International Journal of Advanced Engineering, Management and Science (IJAEMS)
Peer-Reviewed Journal
ISSN: 2454-1311 | Vol-10, Issue-5; Jul-Aug, 2024
Journal Home Page: https://ijaems.com/
DOI: https://dx.doi.org/10.22161/ijaems.105.16

Energy Evaluation and Comparative Analysis of Eco-designed Charcoal Stove and Kerosene Stove

K. A. Ajibola, M. O. Kareem, S. A. Ganiyu, W. A. Adetola

Department of Mechanical Engineering, The Polytechnic Ibadan, Oyo State.
abolanlekafayat@gmail.com

Received: 11 Jun 2024; Received in revised form: 15 Jul 2024; Accepted: 23 Jul 2024; Available online: 30 Jul 2024

Abstract— *Energy sources such as; fuel wood, charcoal, kerosene and others play vital role in meeting local energy demand in many Sub-Saharan Africa (SSA) countries.Their usage is closely linked with economic development, poverty reduction and the provision of vital services. Until recently, kerosene was popularly used as domestic fuel which is greatly due to its availability, low cost, ease of handling and relatively safe but these are not the same anymore due to high cost of procurement and scarcity. Hence, this study of energy evaluation and comparative analysis of improved charcoal stove and kerosene stove aims to compare their energy efficiency and environmental impact. The charcoal stove casing was fabricated from 5 kg old gas cylinder that was condemned for leakage. Red clay and cement were carefully sieved and mixed with water to form the mold. An already fabricated grate was placed at the middle of the cylinder and the concrete was fed between the space. Three cooking tests; Water Boiling Test (WBT), Controlled Cooking Test (CCT) and Frying Test (FT) were conducted with the charcoal stove and the results obtained were compared with the results obtained from an existing kerosene stove. The three experiments revealed that the eco-friendly charcoal stove is better in fuel consumption, heat generation, duration of cooking and cost of procurement. In conclusion, the developed charcoal stove will suitably replace the kerosene stove for low-income earner and rural dweller.*

***Keywords*— Stove, Charcoal, kerosene, Fuel Efficiency, Cooking Duration.**

I. INTRODUCTION

Charcoal and kerosene were preferred cooking fuel for most urban and Peril-urban dwellers (Sander *et al.,* 2011). Basic Charcoal or lump charcoal is usually produced by a process known as slow pyrolysis, by heating wood or other biomass inside relatively air tight enclosure, like an earth covered pit in the ground (earth mound kiln). About half of the world's population has continued to depend on bio-fuels, fuel wood, charcoal, crop residue and dung to provide energy requirement for cooking. This is contrary to what is being obtained in industrialized countries where households have shifted to petroleum fuel and electricity but these are not likely to be available to the rural dwellers. As of 2011, about 1.26 billion people do not have access to electricity and 2.64 billion people rely on traditional biomass (fuel wood, charcoal, dung and agricultural residues) for cooking mainly in rural areas in developing countries. Under a baseline scenario, the numbers of people without clean cooking facilities could remain almost unchanged in 2030 (*IEA et al*., 2013). Household cooking consumes more energy than any other end-use services in low-income developing countries (*IEA et al*., 2013) Kerosene is also a widespread fuel for lighting at the household level and its lamp (also known as hurricane lamp) is a very common feature in most rural households, meanwhile, kerosene as a cooking fuel is still very limited. The case study overleaf, which is fairly representative of many families in rural and peril-urban Sub-Sahara Africa, gives a good illustration of the pattern of energy consumption, the low level of consumption of kerosene as cooking fuel and its importance as an energy source for lighting. Several methods and devices of burning fuel such as electric cooker or stoves, gas and kerosene stoves have since been employed all over the world including developing country like Nigeria. In addition, the down turn in Nigeria economy coupled with nonchalant 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 program 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 (Fapetu and Oke, 2003). Biomass is a renewable energy source obtainable from organic matters, while kerosene is non-renewable energy from crude oil. Although, the two stoves have advantages and disadvantages in terms of energy efficiency, indoor air pollution, and environmental impact.

Chica and Pérez (2019) designed and evaluated a biomass improved cooking stove for developing countries where water boiling tests were conducted. The result obtained revealed an average energy efficiency of 20.9% with a boiling time of 31.6 minutes. In another investigation, the thermal and emission performance of biomass stoves was investigated where water boiling tests (WBT) and food cooking tests (rice and beans) were used. The results indicate that of the 15 charcoal stove samples tested, 62% met the minimum Tier 2 standard, while 51% of the 10 firewood stove samples tested met the minimum Tier 2 standard. The star rating of a biomass stove is determined by the value of the stove's thermal efficiency level. Stoves available in local markets in Nigeria do not have a star rating (Okafor, 2019). Otto (2018) also conducted water boiling tests on aluminum stoves and the result revealed that the thermal efficiency of the stove compared to the traditional stove is much improved. A comparative study of traditional improved clay stoves and Malagasy stoves was conducted by Segbefia *et al*. (2018) and the study revealed that the clay stove performs better than the Malagasy stove.

II. MATERIALS AND METHOD

2.1 Materials

The following materials presented in Table 2.1 were carefully selected to produce a viable stove at a reasonable cost. The fabricated briquettes stove has the following components; Grate, vent door, soil insulation, supports and metallic casing.

Table 2.1: List of Components, Materials and Reason for Selection

S/N	Components	Material	Reason for the selection of material
1	Grate	Mild steel	It has high rust resistance (due to the galvanizing of the steel) and thereby elongates its life span.
2	Vent door	Galvanized plate	This material has low thermal conductivity and thus will prevent heat loss by conduction.
3	Soil-insulation	Red clay	its resistance to spontaneous change in heat and high insulation capacity
4	Pot Support	Aluminum	It has high corrosion, high strength and low cost
5	Stove Casing	Galvanized plate	It has a high heat tolerance.
6	Hinges	Butt hinges	It allows the door to swing smoothly
7	Rivet pin	Stainless steel	It acts as a pivot point allowing the hinge to rotate smoothly
8	Ash Tray	Galvanized sheet	It is at the bottom of charcoal stove used to catch the ashes and helps with cleaning.

2.2 Design considerations

The following considerations were taken into account which ensured effectiveness, efficiency, and safety of the design.

a. **Materials**: The materials were carefully selected to ensure affordability, durability, heat-resistant, and non-hazardous (Mehta and Goyal, 2015).

b. **Geometry**: The size and shape of the stove was carefully considered to optimize heat distribution and cooking efficiency. The stove grate is large enough to hold a sufficient quantity of briquettes or charcoal to maintain the desired heat level. The shape is also designed to ensure proper airflow and heat distribution (ISO, 2016).

c. **Airflow Control**: Proper airflow is essential for maintaining a consistent and efficient burn. The stove has openings to allow for proper airflow, and to control the amount of oxygen that entering the pot. The size and location of the air vents is designed to optimize heat distribution.

d. **Insulation**: Adequate insulation was included to prevent the stove from becoming too hot to handle and to maintain heat for an extended period (Morgan,2013). The stove has a layer of insulation between the briquettes and the exterior of the stove to prevent excessive heat transfer. The insulation materials include red clay and cement.

e. **Safety**: To prevent accidents and ensure user safety, the briquettes stove is designed to be stable and not easily tipped over. It is also designed to prevent accidental contact with the hot briquettes.

f. **Cost**: Briquettes stoves are often used in low-income and developing areas, so cost is an essential consideration. The design is simple and efficient to keep the cost low and make it accessible to those who need it. The stove is designed to be easily maintained (Mehta and Goyal, 2015).

g. **Environmental Impact**: The production and use of briquettes stoves can have a significant environmental impact, so the design also considers the use of sustainable materials and methods, as well as the reduction of pollutants and emissions.

2.3 Method

The charcoal fire stove was fabricated through the following processes;

A. Fabrication process

1 Marking out: Various components used such as door, stand, support, grate are measured and marked before cutting to ensure that the charcoal pot is properly shaped and functional.

2 Cutting: Excess materials are removed based on the marked out dimensions to enable us get the desired shape.

3 Joining: All the different parts of the charcoal stove are joined through the welding and riveting which gives us a cohesive and functional structure.

4 Filing: A file is used to shape and smooth the sharp edges or imperfections left after cutting and joining process, which ensures that we have clean and finished appearance making it safe to handle and use.

5 Coating:- Protective layers are applied to the surfaces of the charcoal pot, such as paint, this helps prevent rust and corrosion and enhance the durability of the charcoal pot.

6 Finishing touches: This is the final step which includes enhancement and additional details to improve the charcoal stove appearance such as polishing and inspection to ensure it is ready for use.

7 Soil insulation: Red clay was used to insulate the stove so as to ensure steady firing and heat generation of the stove.The chose of this material was based on its refractiveness

These are shown on Plate 2.1 – Plate 2.6.

Plate 2.1: Grate

Plate 2.2: Red Clay

Plate 2.3: Vent Door

Plate 2.4: Pot Support

Plate 2.5: Metallic Casing

Plate 2.6: Ash Tray

2.4 Test Analysis

2.4.1. Water Boiling Test (WBT)

0.915 kg of water was poured into 0.400 kg aluminum pots. The stove combustion chamber already loaded with 0.300 kg of charcoal was ignited and the combustion was allowed to stabilize before mounting the aluminum pot. With the aid of thermocouple wires immersed into the water and connected to a digital thermometer, the initial temperature of the water was recorded. The subsequent change in temperature of water up to boiling point was also recorded at 5 minutes intervals. The pot was later removed from the stoves and the fire was immediately turned out off. This is as shown on Plate 2.7 and the procedure was repeated for the kerosene stove with 0.21 kg kerosene and at the end of the two experiments, the un-burnt charcoal and kerosene were weighed. Three trials of the experiments were conducted and the average as discussed in the result.

2.4.2 Controlled Cooking Test

0.175 kg of rice was measured and placed in a small standard pot. Sufficient quantity of water about 1.1 kg was weighed and added to the rice in the pot. The mass of the pot plus its lid together with the rice and water was measured to be approximately 1.9 kg. Charcoal with a weight of 0.3 kg at the sum of fifty naira (₦50.00) was charged into the stove and ignited. Meanwhile, the mass of stove plus fuel was recorded as 1.4 kg andthe timer started immediately the pot holding the rice and water was placed on the burning charcoal. The cooking was monitored intermittently and the timer was stopped immediately the rice was completely cooked (Plate 2.8). The cooking time was recorded and the un-burned fuels were measured after the fire was extinguished. The final masses of pot plus cooked food were also measured. Finally, the specific time and energy consumed were calculated. Three trials were conducted and the average as discussed in the result.

2.4.3 Frying Test

Three spoons of cooking oil were added into an already weighed frying pan and the initial temperature of the cooking oil in the frying pans was recorded.Charcoal of 0.200 kg was charged into the combustion chamber, ignited and the whisked egg was added. The final cooking temperature was taken after the egg has fried to the desired appearance (Plate 2.9). Stopwatch was used to take the time during the experiment and a repeated experiment was carried out using 0.10 kg of kerosene**.** At the end of it all, **t**he un-burnt charcoal and kerosene were weighed to determine the amount of fuel consumed. Three trials were also conducted and the average as discussed in the result.

Plate 2.7: Water Boiling Test *Plate 2.8: Controlled Cooking Test (Rice)* *Plate 2.9: Frying Test*

III. RESULTS AND DISCUSSION

The experimental results were as shown on Table 3.1, 3.2 and 3.3 indicating water boiling, controlled cooking and frying test respectively.

3.1 Water Boiling Test (WBT)

The result of the comparative studies conducted show that the charcoal stove and kerosene stove have different thermal efficiency for the similar water boiling test. The WBT revealed that the charcoal stove has better cooking efficiency in terms of fuel consumption, heat liberation and duration of cooking (Table 3.1). As obtained, 0.165 kg of charcoal was used to raise the water temperature from 26.6 °C to 66.8 °C in 302 seconds while, 0.24 kg of kerosene was used to raise the same initial temperature of water to 67.6 °C in 366 seconds. Invariably, more heat energy was liberated by the charcoal stove which resulted to a better cooking efficiency. This shows that the charcoal stove gives more heat to the cooking pot than the kerosene stove because it takes less time to raise water temperature by 40.2 °C when compared to the kerosene stove that takes much time to raise water temperature from the same level by 41 °C.

Table 3.1 Water Boiling Test

S/N	Test Data	Charcoal stove	Kerosene stove
1	Weight of Aluminumpot used w_1(kg)	0.400	0.400
2	Initial weight of water in pot w_2(kg)	1.0	1.0
3	Final weight of water in pot, w_3 (kg)	0.95	0.90
4	Weight of water evaporated, w_4 (kg)	0.05	0.10
5	Initial temperature of water in pot, T_1(°C)	26.6	26.6
6	Final temperature of water in pot, T_1 (°C)	66.8	67.6
7	Weight of fuel to be used w_5 (kg)	0.300	0.21
8	Weight of Unburnt fuel w_6 (kg)	0.142	0.08
9	Weight of fuel consumed w_7 (kg)	0.158	0.13
10	Time taken to boil water, t_1 (sec)	302	366
11	Specific heat capacity of Aluminum pot (kJ/kg°C)	0.92	0.92
12	Specific Heat capacity of water (kJ/kg°C)	4200	4200
13	Heat of combustion of fuel i.e. calorific (kJ/kg)	29000	43000
14	Latent heat of vaporization of water (kJ/kg)	2260	2260
15	Cost of fuel (₦)	50.00	1500.00

3.2 Controlled Cooking

It was observed that the kerosene stove consumed more energy to cook the same quantity of rice and it also took a longer time for the operation (Table 3.2). This is similar to what was obtained from WBT.

Table 3.2: Controlled Cooking

S/N	Test Data	Charcoal Stove	Kerosene Stove
1	Weight of aluminum pot used for cooking test, w_8 (kg)	0.400	0.400
2	Initial weight of water for cooking test, w_9 (kg)	0.915	0.915
3	Initial Temperature for pot + Water + Rice, T_3 (°C)	26.6	26.6
4	Final temperature of pot + water + Rice, T_4 (°C)	57.5	55.3
5	Weight of fuel consumed, w_{10} (kg)	0.350	0.26
6	Final temperature of water in pot T_2 (°C)	26.6	0.26
7	Time taken for cooking t_2 (sec)	1,145	1,022
8	Weight of un-burnt fuel after cooking, w_{11} (kg)	0.147	0.08
9	Calorific value of charcoal (kJ/kg)	29,000	43,000
10	Specific Fuel consumption of the stoves (kJ/kg)	0.20	0.20

3.3 Frying Test (FT)

The FT revealed that the kerosene stove consumed more energy and more time was also expended to fry the same quantity of egg (Table 3.3).

Table 3.3 Frying Test

S/N	Test Data	Charcoal Stove	Kerosene Stove
1	Weight of aluminum frying pan used for frying test, w_1 (kg)	0.400	0.400
2	Initial weight of cooking oil for frying test, w_{12} (kg)	0.04	0.04
3	Initial Temperature for frying pan + Oil T_3 (°C)	25.4	25.4
4	Final temperature of frying pan + cooking oil T_4 (°C)	76.4	76.4
5	Weight of fuel consumed, w_{13} (kg)	0.250	0.15
6	Time taken for frying t_3 (sec)	92	124
7	Weight of un-burnt Charcoal after frying w_{14} (kg)	0.235	0.12
8	Calorific value of charcoal (kJ/kg)	29,000	43,000
9	Specific Fuel consumption of the stoves (kJ/kg)	0.200	0.20

IV. CONCLUSION

Studies revealed that kerosene stove produced more harmful pollutants from the flame during its combustion which include; carbon monoxide, nitrogen dioxide and some particulate matters. This also resulted to darkening of the pot. Effort is however needed on how the rate of kerosene usage (as fuel for domestic cooking) can be reduced. The results obtained in this present study revealed that charcoal stove has higher performance efficiency with low fuel consumption as compared with the kerosene stove from the three-cooking experiments. Since charcoal is produced from wood, adoption of improved charcoal stove that is 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 Kerosene for cooking. Therefore, the newly developed charcoal stove will conveniently replace the kerosene stove and also provides a suitable channel for the combustion of other biomasses and briquettes for lower income earners and rural dwellers.

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