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Comparative Performance Evaluation of two Improved Clay – Lined Charcoal Cook Stove

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Abstract **-This paper presents the result of the performance evaluation of improved clay-line cook stoves using charcoal as fuel through boiling and controlled cooking test. Experiments were conducted on two different shaped clay-lined charcoal cook stoves to determine the mass of fuel required to boil a given mass of water and cook a given mass of beans. The specific fuel consumption of pyramidal shaped improved clay-lined charcoal cook stove and the rectangular improved clay-lined charcoal cook stove per kilogram of food were obtained as 28,302kj/kgs and 35,092kj/kgs respectively. Also, 0.05kg and 0.15kg of charcoal fuel were used by pyramidal shaped stove to rise water temperature from 28^{0}C to 99^{0}C for 2280 seconds respectively. The thermal efficiencies of the stoves were 49.57% for the pyramidal shaped stove and 13.49% for the rectangular shaped stove.**

Key Words: **Energy, fuel, consumption efficiency and improved stove.**

I. INTRODUCTION

The existence of cookers and other domestic heating equipment's dates back to the ancient times. Since the dawn of mankind, has been faced with the problem of how to efficiently cook and warm his environment and this has been elusive. In this quest, man of Stone Age gathered stones form tripod stove, between which wood is used as the source of energy. The firewood as the first fuel to be used for cooking and heating purposes arise because of its accessibility and ready availability, especially in rural area [3].

About half of the world's population has continued to depend on biofuels, fuel wood, charcoal, crop residue and dung- to provide energy requirement for cooking. However, households in industrialized countries have shifted to petroleum fuel and electricity; these options are not likely to become available to the rural areas [13].

As of 2011, about 1.26 billion people do not have access to electricity and 2.6 4 billion people rely on traditional biomass (fuelwood, charcoal, dung and agricultural residues) for cooking mainly in rural areas in developing countries [9]. Under a baseline scenario, thenumbers of people without clean cooking facilities could remain almost unchanged in 2030 [9]. Household cooking consumes more energy than any other end -use services in low -income developing countries [10; 4].

Available statistics has shown that people living in the developing countries depend on wood for their livelihood and survival. Majority of families in Nigeria use wood for cooking and other domestic purposes, despite the fact that Nigeria is an oil rich country. About 80% the total energy consumed for cooking at home comes from wood [3].

Several method/devices of burning fuel such as electric cooker/stoves, gas cookers, and kerosene stoves have since been employed all over the world including developing country like Nigeria.However the down turn in Nigeria economy coupled with non-challant attitude of leaders, has made some of cooking fuels unreachable to most people of this country. Erratic power supply, breakdown of petroleum refineries and high cost of getting fuels have called for alternative means of cooking and heating purpose that can meet up with both urban and rural requirement.

The programme for increasing cooking efficiency will require a number of activities including the design and development of improved stoves, adopting the designed stove to the local cooking needs and cultural conditions, ensuring that the stoves are being used properly and finally, promotion of the stoves [7].

Generally, the mode of heat transfer in stove from fire to the pot is by convective. To achieve the most efficient convective heat transfer and economic usage of fuel, air shouldbe admitted into the combustion chamber via its sides vent to direct the hot gases from the burning flame to the cooking pot base.

And basically, a society would prefer cook stove that possess the following characteristics [6];

- Provide greater available heat for faster means of cooking
- Consume less fuel
- Work on readily available fuels,
- Provide maximum comfort to the users
- Cost less, and
- Be easily maintained

II. JUSTIFICATION

The traditional method of cooking which has been used for centuries with little modifications, involve burning wood in an open fire sometimes enclosed by metallic, clay or bricks to act as wind shields. This method even though simple and cheap is very unhealthy and hazardous to the users, and inefficient as only 5% to 10% of energy potential in the wood fuel is utilized in the cooking process. The fire wood consumption as well as the energy requirement for cooking would thus be much higher. The soot produced from this method of cookingmay come in contact with the food cooked and thus make the preparation unsanitary.

To reduce the chores of food preparation, make fire wood collection and use easier, make multiple usage of stove at a time, make stove more efficient and less time consuming, and to ensure efficient utilization of heat energy generated in cooking stoves, an improved clay-lined charcoal burning stoves that will utilize high percentage of energy potential in the fuel for cooking and heating at a shortest possible time is required. To overcome these shortcomings, different shapes of improved clay-lined charcoal burning stove have been produced. There is the need to compare the thermal efficiency of the stoves.

III. SIGNIFICANT OF THE STUDY

The outcome of this study shall determine between the two clay-lined charcoal cook stoves, the one that will be more efficient in the utilization of the heat energy generated for faster means of cooking, less time consuming in the cooking process and consume less fuel. The more efficient stove can be easily adopted in our rural areas and some urban centers where wood are the predominant and readily used fuel, for their cooking needs. Production of the stove can also serve as a source of income to welders and clay molders in the in the rural and urban centers

IV. AIM AND OBJECTIVE

The main aim of this study is to compare the performance of a pyramid shaped and rectangular shaped clay-lined charcoal cook stoves through water boiling and controlled cooking tests.

And the specific objectives are;

i) Determination of the mass of charcoal fuel require to boil and cook a given mass of water and beans respectively

ii) Determination of the specific fuel consumptions and the overall thermal efficiencies of the stoves

iii)

V. METHODOLOGY

The methodology adopted in this study is as follows;

i) Review cooking stove development

ii) Test run on the two stoves simultaneously under the same conditions to obtain data;

iii) Calculation of the specific fuel consumption and the overall thermal efficiency of the stoves

VI.SCOPE AND LIMITATION

In this study, comparative performance of two improved clay-lined charcoal cook stoves were carried out through water boiling and food cooking tests to measure the two characteristic of cook stoves, i.e. the specific fuel consumption and overall thermal efficiency. Furthermore, the study was limited to the use of charcoal as fuel in running the two tests, and use of beans for the controlled cooking test.

VII. DEVELOPMENT IN COOKING STOVE

For most human history, people have burn solid fuel like charcoal, wood and agriculture wastes to cook their food, stay warmed and lights their environment. Even today, in both developed and developing countries, rural dwellers have totally depended on wood for cooking and it remains the world's most widely used renewable energy source [5].

Cook stoves is as old as man. After discovering of fire man has been trying different means of keeping fire burning for their cooking processes. Most rural people in the poorer countries cook over open fire, usually set between three or more stones, bricks, inverted pots or moulds of mud that support the cooking pots known as the traditional three stones stove [1].

The first practical cooking stove was designed in the 1970's by Benjamin Thompson Rumford, a British statesman and inventor. These stoves, a box like brick structure, had holes in the top to hold pots. Until the early 1800's most people in Canada and the United States use fireplaces for cooking and heating. And the first stove for cooking was the burning coal type(brazier) in which hot coals was the source of fire. Although similar pottery stoves could be dated back to 3rd Century A.D

The modern day stoves own their origin to brazier. Over the years different kind of stoves have evolved among which are;

- The open fire tripod with three pivots,
- The protected open fire stove which is similar to open fire except that it had either moulded clay or cast metal round it as wind protector,
- Crescent stove was inspired by research into protected open fire stove. It was completely made up of clay and was called nouna stove
- Chinese cast-iron stove dates back to between 25-200A.D. It was made by melting iron then casting in sand moulds. However, these Chinesestoves were later modified by both the former USSR and China into portable brazier stove of various shapes and sizes. Common among them are the round or rectangular wood stoves common in today's market. The major shortcoming of these stoves is that large amount of heat is lost before it gets to the cooking pot.

Several types of cook stoves are used by households and these stoves are often associated with specific energy types. For example, traditional (3-stones), simple non -traditional (e.g., clay pot-style or simple ceramic liners), chimney, rocket, charcoal and gasifier stoves use solid fuels which are common in rural areas of developing countries [13]

Various research works indicates that there has been worldwide search for an improved wood stove. However, in all these countries, the traditional stoves are being improved upon to make them more energy efficient through efficient use of fuel and reduced health risks to users.

Development of improved biomass cookstoves in many countries has witnessed several overlapping stages over the last 30 years [11]. Out of a total solid -fuel population of 3 billion people, about 828 million in developing countries now use improved cookstoves [14]

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VIII. EXPERIMENTATION

A. Materials and Method

The apparatus and materials for the experiments include the two improved clay-lined stoves, aluminium pot, thermocouple wires, mercury-in-glass thermometer, a weighing balance, stopwatches, water, beans, kerosene and matches.

The clay used for the stoves is a mixture of Chanchaga and Maikunkele (all in Niger State) clay in the ratio 1:1. The clay mixture has refractoriness of 1780^0C, firing shrinkage at 100^0C of 4%, bulk density of $1{,}530g/cm^3$, specific gravity of $2.60g/cm^3$, thermal shock resistance of 30^+, true porosity of 23% and permeability of air 0.173cgs [15].

The two characteristics of the stoves were measure i.e. the overall thermal efficiency and the specific fuel consumption via the water boiling and cooking test methods.

B. Test Site

The tests (water boiling and food cooking) were carried out in the open air in the front of Mechatronics Laboratory at Niger State Polytechnic, Zungeru.

C. Experiments Carried Out

i) Water Boiling Test (WBT)

Experiment on the burning rate of charcoal and the stoves efficiency tests through water boiling test (WBT) were conducted as follows:

- 2.95kg of water was poured into the aluminium pots of 0.45kg weight.
- The stove combustion chamber were loaded with 0.9kg of charcoal
- With the aid of thermocouple wires immersed into water contained in the aluminium pot and connected to Commack digital thermometer, the initial temperature of water was recorded.
- The charcoal in the stoves combustion chambers was sprinkled with kerosene and ignited with a match, and combustion was allowed to stabilize before the pot containing water was mounted on stove.
- The subsequent change in temperature of water up to boiling point was recorded at 5 minutes intervals.
- The pot was removed from the stoves and the fire was immediately turned out of the combustion chamber and weighed.
- The unburnt charcoal was also weighed

The equation of thermal efficiency of stoves is express as:

$$\beta = \frac{W_1 C_w (T_2 - T_1) + W_2 C_P (T_4 - T_3) + W_3 H_L}{W_7 H_C} \text{ --------- } 1 \ [7]$$

Where:

W_1 = Mass of water before the test

W_2 = Mass of pot used

W_3 = Mass of water evaporated

W_7 = Mass of charcoal burnt

T_1 = temperature of water before test

T_2 = temperature of water after test

T_3 = Initial temperature of pot

T_4 = Final temperature of pot

C_W = Specific heat capacity of water = $4200KJ/kg^0C$

C_p = Specific heat capacity of the aluminium pot = $0.92KJ/kg^0C$

H_L = Latent heat of vapourization of water = 2,260KJ/kg

H_C = Calorific value of fuel

ii)Controlled Cooking Test

Controlled cooking test (CCT) was conducted to determine the specific consumptionof charcoal fuel and time spent in cooking per kilogram of beans. This test was carried out in the open air on cool morning to stimulate traditional approach to cooking in rural areas of Nigeria.

The experiment was conducted as:

- The cooking pots were weighed empty and later the food stuff (beans) together with the pot was weighed.
- 2.95kg of water was added into the pots containing beans
- All the content (water and beans) were weighed together with the pots
- The initial temperature of the contents in the pots was taken

- 0.9kg of charcoal was loaded into the combustion chamber of the stoves and ignited with a match before pots containing beans and water were placed on the stove.
- The final cooking temperature was taken and thereafter the cooked beans weight was determined
- The quantity of water evaporated from the pots was determined, and also the un-burnt charcoal was weighed to determine the amount of charcoal consumed.
- Stopwatch was used to take the time during the experiment

The specific fuel consumption (SFC) of charcoal of stoves is express as;

$$\text{SFC} = \frac{(W_{13})}{(W_{11})} H_c \text{ ------------------------------------- } 2\ [7]$$

Where; W_{13} = Weight of burntcharcoalduring cooking

W_{11} = Total weight of cooked bean

IX.RESULTS AND DISCUSSION

A. Results of the Experiment

The experimental result of water boiling test is presented in Table I, and controlled cooking test result is shown in Table II.

TABLE IWater Boiling Test Result

S/N	Test Run	Stove A	Stove B
1	Initial Weight of water in port W_1 (kg)	2.95	2.95
2	Weight of Aluminium Pot Used W_2 (kg)	0.45	0.45
3	Final Weight of Water in Pot, W_5 (kg)	2.85	2.90
4	Weight of Water Evaporated, W_4 (kg)	0.10	0.05
5	Initial Temperature of Water in Pot, T_1(^{0}C)	28	28
6	Final temperature of water in pot, T_2 (^{0}C)	88	77
7	Weight of Charcoal to be used, W_3 (kg)	0.90	0.90
8	Weight of Un-burnt Charcoal, W_6 (kg)	0.85	0.75
9	Weight of Charcoal used, W_7 (kg)	0.05	0.15
10	Time taken to boil water, T_1 (sec)	2280	3120
11	Specific Heat Capacity of Aluminium pot, C_P (kJ/kg^{0}C)	0.92	0.92
12	Specific Heat capacity of water, C_W (kJ/kg^{0}C)	4200	4200
13	Heat of combustion of fuel i.e. calorific value of Charcoal, H_C (kJ/kg)	30,000	43,000
14	Latent heat of vapourization of water, H_L (kJ/kg)	2,260	2,260
15	Thermal efficiency (%) of the Stove	49.57	13.49

Table IICooking Test Result

S/N	Test Run	Stove A	Stove B
1	Weight of aluminum pot used for cooking test, W_8 (kg)	0.45	0.45
2	Initial weight of water for cooking test, W_9 (kg)	0.75	0.75
3	Initial Temperature for pot + Water + Beans, T_3 (^{0}C)	28	28
4	Final temperature of pot + water + Beans, T_4 (^{0}C)	99	84
5	Weight of charcoal used for cooking test, W_{10} (kg)	1	1
6	Final temperature of water in pot T_2(^{0}C)	88	77
7	Time taken for cooking T_2 (sec)	2280	3120
8	Weight of un-burnt Charcoal after cooking, W_{12} (kg)	0.50	0.38
9	Weight of un-burnt Charcoal during cooking, W_{13} (kg)	0.05	0.62
10	Calorific value of charcoal H_C (kJ/kg)	30,000	30,000
11	Specific Fuel consumption of the stoves (kJ/kg)	28,302	35,094

B. Discussion of Results

From the result of the comparative studies conducted, it is observed that the pyramidal shaped improved clay-lined and rectangular shaped improved clay-lined charcoal cook stoves had thermal efficiencies of 49.57 and 13.49 percent respectively for the similar water boiling test. Also, 0.05kgand 0.15kg of charcoal fuel were used by the pyramidal shaped stove and rectangular shaped stove to raise water temperature from 28^{0}C to 88^{0}C for 2280seconds and from 28^{0}C to 77^{0}C for 3120 seconds respectively. This shows that the pyramidal shaped improved clay-lined stovegives more heat to the cooking pot than the rectangular shaped type because it takes less time to raise water temperature by 60^{0}C when compared to the rectangular type that takes much time to raise water temperature from the same level by 49^{0}C.

It was also observed that the pyramid shaped and the rectangular shaped improved clay – lined charcoal stoves consumed energy of 28,302 kJ/kgand 35,092 kJ/kg respectively to cook the same quantity of beans. This result shows that less energy is consumed by the pyramid shaped stove to cook the same quantity of beans.

X. CONCLUSION AND RECOMMENDATION

From the results, it can be seen that the pyramidal shaped improved clay-lined charcoal stove has higher efficiency (i.e. low fuel consumption) than the rectangular shaped type.

Studies have however showed that using wood as a source of domestic fuel causes deforestation and ultimately desertification. The concerted effort made to discourage the use of wood as domestic fuel for the sake of protecting our environment has failed as majority of rural dwellers have continued to use wood for their cooking.

From the above, it is obvious that the needed effort is how the rate of using woods as fuel for domestic cooking can be reduced. since charcoal is produced from wood, adoption of improved clay-lined charcoal cook stove like the pyramidal shaped type tested (that will consume less fuel) for domestic cooking in our rural areas will certainly be a step in the right direction to reduce drastically the rate of using fuel wood for cooking and consequently reduce the much afraid desert encroachment and soil erosion. This step will also bring about efficient utilization of un-burnt wood fuel (charcoal) that is regarded as waste materials in our rural areas.

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