of the unused fuel and that of charcoal (if any) were recorded. The weight of the pot with the remaining content was recorded. Thus for the water boiling test; the heat computation equation for single hole biomass burning stove is as follows:

Heat given by fuel = weight of fuel consumed × calorific value of fuel.

Heat obtained from recovered charcoal = weight of charcoal × calorific value of charcoal. Net heat supplied to stove = Heat given by fuel used – Heat obtained from recovered charcoal. Heat utilized in raising water temperature = weight of water heated × temperature difference × specific heat of water. Heat utilized in evaporation of water = weight of water evaporated × latent heat of vaporization of water. Heat used in raising pot temperature = weight of pot × temperature difference × specific heat of material of the pot.

Total heat utilized = Heat utilized in raising water temperature + Heat utilized in evaporation of water + Heat used in raising pot temperature.

Percentage Heat Utilized (PHU) = Total heat utilized divide by net heat supplied × 100%.

$$PHU = \frac{M_p C_p \left(t_p - t_c\right) + M_w C_w \left(t_w - t_c\right) + M_v L}{M_f B_f - M_c B_c} \times 100\%$$

Where, $M_p$ = mass of empty pot with lid, kg; $C_p$ = specific heat capacity of pot material, kJ/(kg·K); $t_c$ = Initial temperature of pot with water, ℃; $t_p$ = final temperature of pot, ℃; $t_w$ = final temperature of water, ℃; $M_w$ = initial mass of water, kg; $C_w$ = specific heat capacity of water, kJ/(kg·K); $M_v$ = mass of water evaporated, kg; $L$ = latent heat of vaporization of water, kJ/(kg·K); $M_f$ = mass of fuel burnt, kg; $B_f$ = calorific value of fuel, kJ/kg; $M_c$ = mass of charcoal recovered, kg; $B_c$ = Calorific value of charcoal, kJ/kg.

The results from the water boiling test were used to calculate the degree of fuel efficiency ($n_f$) for the different operating conditions of the powered stove as recorded by Micuta[10]. The degree of fuel efficiency provides an excellent means for visual appreciation of the relative values of the stoves being tested.

The Eindhoven formula was employed to determine the degree of fuel efficiency. The degree of fuel efficiency figure is an indication emphasis on the importance of a cooking system which apart from stoves and fuels also includes the cooking pots.

The formula express degree of fuel efficiency ($n_f$), for stoves as:

$$n_f = \frac{M_w c(t_b - t_l) + M_v R}{M_F B}$$

Where, $n_f$ = fuel efficiency rate; $M_w$ = Initial mass of water in the pot, kg; $M_f$ = mass of water evaporated during the experiment, kg; $c$ = specific heat capacity of water, kJ/(kg·K); $t_b$ = final temperature of water, ℃; $R$ = latent heat of vaporization of water, kJ/(kg·K); $B_f$ = calorific value of fuel, kJ/kg.

### 2.2.2 Controlled Cooking Test (CCT)

The controlled cooking test comprises a series of cooking experiments aimed at determining certain parameters that are specific to the stove system it can also be used to compare the performance of various fuels in a given stove. It can also effectively determine whether the stove can cook a variety of meals usually prepared in a particular locality. The tests were carried out with a variety of food items such as rice, beans and yam.

Detail of the procedures followed in carrying out the controlled cooking test is as follows:

Specific amount of fuel was weighed. Mass of empty pot with lid was weighed and recorded. One kilogram of the food item was weighed and poured into the pot. Fire was started as in the WBT and the fan switched on and the stop watch was also started. When the food item was cooked, the pot was brought down and the fire put out and the time was stopped.

The mass of the pot with cooked food was recorded. The mass of the fuel burnt was determined and recorded. The controlled cooking test enabled the determination of the following parameters.

2.2.3 Specific Fuel Consumption (SFC)

The expression of the quantity of fuel consumed per unit mass of cooked food is given by:

SFC = Mass of fuel consumed

Total mass of cooked food

$$S.F.C = \frac{M_F(1-X)-1.5M_c}{M_K - M_P}$$

Where, $M_F$ = mass of fuel burnt, kg; $M_p$ = mass of pot with lid, kg; $M_k$ = mass of pot with lid and cooked food, kg; $X$ = moisture content of fuel used; $M_c$ = mass of charcoal recovered, kg.

2.2.4 Specific Time (ST)

This refers to the average time spent per unit mass of food cooked on the stove and is given by the relation:

ST = Total time spent in cooking

Total mass of cooked food

$$S.T = \frac{t_s}{M_{KF}}$$

Where, $t_s$ = total time spent in cooking, min; $M_{kF}$ = total mass of cooked food, kg.

2.2.5 Determination of the volumetric air flow rate

Before the commencement of both tests; water boiling and controlled cooking, the volumetric flow rate of air produced by the fan in the blower unit was determined by using the tachometer at the three different speeds.

The tachometer was switched on and its light was pointed directly at the centre of the rotating shaft. The result of the tachometer reading (Fan speed in m/min) was displayed digitally. The volume flow of air, V, was determined from the relation[11].

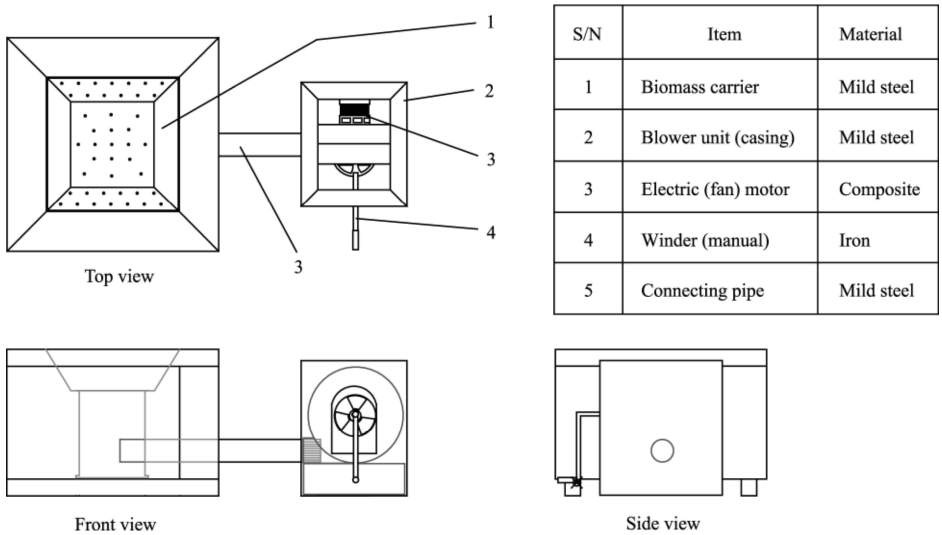
Volumetric air flow rate = fan speed × area of the connecting pipe.

$$V = nA$$

Where, $V$ = volumetric air flow rate, $m^3/s$; $n$ = speed of the fan, m/s; $A$ = diameter of the fan impeller, m.

2.2.6 Description of stove

Figure 1 is a third angle projection of the stove configurations. It was made from mild steel metal. The blower unit is fitted with a fan which can be regulated at different speeds by using electrical energy. A provision for a manual winding key is also made on the blower.




| S/N | Item | Material |
|---|---|---|
| 1 | Biomass carrier | Mild steel |
| 2 | Blower unit (casing) | Mild steel |
| 3 | Electric (fan) motor | Composite |
| 4 | Winder (manual) | Iron |
| 5 | Connecting pipe | Mild steel |

Figure 1 Assembly drawing of stove in the third angle projection

2.2.7 Heat analysis of stoves

From open fire cooking there are some inevitable losses of heat generated and only a fraction gets transferred to the cooking pot. As for enclosed and thick or insulated stoves the loss of heat generated is comparatively reduced thereby raising the efficiency of a fuel for cooking. As soon as the fuel is kindled, the stove body along with the water in the cooking pot starts getting the heat so generated. Depending on the relative thermal capacities of the stove and the cooking pot containing water each will reach a steady state one after the other. The heat analysis of the energy balance and efficiency in both get simplified, the rate of useful energy transferred being just proportional to the rate of evaporation of water. This will lead to meaningful efficiency figure only if the energy used up in the non–steady phase to heat up the stove is negligible.

When solid biomass fuel is burnt in a stove, the effective heat, $\Delta H_e$, available from a fuel per unit weight is given by[4,6,12]:

$$\Delta H_e = \Delta H_{nd}\frac{100M}{100} - \frac{LM}{100} - \Delta H_{CH}\frac{W_{CH}}{100} - \Delta H_{CO}(CO) - \Delta H_2(H_2) \quad (1)$$

Where, $\Delta H_{nd}$ = net calorific value on dry weight basis, kJ/kg; $M$ = moisture of water in the fuel, %; $L$= the latent heat of vaporization of water, kJ/(kg·K); $W_{CH}$ = the heat of combustion of charcoal on dry weight basis, kJ/kg; and $\Delta H_{CO,}$ $\Delta H_2$ = the heat of combustion of co and $H_2$ in, kJ/kg.

Heat release rate which is also the power of the stove is simply given by:

$$Q = M\Delta H_e \quad (2)$$

Where, $H_e$ = the calorific value of the fuel used, kJ/kg.

Guided by some experimental measurements on heat balance in stoves and some known facts about fuel wood combustion, this heat release rate may be put as:

$$M\Delta H_e = Q_k + M\Delta H_e(Q_{ls}+Q_{lg}+Q_{lv})+MQ_{lg} \quad (3)$$

Where, $Q_k$ = useful heat transfer rate to the cooking pot; $Q_{ls}$ = rate of heat loss from the fire box to the atmosphere; $Q_{lg}$ = rate of heat loss to the surrounding from the stove body under fire box; $Q_{lv}$ = rate of heat loss from the cooking pot to surrounding; $MQ_{lg}$ = rate of heat loss as sensible heat loss in the outgoing combustion gases.

From the above expression, the efficiency of the stove system is the ratio of useful heat, $Q_K$, to heat release rate $Q = M\Delta H_e$ while other terms involve losses from the stove and other parameters. So the greater the $Q_K$ will be, the greater the efficiency.

Estimating each of these terms one by one starting with $Q_K$ we have:

Estimation of heat transfer to the cooking pot: $Q_K$

The rate of heat transfer, $Q_K$, to the cooking pot given by:

$$Q_K = U_{AV}(T_g - T_w) \quad (4)$$

Where, $U$ = overall heat transfer coefficient related to its components by the relation

$$1/U = 1/(U_g + U_r) + S_m/K_m + 1/U_{wt}$$

Where, $U$ and $U_{wt}$ are convective heat transfer coefficients of the hot combustion gases and water respectively[13]; $U_r$ = radiative heat transfer coefficient; $S_m$ = thickness of the stove; $K_m$ = material of the stove conductivity; $A_v$ = Area of the pot bottom, And $S_m/K_m$ and $1/U_{wt}$ are considered negligible as compared to $U_g$, $U_g$ can be expressed in terms of overall gaseous conductivity $K_v$, the Nusselt number NU, and characteristic length i.e. radius of pot and that of firebox as:

$$U_g = K_v\frac{N_u}{d}$$

This when substituted into (4) we have:

$$Q_k = \frac{K_v}{d}N_u A_v(T_g - T_w) + U_r A_v(T_g - T_w) \quad (5)$$

Where, $T_g$ and $T_w$ are gaseous and water temperatures respectively.

Estimation of the heat loss through the walls of the firebox to the ambient is given by:

$$Q_{Ls} = A_s U_s (T_g - T_a) \quad (6)$$

Where, $A_s$ = total inside area of the surface of the walls; $U_s$ = the overall heat transfer coefficient given by:

$$\frac{1}{U_s} = \frac{X_s}{K_s} + \frac{X_m}{K_m}$$

$\frac{X_s}{X_m}$ , $K_s$ and $K_m$ being the thickness and thermal conductivities of the metal and insulating material of the stove wall respectively.

$\frac{X_m}{K_m}$ is retaining wall normally negligible and $\frac{X_s}{K_s}$ is rather considered as important ratio. $T_g$, $T_a$ are flue gases and outside temperature respectively.

Estimation of heat loss from the cooking vessel to the ambient $Q_w$ is given by

$$Q_w = U(T_w - T_a)A_{v3} = (U_c + U_r)(T_w - T_a)A_{v3} \quad (7)$$

Where, $U_c$ and $U_r$ are convective and radiative heat transfer coefficients and $T_w$ and $T_a$ are water and ambient temperatures respectively.

Estimation of the energy loss as sensible heat of the product gases.

From the Equation (3), The energy flux of the outgoing gases represented by $MQ_{Lg}$ is given by:

$$MQ_{Lg} = MZ_{mi}H_{ig} \tag{8}$$

$M_i$ is the entropy increase per unit weight of the component from the initial temperature $T$ to the final temperature $T_g$ of the fire. Therefore, the enthalpies in general are given by:

$$H_i = C_{pig}\Delta_T = C_{pig} \quad T = C_{pig}(T - T_a) \tag{9}$$

$C_p$ = average specific heat at constant pressure between two temperature limits.

The expression for $Q_{Lg}$ can be written as:

$$MQ_{Lg} = MC_{pig}M_i(T_g - T_a) \tag{10}$$

From above equation, if we assumed complete stoichiometry, the products will consist of $CO_2$, $H_2O$, $O_2$ and $N_2$ will be independent of temperature. However, the products are expected to contain CO and $H_2$ even the air available is theoretically minimum or a few times this quantity.

The ratio of the heat flux of the out going gases to heat release rate is independent of the burning rate. Since the burning rate $M$ is connected to stove parameters like size of the firebox, height of the side opening etc. hence the result would imply that, the heat flux of the outgoing gases is the same for all stoves.

2.2.8 Efficiency definition

The absolute efficiency $Z_a$ is defined as follows in a biomass burning stove.

$$Z_a = \frac{E_F + E_W}{E_N} \tag{11}$$

Where, $E_F$ = energy absorbed by food, kJ; $E_W$ = sensible heat of water, kJ; $E_N$ = wet Energy consumed, kJ.

However, this definition neglects the energy requirement to keep the water simmering at 90℃. Secondly, experimental measurements of efficiency based on efficiency estimation in a pot- stove system consist in heating a few kilogram of water on the stove in a metallic pot diameter comparable to that of the fire box and height such that, it is about half full, involves the use of the following:

The average heat release rate

$$Q = \frac{(M_f - Mi)}{t}\Delta H_e \tag{12}$$

Where, $M_f$ = the total mass of the fuel burnt, kg; $M_i$ = mass of the last charge, kg; $t$ = time interval of start to the feeding of the last charge, min; $H_e$ = calorific value of fuel used, kJ/kg.

Amount of heat absorbed by water

$$Q_{gw} = M_wC_{pw}(T_w - T_a) + M_{ev}L \tag{13}$$

Where, $M_w$ = the initial amount of water in the pot, kg; $C_{pw}$ = specific heat of water, kJ/(kg·K); $T_w$ = the boiling temperature of water; $T_a$ = Initial temperature of water; $L$ = latent heat of vaporization of water, kJ/(kg·K); $M_{ev}$ = amount of water evaporated, kg.

Neglecting the first term of the above equation and the experiment conducted after the water has started boiling and noting the rate of water boiling away over a certain period of time; it leads to efficiency definition as follows:

$$Z = \frac{Q_{gw}}{Q} \tag{14}$$

Where, $Q_{gw}$ and $Q$, as defined above.

## 3 Results and discussion

### 3.1 Water boiling test

Figures 2 to 4 show changes in temperature during water boiling by using powered stove and different biomass. The temperature − time graphs are characterized by slow temperature rise in the first few minutes of the experiment, followed by a sharp rise to 98℃ which was maintained for the remaining time of the experiment. A good proportion of the heat supplied at the initial stages of the experiment was absorbed by the stove material and water as sensible heat accounting for the slow rise in water temperature. When the fire was fully established and all parts of the stove attained steady state heat, water temperature rose rapidly to reach the peak and stabilized, corresponding to the maximum rate of heat absorption.

Figure 2 shows that while burning wood at volumetric air flow rates of 0.16 m$^3$/s, 0.14 m$^3$/s and 0.13 m$^3$/s, it took 10, 12 and 14 min respectively to bring 4.5 L of water to boiling point. With manual winding of volumetric flow rate of 0.09 m$^3$/s, it took 22 min. For natural air flow rate, a situation akin to 'Abacha Stove', it took 36 min. This result indicates that when the stove was powered shorter time was taken to boil water. Increase in air flow rate resulted in better combustion and greater heat supply. The air assisted in directing the flames from the fire to the bottom of the pot, thereby supplying intense heat, which rapidly brought the water to boiling point. Manual winding took longer time, while the natural air flow ‘Abacha Stove’ condition took the longest time to bring the water to a boil. The low air flow rates in the manual winding as well as natural conditions did not favour easy combustion of the biomasses and performed minimally with low heat output. These findings were consistent with Micuta[10] who reported that to ensure proper combustion in the fire box, it is necessary to provide an adequate, but not excessive supply of air.

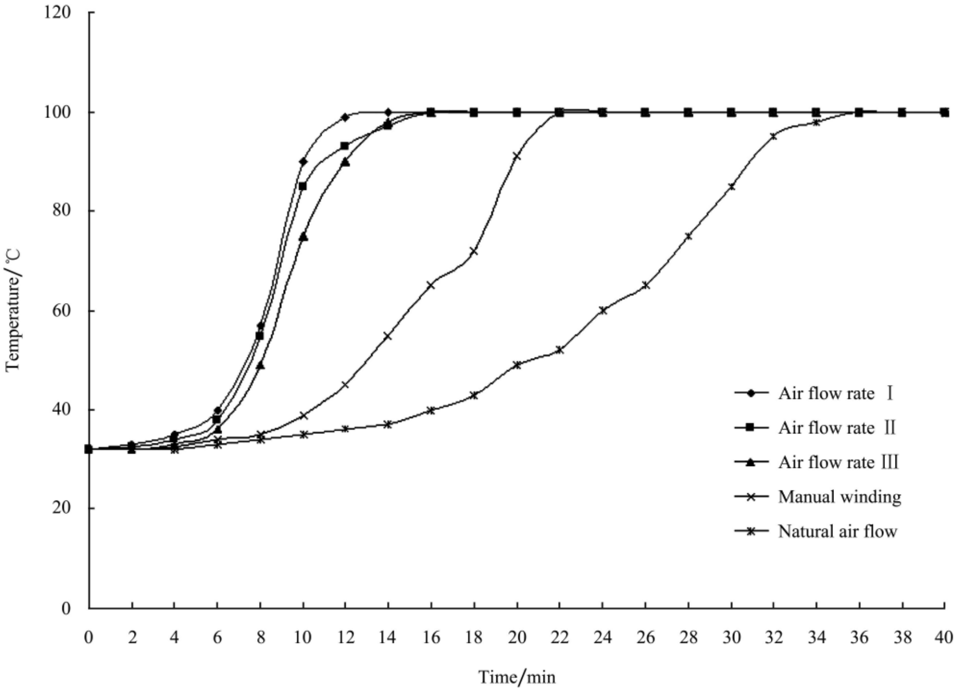



Figure 2 Plot of variation of water temperature with time at different air flow rates burning wood

In Figure 3 the performance of the powered stove for water boiling test using corn cobs followed the same trend with that of wood fuel. However at the same volumetric air flow rate, it took longer time to bring 4.5 L of water to boiling point when corncobs were used. For example whereas it took 10, 12, and 14 min corresponding to air flow rates of 0.16, 0.14 and 0.13 $m^3$/s respectively to bring 4.5 L of water to boiling point by using wood, it took more time of 12, 14 and 16 min correspondingly by using corn cobs at the same volumetric air flow rates. The same trend was observed with manual winding and natural air flow. The longer time taken to bring water to boiling point by using corn cobs could be due to its low calorific value[14] and inability to produce strong flame during combustion compared to wood fuel. Also corn cobs tend to burn faster producing much ash which tends to clog air holes on the fuel carrier thereby retarding the penetration and circulation of air for proper combustion of corncobs.

Shown in Figure 4 are the temperature variation curves of the boiling water test by using charcoal as fuel in the firebox. It took 20, 22 and 28 min corresponding to volumetric air flow rate of 0.16 $m^3$/s, 0.14 $m^3$/s, and 0.13 $m^3$/s respectively to bring water to boiling point. For manual winding of 0.09 $m^3$/s volumetric air flow rate, it took 35 min, while 78 min were required when the stove was used with natural air flow condition.

Comparing the three biomasses, it took longer time to bring water to boiling point by charcoal followed by wood and corn cobs. This may be attributed to the fact that charcoal burns more slowly with low flame, even though it has a high calorific value. These findings are consistent with the Kuteesakwe[12] who reported that it takes more air to completely burn one kilogram of charcoal than one kilogram of wood. It is however imagined that for long time cooking charcoal fire will be more sustaining and effective compared with the other biomasses studied.

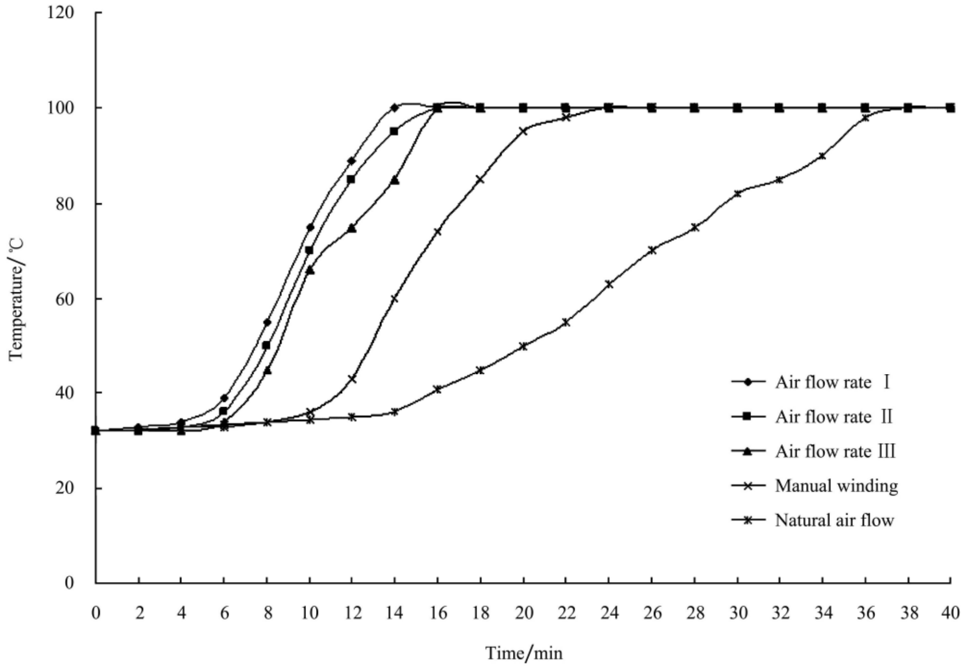



Figure 3 Variation of water temperature with time at different volumetric air flow rate burning corn cobs

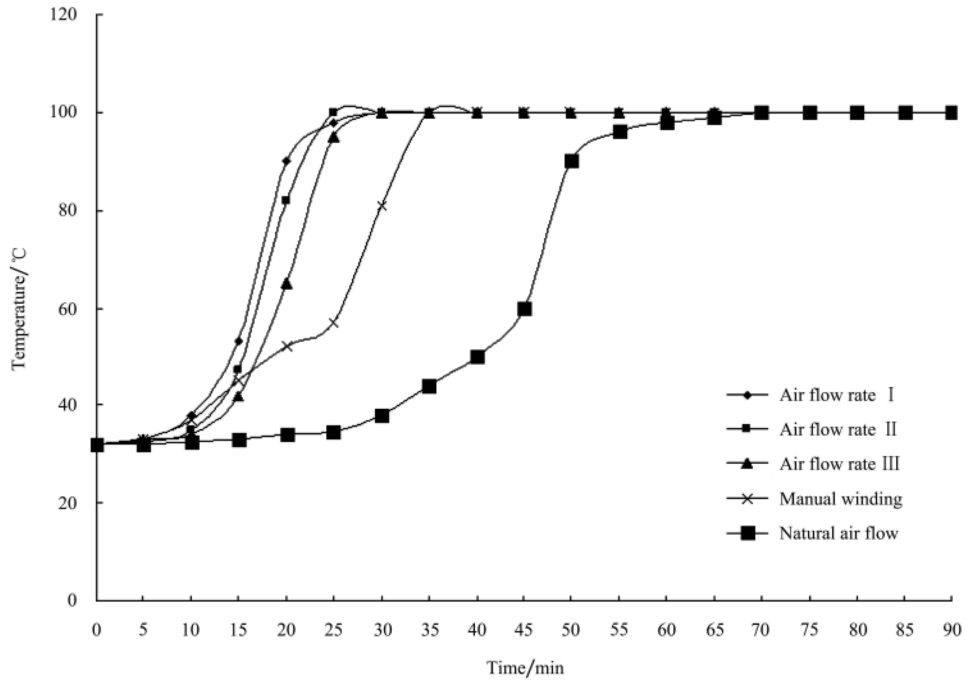



Figure 4 Plot of variation of water temperature with time at different air flow rates burning charcoal

The time taken to boil 4.5 L of water on the powered stove is comparatively shorter than most of the biomass burning stoves reported in literature. Awulu[15], found while evaluating the performance of an improved fuel wood stove that 4 L of water was brought to boil in 39 min. Akinbode[7], while testing the efficiency of Nigerian wood stoves found that metal tripod, metal cylinder, clay type and three-stone, open fire took 24, 40, 50 and 55 min respectively to bring 4 L of water to boil.

Table 1 shows the percentage of the heat utilized by the powered stove while burning wood, corn cobs and charcoal. The results indicate that the percentage of the heat utilized decreased with volumetric air flow rate irrespective of biomass. For air flow rate of 0.16 $m^3/s$, the percentage of the heat utilized was 42.02%, 38.93% and 30.53% for wood, corn cobs and charcoal respectively.

These values were generally higher than 35.74%, 33.60% and 28.48% when the air flow rate was 0.13 $m^3/s$. For all the biomasses used, the lowest heat utilization was recorded under natural air flow condition followed by manual winding. Table 3 also shows that at any given flow rate there was no significant difference ($P \geq 0.05$) in heat utilization between wood, corn cobs and charcoal.

**Table 1 Percentage of the heat utilized**

| | | | |
|---|---|---|---|
| NA | 19.44[a] | 18.21[a] | 13.51[a] |

Note: Means with the same superscript along the row are not significantly at $P<0.05$ level of significance. MW = Manual winding, NA = Natural air flow.

Table 2 shows the degree of fuel efficiency. Results from the table indicate slight variation in the degree of fuel efficiency with volumetric air flow rate for all the biomass used, and followed the same trend with percent heat utilization. For 0.16 $m^3/s$ air flow rate, the degrees of fuel efficiency of wood was 0.478, corn cobs was 0.316 and charcoal 0.287. However for air flow of 0.13 $m^3/s$, the degree of fuel efficiency was 0.421 for wood, 0.305 for corn cobs and 0.250 for charcoal, showing a slight decrease with decrease in air flow rate. The lowest degree of fuel efficiency value of 0.051 was recorded for natural air flow when charcoal was used. Even though the degree of fuel efficiency of wood was the highest for all the air flow rates studied, there was no statistical difference ($P \geq 0.05$) between the biomass.

**Table 2 Degree of fuel efficiency**

| Volumetric air flow rate /$m^3 \cdot s^{-1}$ | Biomass | | |
|---|---|---|---|
| | Wood | Corn cobs | Charcoal |
| 0.16 | 0.478[a] | 0.316[a] | 0.287[a] |
| 0.14 | 0.425[a] | 0.313[a] | 0.263 |
| 0.13 | 0.421[a] | 0.305[a] | 0.250[a] |
| 0.09MW | 0.351[a] | 0.274[a] | 0.214[a] |
| NA | 0.136[a] | 0.094[a] | 0.051[a] |

Note: Means with the same subscript along g the row are not significantly different at $P$=0.05 level of significance. MW=Manual winding, NA=Natural air flow rate.

## 3.2 Specific fuel consumption and specific time spent

Table 3 shows both the Specific Fuel Consumption (SFC) and Time Spent (TS) for cooking yam, rice and beans at different air flow rates by using wood fuel. The specific fuel consumption decreased while the time spent for cooking increased with decrease in volumetric flow rate for the food materials studied. For yam cooking, specific fuel consumption was 0.389 for air flow rate of 0.16 $m^3/s$, 0.239 for hand winding (0.09 $m^3/s$) and 0.169 natural air flow, showing a decrease with volumetric air flow. On the other hand the time spent for cooking increased from 8.80 min to 15.68 min and 20.88 min corresponding to 0.16 $m^3/s$, hand winding (0.09 $m^3/s$) and natural air flow respectively.

**Table 3 Average specific wood consumption (kg wood/kg cooked food) and specific time spent (min/kg cooked food)**

| Food item parameter | Volumetric air flow rate/$m^3 \cdot s^{-1}$ | | | | |
|---|---|---|---|---|---|
| | 0.16 | 0.14 | 0.13 | 0.09mw | NA |
| SWC YAM TS | 0.389* | 0.359* | 0.334* | 0.239* | 0.169* |
| | 8.80[a] | 10.71[a] | 11.26[a] | 15.68[b] | 20.88[C] |
| SWC RICE TS | 0.422* | 0.407* | 0.378* | 0.314* | 0.254* |
| | 10.15[a] | 11.38[a] | 12.34[a] | 15.85[b] | 22.76[c] |
| SWC BEANS TS | 1.153* | 1.101* | 1.036* | 1.009* | 0.939* |
| | 27.29[a] | 28.92[a] | 31.39[a] | 38.51[b] | 46.11[c] |

Note: Means with same superscript along the row are not significantly different at $P<0.05$ level of significant. TS = Time spent, SWC = Specific wood consumption, Mw = manual winding, Na = natural air flow.

Statistically however, there was no significant difference ($P \geq 0.05$) in the specific fuel consumption during yam cooking at the air flow rates studied. Table 4 revealed that variation in the volumetric air flow from 0.16 $m^3/s$ to 0.13 $m^3/s$ did not significantly ($P \geq 0.05$) affect specific time spent for cooking yam, however there was significant difference ($P \leq 0.05$) between the range of volumetric air flow and both hand winding and natural air flow conditions. This indicates that at low or no fan speed, combustion is low and less biomass is consumed

**Table 4 Average specific corn cobs consumption (kg corn cobs/kg cooked food) and specific time spent (min/kg cooked food)**

| Food item parameter | Volumetric air flow rate/$m^3 \cdot s^{-1}$ | | | | |
|---|---|---|---|---|---|
| | 0.16 | 0.14 | 0.13 | 0.09MW | NA |
| SCCC YAM TS | 0.473* | 0.465* | 0.446* | 0.349* | 0.262* |
| | 10.41[a] | 11.68[a] | 12.30[a] | 17.01[b] | 22.93[C] |
| SCCC RICE TS | 0.499* | 0.472* | 0.499* | 0.349* | 0.274* |
| | 12.44[a] | 14.15[a] | 15.58[a] | 21.10[b] | 25.60[c] |
| SCCC BEANS TS | 1.528* | 1.500* | 1.440* | 1.259* | 1.089* |
| | 30.23[a] | 31.23[a] | 31.88[a] | 46.01[b] | 62.44[c] |

Note: Means with same superscript along the row are not significantly different at $P< 0.05$ level of significance. TS=Time spent, SCCC=Specific corn cobs consumption, MW=Manual winding, NA=Natural air flow.

resulting in more time required for cooking. The same trend was observed for rice and beans cooking as shown in Tables 4 and 5.

**Table 5 Average specific charcoal consumption (kg charcoal/kg cooked food) and specific time spent (min/kg cooked food)**

| Food item parameter | Volumetric air flow rate/$m^3 \cdot s^{-1}$ | | | | |
|---|---|---|---|---|---|
| | 0.16 | 0.14 | 0.13 | 0.09MW | NA |
| SCC YAM TS | 0.272* | 0.241* | 0.228* | 0.190* | 0.151* |
| | 12.62$^a$ | 13.23$^a$ | 15.26$^a$ | 18.93$^b$ | 25.29$^c$ |
| SCC RICE TS | 0.330* | 0.314* | 0.282* | 0.239* | 0.159* |
| | 18.68$^a$ | 20.36$^a$ | 21.08$^a$ | 25.89$^b$ | 47.65$^c$ |
| SCC BEANS TS | 0.526* | 0.485* | 0.435* | 0.311* | 0.265* |
| | 32.83$^a$ | 34.32$^a$ | 37.50$^a$ | 55.64$^b$ | 78.41$^c$ |

Note: Means with the same superscript along the row are not significantly different at $p<0.05$ level of significant. TS = Time spent, SCC = Specific charcoal consumption, Mw = manual winding, NA= Natural air flow rate.

Tables 3 to 5 show that for all air flow rates studied, the specific time spent to cook beans was longer followed by rice and yam in that order, and the specific fuel consumption for cooking the food items followed the reverse order. Also in comparison of Tables 3 to 5, the specific charcoal consumption for cooking yam, rice and beans was less followed by wood and corncobs. On the other hand the time spent for cooking the food items was longer by charcoal followed by wood and corncobs.

## 4 Conclusions

The powered stove evaluated is capable of utilizing wood, charcoal and corncobs for domestic cooking. Performance evaluation of the stove has shown that the task of cooking food stuffs such as yam, rice and beans could be successfully accomplished within shorter time by using different biomass. Consumption of the biomass was seen to decrease with decrease in the volumetric air flow rates, while the time taken to successfully cook a meal was seen to increase with decreased in the volumetric air flow rates. Statistical analysis of fuel consumption and time spent showed that no significant difference existed in the fuel consumption between the powered, manual winding and natural air flow rate conditions, however significant difference was found between the times spent in cooking a meal.

Charcoal and corncobs were found to be suitable substitutes for wood fuel hence, popularization of the powered stove will bring about a remarkable reduction in fuel wood consumption, reduce the time spent in cooking by fast- ignition and maintaining fire. It will also alleviate the problem of agricultural waste disposal. This will further go a long way to increase the conservation of our petroleum products for exports earnings and supplement our national energy requirements.

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