# Performance Evaluation of Nozzle Type Improved Wood Cook Stove

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**Abstract-**This work highlighted on the health and environmental implications of relying on biomass fuel as the source of domestic fuel for cooking over 3-stone open fires and other inefficiency cook stoves. It also highlighted on the previous efforts to develop improved domestic cook stoves and briefly discussed the methods for evaluating the performance of the cook stoves. It conducted water boiling test to evaluate the performance of the nozzle type cook stove to compare its performance with the 3-stone open fires, which it was designed to replace. The results showed that this stove performed better in terms of thermal efficiency, cooking duration and specific fuel consumption. The tests also showed that its burning rate was 0.40kg/hr and handled fuel more efficiently and economically than the open fire, which the burning rate was 0.89kg/hr. The thermal efficiency of this stove was 34.0%, while that of the open fire was 9.5%. The amount of heat dissipated into the cooking environment by the nozzle stove was calculated to be 12.20kJ which was quite minimal compared to the 3-stone open fire which 82% of the heat energy is dissipated into the cooking environment. The annual thermal energy saving by this stove is estimated to be 53.57TJ, while its emission reduction is 26.42tCO$_2$equivalent per year.

**Keywords**: improved wood cook stove and performance evaluation

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## 1 INTRODUCTION

**I**n many developing countries over 60% of the households use biomass such as fuelwood, crop residue and dung as their major source of energy for cooking [1] and other heating purposes. In the last few decades, most of these developing countries have experienced a rapid depletion of natural forest resources, which has resulted in hardship for the people living in rural areas, especially women and children who spend a considerable part of their time and energy in search of fuelwood and often have to cover long distances. The prevailing economic and energy supply situations in these countries indicate that biomass will continue to be their major cooking fuel [1] since the poor do not have access to not only scarce, but also very expensive modern cooking fuels such as kerosene and cooking gas.

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In Nigeria, about 67% of the country's population depends on fuel wood for their daily cooking and often on the traditional open-fires or inefficient cook stoves [2]. In the traditional open-fire cooking, only 8% of the heat energy is absorbed by the water and food, 10% lost by evaporation from the pot and 82% lost to the environment [3]. This results in waste of fuelwood, long hours spent in cooking and drudgery among women and children mostly involved in cooking. Cooking over the traditional open-fires also create health problems such as lung and eye ailments due to smokes and high spending for households that depend on the wood market.

With about 100 million m$^3$ of wood consumed annually, Nigeria's forests are under severe pressure from harvesting fuelwood for cooking [2].The environmental consequences of deforestation– the erosion of watersheds, flooding, destruction of farmlands and desertification, are devastating. In 2000, it was estimated that the number of people that will be affected worldwide by fuelwood shortage will increase from the current one billion to nearly 2.8 billion. And those suffering an acute scarcity of fuelwood will increase from 100 million to over 350 million over

that same period [3]. Thus, when the forests are gone, so the firewood they supply is gone - the primary fuel of up to 90% of the people in most developing countries.

Improved cook stoves (ICSs) are basically developed to address the negative environmental, health and social impacts of cooking with the traditional open fires and other inefficient cook stoves. The ICSs increase fuel combustion efficiency thereby reducing the amount of pollution released into indoor cooking environments. A number of ICSs have been developed and one of such stoves is the Kenya Ceramic Jiko stove which directs about 25-40 % of the useful heat generated to the cooking pot [4]. This represents a significant improvement compared to the traditional open fires which directs only about 5-10% of the heat generated from the fire to the pot. Other ICSs include the Kilakala mud stove built with locally available materials. It has a fuel saving capacity of 30%, but one major disadvantage of this stove is that it did not provide sufficient illumination [5]. The improved vented mud stove, a two-pot stove with chimney developed in India has the average thermal efficiency values across fuels that vary from 10 to 23.5%. The Angethi stove used for charcoal and char briquettes, fabricated with galvanized iron bucket, mud/concrete, and grate has a thermal efficiency of 17.5% [4]. The traditional mud stove, which is a simple U-shaped heavy stove for a single pot made with clay and coated with cow-dung clay mixture has an average thermal efficiency of 17.9% [6]. The save80 stove developed in Germany has a thermal efficiency of 35% and saves 80% of the fuelwood used compared to the traditional open fire [7]. However, despite all these efforts to develop ICSs, there are still very large rooms for improvement in terms of thermal efficiency and emission reduction. Also many households in the rural and semi-urban areas that still rely on traditional open fire for cooking do not have access to ICSs, which are either expensive or unavailable.

The present work is focused on the performance evaluation of the nozzle type improved cook stove developed to replace the

traditional three stone open fires. The stove was designed based on the concept of accelerating the volatiles from combusting fuelwood through the converging nozzle section of the combustion chamber of the stove to increase the convective heat transfer to the pot. In this design emissions are reduced by tangentially admitting preheated secondary air at into the combustion chamber with a baffle placed above the fuel bed to generate recirculation zones to improve combustion efficiency.

## 2 DESCRIPTION OF THE NOZZLE TYPE COOK STOVE

The stove is designed to increase convective heat transfer, which is the dominant mode (50%) of heat transfer in woodstoves. It is fabricated with mild steel sheet thickness of 2mm and made of double walls separated by 20mm thickness glass wool insulator to minimize heat losses to the surroundings. The combustion chamber of the stove consists of two sections – fuel-bed and volatile combustion sections. The fuel-bed section is provided with two side openings which serve the purpose of admitting tangentially preheated secondary air into the combustion chamber and the other one serves as the fuel inlet and the primary air inlet. The volatile combustion section serves the purpose of providing sufficient space for complete burning of the volatiles released from the combusting wood fuel. A baffle placed above the fuel-bed section increases the residence time of the flue gases in the combustion chamber for achieving complete combustion and directs the hot gases towards the pot to improve convective heat transfer.

## 3 METHODS OF EVALUATING THE PERFORMANCE OF THE STOVE

A number of standard methods have developed for evaluating the performance of cook stoves. Such methods are the constant heat output, constant temperature rise, constant time and water boiling test [8]. But water boiling test method is mostly used because it is short and provides a simple simulation of standard cooking procedures. It measures the quantity of fuel consumed and time required for the simulated cooking and usually employed in investigating the performance of cook stoves under different operating conditions [9]. It also provides a quick method of comparing the performance of cook stoves. This method is therefore employed in evaluating the performance of the nozzle type cook stove and compared with the performance of the 3-stone open fire, which it intends to replace.

## 3.1 Water Boiling Test (WBT) Method

The WBT protocol developed by Shell Foundation was employed in evaluating the performance of the stove [10]. It consists of three phases: a high-power (cold start) phase, a high power (hot start) phase, and a low power (simmer) phase. These tests offered very important indicators in evaluating the ability of cook stoves to conserve fuel. Each of these tests was performed three times after allowing the stove to cool down before starting the next round and the average then taken to obtain the thermal efficiency of the stove. The results obtained are shown on tables 1, 2 and 3 below. The test was conducted indoors with sufficient ventilation to vent harmful stove emissions and the stove protected from wind disturbance. The procedures for the tests are as follows:

## 3.2 High-power (cold start) phase Test

The nozzle type stove at room temperature and the 3-stone open fire with the pre-weighed 5kg of fuelwood were used to boil 2.5L of water in the two 28cm diameter pots. The two pots without their lids were weighed and 2.5L of water was put into the pots and weighed again to determine the weight of the water. The ambient and the initial temperature of water in the two pots were recorded. Six pieces of fuelwood of about 20mm diameter from the weighed bundles were slotted into the combustion chamber through the fuel inlet opening, while the 3-stone fire was set up with six pieces of fuelwood. The fuelwood was ignited to initiate burning. The two uncovered pots were respectively placed on the nozzle stove and 3-stone fire the moment the fuel wood started burning and the temperature of the water in the pot were measured and recorded at intervals of five (5) minutes until the moment the water boil vigorously. The time and final temperature of the water in two pots were recorded. The pots were then removed and the fire put out immediately with help of dry sand. The remaining water in the two pots was weighed. The unburned fuel wood removed from the stove and the 3-stone fire together with the remaining pre-weighed bundle was weighed. The loose charcoal knocked off from the ends of the fuel wood together with the ones removed from the stove the 3-stone fire was

weighed. The results obtained are shown on table 1 below.

## 3.3 High-power (hot start) Phase Test

This follows immediately after the first test while stove and the 3-stone were still hot. The two pots were refilled with fresh cold water and the entire processes of the high-power (cold start) phase test were repeated. This test helps to identify the differences in performance of the stove and the 3-stone when cold or hot. The results obtained are shown on table 1 below.

## 3.4 Low-power (simmering) Phase Test

This phase was designed to test the ability of the stove and the 3-stone open fire to simmer water using as little fuelwood as possible. This test followed immediately after the second test. In this test, the two pots were refilled with 2.5L of cold water and weighed. The initial temperatures of the water in the pots were recorded and the water was made to boil as described in the first test. The boiling time and temperature of the boiled water were recorded. The pots with the boiled water were weighed and quickly returned to the stove the 3-stone open fire. The remaining part of the pre-weighed 5kg of fuel wood was weighed and the fires of the stove and the 3-stone open fire were reduced to keep the water as close to $3^0C$ below the boiling point as possible. The fires were then maintained at this level for next 45minutes. After the 45 minutes the temperature of the water in the two pots were recorded. The remaining fuel wood removed from the stove and the 3-stone open fire and the unused wood from the pre-weighed bundle were weighed. The pots with the remaining water were also weighed. The loose charcoal knocked off from the fuel wood together with the ones removed from the stove and the 3-stone open fire were weighed. The results obtained are shown on table 1 below.

## 4 MATERIALS/APPARATUS USED FOR THE TESTS

The apparatus used for test were: (i) 28cm diameter pot without lid, (ii) a digital thermocouple for measuring the ambient and temperature of the water being heated,
(iii) a digital balance for measuring the weight of the fuelwood, charcoal, water and pots,
(iv) Stop watch (Timer), (v) Metal tray to hold charcoal for weighing,

(vi) Two bundles of air-dried fuelwood each weighing 5 kg for each test.
(vii) 10 liters of clean water for each test.

## 5 TEST RESULTS AND DATA ANALYSIS

Tables 1, 2 and 3 below present the average of measured data for the high-power (cold start), high-power (hot Start) and low-power (simmer) phase WBT for the Nozzle type stove.

**Table 1: High-power (cold start), high-power (hot Start) and Low-power (simmer) phase WBT for Nozzle Type Stove.**

| Description | High-Power (Cold Start) | High-Power (Hot Start) | Low-power (simmer) |
|---|---|---|---|
| Ambient Temp.($^o$C ) | 28.30 | 28.30 | 28.30 |
| Initial Water Temp. ($^o$C ) | 29.80 | 30.00 | 97.50 |
| Weight of Fuelwood(kg) Consumed | 0.30 | 0.28 | 0.25 |
| Weight of Water (kg) evaporated | 0.25 | 0.28 | 0.42 |
| Weight of Charcoal (kg) produced | 0.04 | 0.03 | 0.12 |
| Final Water Temp. ($^o$C ) | 97.5 | 97.5 | 93.4 |
| Time (min) | 29.00 | 29.00 | 45.00 |

**Table 2: High-power (cold start), high-power (hot Start) and Low-power (simmer) phase WBT for 3-stone open fire**

| Description | High-Power (Cold Start) | High-Power (Hot Start) | Low-power (simmer) |
|---|---|---|---|
| Ambient Temp.($^o$C ) | 28.30 | 28.30 | 28.30 |
| Initial Water Temp. ($^o$C ) | 29.80 | 30.10 | 96.50 |
| Weight of Fuelwood(kg) Consumed | 0.88 | 0.92 | 0.72 |
| Weight of Water (kg) evaporated | 0.15 | 0.20 | 0.40 |
| Weight of Charcoal (kg) produced | 0.07 | 0.05 | 0.25 |
| Final Water Temp. ($^o$C ) | 97.20 | 97.30 | 94.6 |
| Time (min) | 50.00 | 49.00 | 45.00 |

### 5.1 Analysis of the Test Results

Fig. 1 shows the temperature rise versus time for the water boiling tests carried out with the nozzle type stove and the traditional three stone open-fire for the high-power (cold start), high-power (hot Start) and low-power (simmer) phase tests respectively.
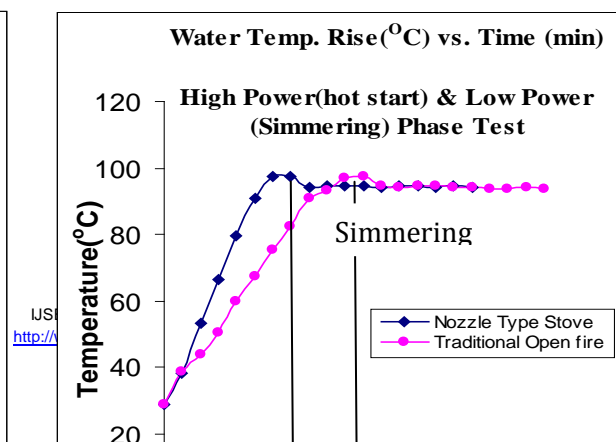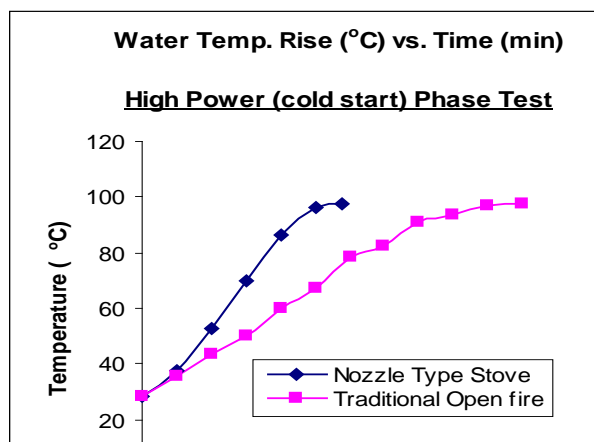
Boiling

**Fig. 1: Temperature rise versus time for the water boiling tests**

The tests showed that it took the traditional open fire 55min to boil 2.5L of water with 0.88kg of fuel wood, while it took the nozzle type cook stove 29min. with 0.30kg of fuel wood to boil the same quantity of water during the high power (cold start) phase test. It also took the traditional open fire 60min to boil 2.5L of water with 0.92kg of fuel wood, while it took the nozzle type cook stove 28min. with 0.28kg of fuel wood to boil the same quantity of water during the high power (hot start) phase test. The nozzle type stove consumed 0.25kg fuelwood for 45min. simmering, while the 3-stone open fire consumed 0.40kg for 45min. simmering. The nozzle type stove consumed 1.0kg of fuelwood to simmer, while the 3-stone open fire to simmer for 45minutes.

The following characteristics of the stove were determined from the water-boiling test:

**(i) 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[9]:

$$R = \left[\frac{100(Wi - Wf)}{(100+M)} - \frac{Mc \times Hc}{Hw} \cdot \frac{1}{t}\right] \quad ..... (1)$$

**(ii)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 ($\eta_{th}$) of the stove can be determined using the equation [4]:

$$\eta_{th} = \eta_h \times \eta_c \qquad .......... \qquad (2)$$

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

$$(\eta_{th}) = \text{Burning Rate x PHU} ....... ..... . (3)$$

The percentage heat utilized (PHU) is determined by equation (4) below:

$$PHU = \frac{M_w C_p(T_b - T_o) + M_{ev}L}{M_f H_f} .......... . (4)$$

**(iii) Specific Fuel Consumption (SFC)**

The specific fuel consumption is expressed as:

$$SFC = \frac{[W_f (1 - M) - 1.5M_c]}{M_w} \quad ... ... \qquad (5)$$

**(iv)Power Consumption for Boiling or Simmering:**

This measures the wood energy consumed by the stove per unit time. It indicates the average power output of the stove (in Watts) during the high-power test. The power consumed (PC) for boiling is expressed as:

$$PC = \frac{[W_f(1 - X) - 1.5M_c] \times H_w}{60t} ...... \qquad (6)$$

$W_i$ = initial weight of fuelwood at start of test (kg)
$W_f$ = final weight of fuelwood at end of test (kg)
M = moisture content of fuelwood (%)
$H_c$= Calorific value of charcoal = 28.8MJ/kg
$H_w$= Calorific value of fuel wood
    = 15.5MJ/kg
t = total time taken for boiling the water.
$W_{wi}$ = initial weight of water in the pot (kg)
$W_{wf}$ = final weight of water in the pot (kg)
$T_i$ = initial temperature of water ($^o$C)
$T_f$ = final temperature of water ($^o$C)
$C_w$ = specific heat capacity of water
    = 4.18kJkg$^{-1}$K$^{-1}$
L = Latent heat of vaporization of water at 100 $^o$C = 2.26 x 10$^6$ J/kg
$M_p$ = weight of the aluminium pot = 0.7kg
$C_p$ = Specific heat capacity of pot
$M_c$ = weight of charcoal (kg)

M$_{ev}$ = weight of water evaporated(kg)

**Table 2: Parameters determined from Water Boiling Test**

| Parameters determined from WBT | High-Power (Cold Start) Phase | | High-Power (Hot Start) Phase | | Low-Power (Sismmering) Phase | |
|---|---|---|---|---|---|---|
| | Traditional 3-stone open fire | Nozzle Type Stove | Traditional 3-stone open fire | Nozzle Type Stove | Traditional 3-stone open fire | Nozzle Type Stove |
| Burning Rate R(kg/hr) | 0.89 | 0.40 | 1.03 | 0.45 | 0.46 | 0.31 |
| Thermal Efficiency ($\eta_{th}$)(%) | 9.50 | 34.00 | 9.20 | 39.00 | 30.00 | 46.00 |
| Specific Fuel Consumption (SFC) | 0.27 | 0.85 | 0.31 | 0.087 | 0.150 | 0.022 |
| Power Consumption for Boiling | 3.32 | 1.73 | 3.72 | 1.72 | 0.81 | 0.19 |

The above results indicate that the 3-stone open fire has a higher burning rate than the nozzle stove. The higher the burning rate the faster the fuel is used up and this is a disadvantage for a stove to have very high burning rate. The lower burning rate achieved by the nozzle stove indicates that this stove handles fuel more economically than the 3-stone open fire. These results indicate that the 3-stone open fire has a lower thermal efficiency than the nozzle stove due its higher burning rate since both parameters are inversely proportional to each other. The higher thermal efficiency of the nozzle stove is due to its proper insulation to reduce heat losses by conduction, increase in radiation heat transfer by increasing flame temperature and increase in convective heat transfer achieved by accelerating the burning hot gas up the converging nozzle of the volatile combustion section before impinging on the pot. Thermal efficiency of the nozzle stove is higher than of the improved vented mud stove, a two-pot stove with chimney developed in India, Kilakala mud stove reported by Otiti [5], Angethi stove by Ayo [4], traditional mud stove, which is a simple U-shaped heavy stove reported by George [6].

**5.2 Heat Losses across the Walls of the Combustion Chamber (Q$_w$)**

The combustion chamber of this stove consist of two sections- fuel bed section which has a hollow cylindrical cross section and volatile combustion section which is a hollow conical frustum cross section. The heat losses by conduction across the walls of each of these sections are determined using Fourier's law. The Fourier's law [11] for the radial conduction heat flow for a hollow cylinder is given as:

$$Q_r = -kA\frac{dT}{dr} \dots\dots\dots\dots\dots\dots \quad (7)$$

where k = thermal conductivity of the cylinder material;

A = area of the walls of the cylindrical fuel-bed section which heat transfer occurs;

dT/dr = radial temperature gradient across the walls.

For a steady heat flow, $Q_r$ is independent of $r$ and T$_i$ > T$_o$, the equation can be integrated and

equation (5) gives: $$Q = \frac{2\pi L(T_i - T_o)}{\frac{1}{k}in(\frac{r_o}{r_i})} \dots\dots \quad (8)$$

The subscripts $i$ $and$ o represent the inside and outside surfaces of the cylinder.

For the composite hollow cylinder consisting of three layers of materials as shown in fig.3 above: a steel plate surrounding the internal part of the combustion chamber, insulating mud and a steel plate casing, the equation for conduction heat losses becomes:
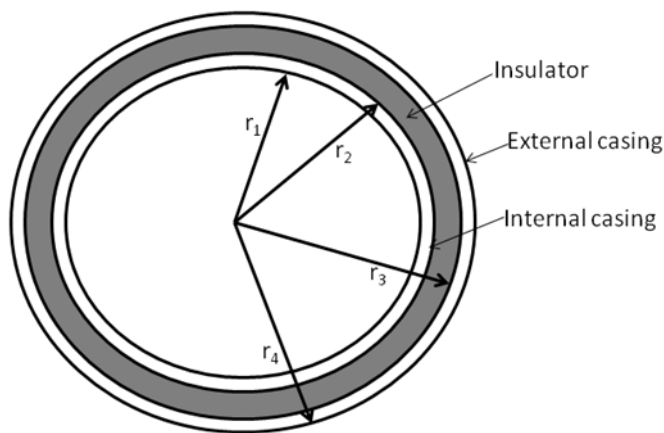
Sectional View of the Combustion Chamber

Fig.2: Sectional View of the Combustion Chamber

$$Q = \frac{2\pi L(T1-T2)}{\frac{1}{h1r1}+\frac{in\left(\frac{r2}{r1}\right)}{k1}+\frac{in\left(\frac{r3}{r2}\right)}{k2}+\frac{in\left(\frac{r4}{r3}\right)}{k3}+\frac{1}{h2r4}} \quad (9)$$

Where $r_1$ = 0.128m, $r_2$ =0.130m , $r_3$ =0.148m and $r_4$ = 0.150m are radii of the composite as shown figure1, $k_1$= $k_3$=35W/mK and $k_2$ = 1.28W/mK and are thermal conductivities of the steel plate and the clay $h_1$ = 50W/m²ᵒC and $h_2$ = 10W/m²ᵒC are the inside and outside surface heat losses coefficients respectively. From equation (9) the conduction heat losses from the fuel bed section of the stove Q = 0.720kJ.

Heat loss Q due to conduction in the volatile combustion section of the stove which has a hollow conical frustum cross section is determined by the equation:

$$Q = \frac{\pi(T1-T2)}{\frac{1}{h_1r_1}+\frac{in\frac{r_2}{r_1}}{k_1L_1}+\frac{in\frac{r_3}{r_2}}{k_2L_2}+\frac{in\frac{r_4}{r_3}}{k_3L_3}+\frac{1}{h_2r_4}} \quad (10)$$

Where, $L_1 = r_1/2C_1$, $L_2 = r_2/2C_2$ and $L_3 = r_3/2C_3$, and L = slant height of the conical nozzle, $C_1$, $C_2$ and $C_3$ = numerical constants.
From equation (7) the conduction heat losses from volatile combustion section of the stove
Q = 0.356kJ.

## 5.3 Convective Heat Losses from the Pot

The convective heat losses ($Q_C$) from the pot side surface and top can be determined by using the equation:
$$Q_c = h\, A(T_w - T)\, t \quad \ldots\ldots\ldots\ldots\ldots \quad .(11)$$
A= surface area of the pot in m²,
t = duration of the experiment in seconds.
$T_w$ = wall temperature (K) for pot side surface = 120ᵒC,
T= ambient temperature = 25ᵒC
h= mean heat transfer coefficient
The heat transfer coefficient h is calculated using the Nusselt number relations for free convection given as:
$$Nu = h\, L/k \ldots\ldots\ldots\ldots\ldots \quad (12)$$
$$Nu = C(GrPr)^n \ldots\ldots\ldots\ldots\ldots \quad (13)$$
In cook stoves the values of $C$ and $n$ are taken as 0.53 and 0.25 respectively [12].

$$Gr = g\beta\Delta T L^3/\upsilon^2 \ldots\ldots\ldots\ldots \quad (14)$$

where $Gr$ and $Pr$ are the Grashoff and Prandtl numbers Nu= Nusselt number,
L = characteristics length (height for combustion chamber and pot sides, diameter for pot lid) and $k$ = thermal conductivity (hot gas). g = acceleration due to gravity m/s²,
β= volumetric expansion coefficient (approximately = $1/T$), K⁻¹
ΔT = $T_w$ − T (temperature difference between the pot surface and the ambient)

The flue gasses flowing through a stove have different chemical composition than air. But when running fuel lean so that CO emissions are reduced, the differences in the properties of air and flue gas become negligible. In calculating h, the flue gasses flowing through the stove are therefore treated as a gas with the same properties of air at the temperature (T), which is the wall temperature of the pot side or stove. From the property table at the wall temperature for the pot side $T_w$ = 400K, $\upsilon$=2.5909x10⁻⁵m²/s and k = 3.3651x10⁻²(W/mK).
Pr = 0.689, Gr = 57412803.91, Nu = 42.10 and h =5.31W/m²ᵒC .
From equation (11) the convective heat losses ($Q_C$) from the pot side surface and the top are determined as follows: $Q_{\text{pot side surface}}$ = 1.23kJ and $Q_{\text{pot top surface}}$ = 10.54kJ.

## 5.4 Radiative Heat Losses from the Pot side

The radiative heat losses ($Q_r$) from the pot side surface and top can be determined by using the Stephan-Boltzmann equation [11]:

$$Q_r = \sigma \varepsilon A_b (T^4_w - T^4) \text{ (kJ)} \quad \text{……..} \quad (15)$$

Where $\sigma$ = Stefan-Boltzmann constant

$$= 5.6697 \times 10^{-8} \text{ W/m}^2/\text{K}^4$$

$\varepsilon$ = emissivity, for blackened aluminium

   pot side = 0.6

$T_w$ = Temperature of the pot surface

   = 108 + 273 = 381K

T = Ambient Temp = 27 + 273 = 300K

A = surface area of the pot side

From equation (15) the radiative heat losses from the pot side surface and the top are determined as follows:

$Q_{pot\ side\ surface}$ = 0.051kJ  and

$Q_{pot\ top\ surface}$ = 0.026kJ

The total heat losses ($Q_T$) from the stove and pot is obtained as follows:

$$Q_T = Q_w + Q_c + Q_r = 12.20 \text{kJ} \quad \text{……..} \quad (16)$$

The above result shows minimal heat dissipation in the kitchen resulting in more comfortable cooking environment. This unlike the 3-stone open fire, 82% of the heat energy is dissipated into the cooking environment thereby making environment uncomfortable.

## 5.5 Annual Energy Savings Potential of The Stove

Cooking with fuelwood in Nigeria is mostly through the traditional open fires method, which incurs about 90% of energy losses, thus indicating very great potential for energy savings. The annual energy saving potential of the nozzle stove is estimated using the equation (17) below [13]. Annual Energy Saving

$$\text{(AES)} = FW_{A\ savings} \cdot NCV_{fuelwood} \text{ ……} \quad (17)$$
$$= FW_A \cdot (1 - \eta_{old} / \eta_{new}) \cdot NCV_{fuelwood} \text{ …} \quad (18)$$

$FW_A$ = Quantity of fuelwood used by a household that rely on the traditional 3-stone open fire. This was estimated to be 4.9561t per annum [13].

$\eta_{old}$ = Efficiency of the traditional 3-stone open fire which the nozzle stove is designed to replace determined to 9.5% by WBT.

$\eta_{new}$ = Efficiency of the the nozzle stove designed to replace the traditional 3-stone open fire. This was determined to be 34.0% by WBT.

$NCV_{fuelwood}$ = Net calorific value of fuelwood = 0.015 TJ/tonne, or 4,167 kWh/t

Thus the annual energy savings (AES) potential of the stove by a household that depends on 3 – stone open fire for daily cooking and other heating purposes is estimated to be 51.03TJ.

## 5.6 Emission Reductions of the Nozzle Type Stove

The energy requirement in the household energy sector in Nigeria is dominated by fuelwood, meeting up to 80% of the demand, followed by kerosene (10%), LPG (4%), charcoal (3%), and other biomass (3%) [13]. It follows that kerosene is the fossil fuel likely to be used by a similar household. The emission reduction is estimated on the basis of the emission of a fossil fuel with the same energy content as the non-renewable biomass displaced. The annual emission reduction by this stove is estimated using the equation (19) below [13]:

$$AER = FW_{A\ savings} \times F_A \times$$
$$NCV_{fuelwood} \times EF_{fossil\ fuel} \text{ …… …} \quad (19)$$
$$FW_{A\ savings} = FW_A \cdot (1 - \eta_{old} / \eta_{new}) \text{ …..} \quad (20)$$

$FW_A$ = Quantity of fuelwood used by a household that rely on the traditional 3-stone open fire (tonnes/annum).

This was estimated to be 4.9561t per annum.

AER = Annual emission reductions in t $CO_2$equivalent.

$FW_A$ = Quantity of fuelwood used by a household that rely on the traditional 3-stone open fire.

$F_A$ = Fraction of fuelwood saved by the stove in year.

$NCV_{fuelwood}$ = Net calorific value of fuelwood

EF = fossil fuel emission factor for the substitution of fuelwood by similar households.

$$AER = 4.9561t \times (1 - 0.095/0.340) \times 0.69 \times$$
$$0.015 \text{ TJ/t} \times 71, 5 \text{ t } CO_2/\text{TJ}$$
$$= 26.31t \ CO_2/\text{years.}$$

Thus the annual emissions reduction of this stove by a household using 3-stone open fire for cooking and other heating purposes is estimated to be 25.31t $CO_2$ equivalent /year. This is achieved by admitting preheated air tangentially through the annual channels into the combustion chamber and above

## 6 CONCLUSIONS

This work has conducted performance evaluation the nozzle type improved wood cook stove using water boiling test method to compare its performance with the 3-stone open fire mostly

used in the rural areas in most developing countries. The results of the cold start high power, hot start high power and lower power phase tests showed that this nozzle type stove performed better in terms cooking duration and specific fuel consumption. It has lower burning rate, therefore burns fuel more efficiently and economically than the 3-stone open fire, which has higher burning rate. The thermal efficiency of this stove is 34.0%, while that of the open fire is 9.5%. The annual thermal energy saving by this stove is estimated to be 53.57TJ, while its emission reduction is 26.42tCO$_2$ equivalent per year. The improved wood cook stoves include the reduced sufferings of especially women and children involved in cooking and collection of fuelwood, reduced risk of burns and money spent by households on fuel wood, indoor air pollution from fuel wood smoke, thereby minimizing its harmful effects on human health and reduced demand for fuel wood.

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