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Camporative Study on Efficiency of Some Common Charcoal Stoves for Domestic Application in Sokoto Metropolis.

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ABSTRACT
Considering the situation of Nigeria today, it is not easy to figure out any commodity that is cheap. Least you can get charcoal today in Sokoto is ₦100, which quantity is not even enough to cook food for a moderately large family. As a result, a more energy efficient stove need to be suggested to lower the amount of charcoal to be burned for cooking. This paper study four different types of charcoal stoves, which three are readily available in Sokoto, namely: Rim stove, Circular stove, Square stove, and Improved stove, which was fabricated. The proximate and ultimate analyses of the charcoal were carried out, the results of which 90.9 total carbon and 32,528.31kJ/kg^{o}CLower calorific Value (LCV). 1kg of the samples of the charcoal were fetched and added to each of the stoves. The stainless steel cooking pot was weighed and 3 kg of water added into it and placed on the glowing charcoal in the stove and time taken for the water to boil was noted. The wind speed of the day was noted at the beginning and the end of the experiment, which average was 65m/s. The results of the boiling test show that Stove 5 (Nansu or Improved) has a better economic implication than others with the least time for water to boil (30 minutes) and most efficient (24.42 %). This means that using the improved (Nansu) stove will give more efficient and economical cooking.
KEYWORD: Charcoal, Stove, Calorific-Value, Burning-Rate, Thermal-Efficiency, Latent-Heat

I. INTRODUCTION

Energy is at the heart of all human development. To this end, Sustainable Development Goal 7 (SDGoal 7) to ensure access for all to reliable, sustainable and modern energy services at an affordablecost is defined by the United Nations. However, millions of people around the world live in energypoverty, marked by lack of access to modern energy sources and lack of access to clean cooking energy (IEA, 2017). About 40% of households worldwide cook on open stoves or inefficient biomass cookingstoves. A World Bank study conducted in 2015 indicates that 81% of households in Sub-SaharanAfrica use solid fuels for cooking energy needs (Jagger and Das, 2018). Evrad et al., (2020) stated that recently, the special report Africa Energy Outlook 2019 published by the International Energy Agency (IEA), shows that about 850 millionpeople in Sub-Saharan Africa still use wood energy as their main source of energy.

The existence of cookers and other domesticheating equipment's dates back to the ancient times. Sincethe dawn of mankind, has been faced with the problem ofhow to efficiently cook and warm his environment and thishas been elusive. In this quest, man of Stone Age gatheredstones form tripod stove, between which wood is used asthe source of energy. The firewood as the first fuel to beused for cooking and heating purposes arise because of itsaccessibility and ready availability, especially in rural area (Haruna and Jibril, 2015 and Aliyuet al., 2003).

According to Sunil and Govinda (2013), about half of the world's population hascontinued to depend on biofuels, fuel wood, charcoal, cropresidue and dung- to provide energy requirement forcooking. However, households in industrialized countries have shifted to petroleum fuel and electricity; these optionsare not likely to become available to the rural areas.

As of 2011, about 1.26 billion people do not haveaccess to electricity and 2.6 4 billion people rely ontraditional biomass (fuelwood, charcoal, dung andagricultural residues) for cooking mainly in rural areas in developing countries. Under a baseline scenario,thenumbers of people without clean cooking facilitiescould remain almost unchanged in 2030 (Haruna and Jibril, 2015 and IEA, 2013). Household cooking consumes more energy than any other end –useservices in low

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-income developing countries (Daioglouet al., 2012 and IEA, 2006).

The cooking stoves used by households are not always efficient and pose serious environmental and health problems. Indeed, traditional three-stone cooking stoves are mostly used in rural areas. Traditional cooking stoves are most commonly used by low-income households. This type of traditional cooking stove is generally identified as a very inexpensive or free device, which may include a simple open fire, built on the ground with three stones to support a pot, or a basic ceramic, clay or metal stove. It is characterized by very low efficiency, unlike improved cooking stoves, which have better performance. Traditional cooking stoves in Africa have average energy efficiency scores ranging from 18% to 21% for wood-burning stoves and 21% to 24% for charcoal stoves (IEA, 2017). Meanwhile, these scores are much higher for improved cooking stoves. Several works are therefore being carried out to implement improved cooking stove technologies to improve household health and economy. Many cooking stove models have been implemented in many countries around the world (Akolgoet al., 2018).

Economic is one of the most paramount considerations today in choosing any appliance for use. Cooking stoves are not left out because of the cost of charcoal and woods today. The ability to be able to know the best stove or charcoal or wood to use will save a lot of cost expended for cooking.This research will recommend the best charcoal and stove for economic cooking

The objective of the research is to

- ✓ Fabricate different types of charcoal stoves
- ✓ Carryout proximate and ultimate analyses on some charcoal samples bought from the market
- ✓ Tests the stoves on boiling of water and cooking of rice
- ✓ Compare the efficiencies and performances of the various stoves.

II. MATERIALS AND METHODS

To perform the research, the following materials or equipment were made available: a cooking vessel, charcoal, Digital Thermometer, Ruler, anemometer, weighing scale, Charcoal Stoves of different construction (Five different types) and Water.

The rim stove, Square stove and the clay stove were all bought from the Kara market in Sokoto. The circular stove was bought at Federal low-cost, Arkilla, Sokoto, Sokoto state. The Nansu (improved) stove was fabricated at the workshop of the Umaru Ali Shinkafi Polytechnic, Sokoto. Charcoal was obtained from the seller in the market, which was identified to be obtained from Mahogany(Nze or Kadanbara) and was characterized as described below.

Proximate Analysis

Proximate analysis was carried out to determine the moisture content, volatile matter, fixed carbon, total carbon and ash content. The analysis was carried out in accordancewith the following standards. ISO 18134-3 for moisture content, ISO 1213 for volatile matter content, ISO 18122 for ash content and ISO 18123 for fixed carbon content.

Percentage Moisture Content

The Charcoal samples were crushed and pulverized into powder form. 1g of the pulverized charcoal samples was fetched and placed inside the crucible and closed. The content was inserted into a Muffle furnace and was heated at a temperature of 110^{o}C for 45min. The crucible was taken out and allowed to cool and weighed.

Percentage Volatile Matters

Samples of pulverized charcoal were dried and rendered moisture free and 1g inserted into the crucible. The sample was further heated in a crucible fitted with cover in a muffle furnace at a temperature of 1000^{o}C for 5min. The content were removed, cooled, weighed again, and the percentage volatile matter in the combustible components of the sample was determined.

Percentage Ash Content

1g weight of pulverized charcoal samples were placed in the crucible in presence of air at 800^{o}C in a muffle furnace till a constant weight is achieved. The crucible was weighed and 1g sample of solid charcoal were placed into the crucible and measured again. The samples were burnt in the presence of air at a temperature of 800^{o}C in a muffle furnace until constant weight was reached.

Percentage Fixed Carbon

The percentage fixed carbon was determined directly by deducting the total sum of moisture, volatile matter and ash percentage from 100 as:

%Fixed Carbon = 100 - (moisture content + volatile matter content + ash content)%.

The percentage total carbon of the sample was determined directly by adding the volatile matter and the fixed carbon together (%Total Carbon = Volatile matter + Fixed Carbon).

Ultimate Analysis

The ultimate analysis was carried out according to ASTM D5373 to reveal the H, C O, and N contents of the charcoal.

Determination of Calorific Value

This was carried out in accordance with ISO, ASTM, UNE and EN standard using an XRY-1A Model of Calorimeter.The outer bucket of the Bomb calorimeter was filled with water and stirred for even temperature. Samples of Charcoal were crushed and pulverized, after which 1g of the samples were weighed and placed into a crucible and placed into the holder. Oxygen was filled into the Bomb Calorimeter until the pressure in the oxygen bomb is 2.8MPa to 3.0MPa through the oxygen pipe. The oxygen bomb was placed on its seat in the inner bucket. Ignition wire was connected to the control case and the instrument covered and the sensor was inserted into the inner bucket. The power and the stir switches were turned on to show the inner bucket temperature and buzzer alarmed after 30 seconds and the indicated temperature recorded and the end button to end the test. The reading was checked to be 30,000kJ/kg.

Water Boiling Test

The water boiling test was carried out on Thursday, 15th September, 2022 from 10am. The stoves were weighed, then 1kg of sample of charcoal were also weighed, so also the pot and 3kg of water was weighed and poured into the pot and the temperature taken as well as the atmospheric temperature and room temperature. The first stove was ignited using safety matches and kerosene. It was allowed to glow and then the pot and water placed on it. The system was monitored until the water started boiling and the temperature taken. The water was allowed to cool and then the water was reweighed and the final mass taken. The charcoal was quenched dried in the Muffle Furnace and reweighed. The process continued in that format with other stoves. Average wind speed of the day was 64m/s.

III. RESULTS, ANALYSES AND DISCUSSIONS

Table 1: Proximate Analyses of the Two Charcoal Samples

S/N	Content	First Test	Second Test	Average
1	Moisture	6.8	6.5	6.7
2	Volatile matter	12.7	13.4	13.1
3	Ash	2.4	2.3	2.4
4	Fixed Carbon	78.1	77.4	77.8
5	Total Carbon	90.8	90.8	90.8

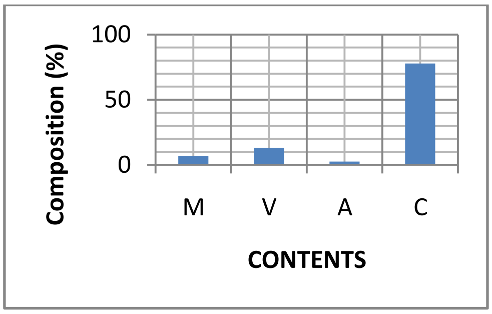

Fig. 1: Proximate Analysis Values of the Charcoal

From figure 1, drawn using table 1, it can be observed that the value of carbon content is very, which signifies that the charcoal is capable giving good burning. This is interestingly followed by the volatile matters, which themselves support burning, as such the tendency of the fuel to give good burning guaranteed. The low value of moisture content shows the ability of the charcoal to easily burn. Low content of ash mean that the charcoal is capable of given high calorific value, as such high heat could be produced from the burning of the fuel.

Table 2: Ultimate Analyses of the Two Charcoal Samples

S/N	Content	First Test	Second Test	Average
1	Carbon	53.6	52.5	53.1
2	Hydrogen	5.7	6.0	5.9

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3	**Oxygen**	**39.9**	**40.8**	**40.4**
4	**Nitrogen**	**0.8**	**0.7**	**0.8**
5	**LCV (kJ/kg)**			**32,528.31**

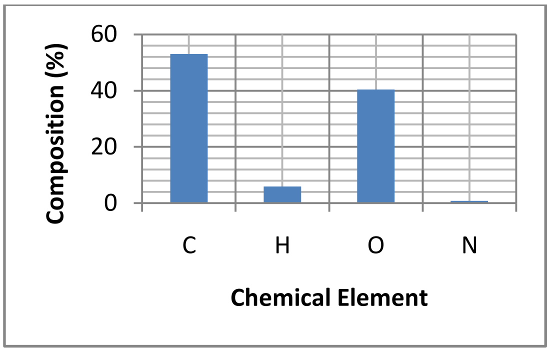

Fig. 2: Ultimate Analysis Values of the Charcoal

Figure 2 gives the results of the ultimate analysis, which are displayed in numbers in table 2. It can be seen that the carbon content is the highest, followed by oxygen content, showing the grate tendency of the charcoal to give good burning, with little or no smoke. Low hydrogen signifies low water content in the charcoal, as such its ability to burn easily. Low nitrogen gas (NO and NO_2) will be emitted, thereby checking atmospheric pollution through the formation of Nitric acid.

Table 3: Characteristics of the Stoves used for the research experiment

S/N	Type of Stove	Height (cm)	Width (cm)	Mass (kg)	Volume (m^3)	Density (Kg/m^3)
1	**Rim**	**30**	**38 (Dia)**	**3.24**	**0.136**	**23.82**
2	**Square**	**25**	**30**	**1.13**	**0.075**	**15.07**
3	**Circular**	**25**	**30 (Dia)**	**1.03**	**0.071**	**14.51**
4	**Clay**	**25**	**40 (Dia)**	**3.54**	**0.126**	**28.10**
5	**Nansu (Improved)**	**25**	**50 (Dia)**	**7.82**	**0.196**	**39.90**

NB: stove 1= Rim; stove 2 = Square; stove 3 = Circular; stove 4 = Clay; stove 5 = Nansu

Table 3 listed the five different types of stoves used in the research and their various characteristics, such as height, width mass, volume and density. These characteristic may have some contribution to the performance of each of the listed stoves, though no research has revealed that fro reference to be made to that.

Table 5: Water Boiling Testing Results with sample A of the Charcoal

S/N	Test Parameter	Stove 1	Stove 2	Stove 3	Stove 4	Stove 5
1	**Mass of Pot,Mp(kg)**	**0.42**	**0.42**	**0.42**	**0.42**	**0.42**
2	**Specific heat capacity of pot, C_p (kJ/kg°C)**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**
3	**Initial mass of Charcoal, M_{C1} (kg)**	**1**	**1**	**1**	**1**	**1**
4	**Final mass of charcoal, M_{C2} (kg)**	**0.89**	**0.88**	**0.86**	**0.87**	**0.90**
5	**Mass of charcoal burnt, M_{C3} (kg)**	**0.11**	**0.12**	**0.14**	**0.13**	**0.10**
6	**Specific heat capacity of water, C_w (kJ/kg°C)**	**4200**	**4200**	**4200**	**4200**	**4200**
7	**Initial mass of water in the pot,**	**3**	**3**	**3**	**3**	**3**

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	M_{w1} (kg)					
8	Final mass of water in the pot, M_{w2} (kg)	2.85	2.87	2.89	2.90	2.92
9	Mass of water loss from the pot, M_{w3} (kg)	0.15	0.13	0.11	0.10	0.08
10	Initial temperature of water in pot, T_{w1} (^oC)	30	30	30	30	30
11	Final temperature of water in pot, T_{w2} (^oC)	90	89	88	92	93
12	Time for water to boil, t (min)	32	33	35	36	30
14	Burning Rate of Charcoal (kg/min)	0.0025	0.0030	0.0034	0.0031	0.0023
15	Calorific value of the Charcoal, LCV (kJ/kg^{o}C)	32,528.31	32,528.31	32,528.31	32,528.31	32,528.31
16	Latent heat of vaporization of water, Q_L, (kJ/kg)	12,600	10,738	8,932	8,680	7,056
17	Useful Heat Delivered by Charcoal, Q_C (kJ)	757,890	706,996	731,783	782,068	794,364
18	Thermal Efficiency of stove, η_S (%)	23.29	22.90	22.50	24.04	24.42

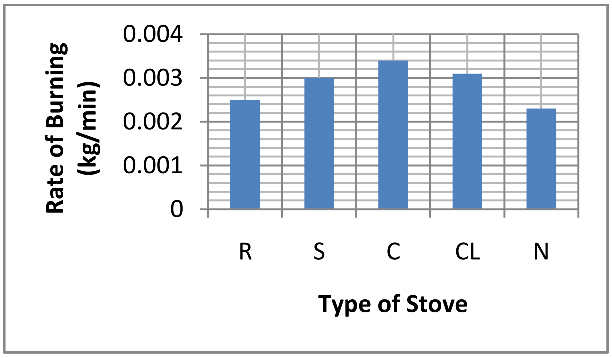

Fig. 3: Burning Rate of Charcoal in Various Stoves

Figure 3 display the rate of burning of the charcoal in the various stoves. It can be observed that stove C, that is, the circular stove has the tallest bar, indicating the charcoal was consumed faster in it than any other stove. The least being the improved stove (N), with a value slightly above 0.002 (0.0023 precisely), which indicate least charcoal consumption during the water boiling test. It can be deduced here that Nansu (improve) stove is the best for economical cooking.

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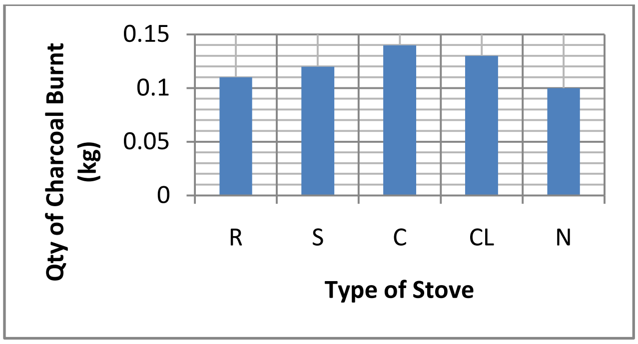

Fig. 4: Quantity of Charcoal Burnt in various Stoves

From figure 4 it can be observed that stove C still has the highest charcoal consumption, with almost 0.15 quantity of charcoal burnt, while stove N has the least quantity of charcoal burnt. The implication of this is that improved stove is more economical in charcoal consumption than any of the remaining stoves, as such is will be a better choice for economic reason.

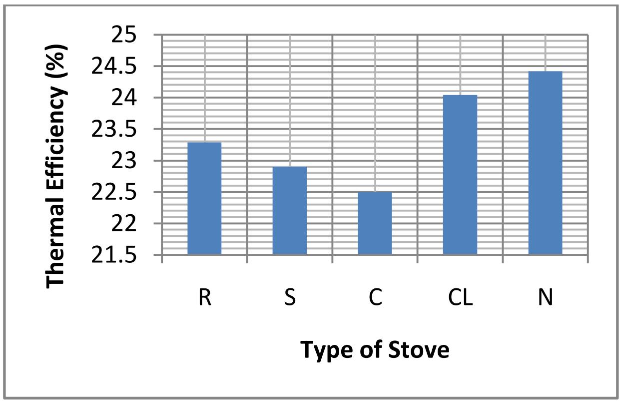

Fig. 5: Thermal Efficiencies of the various Stoves

The most efficient stove is N as indicated on figure 5, while, stove C is the least efficient stove from the five stoves, with efficiency of 24.42%, closely followed by stove CL (24.04%). Therefore, for efficient cooking, the best stove is the Nansu (improved) stove (22.48%). The high efficiencies of the two stoves (CL and N) may be connected to the insulating nature of the two, such that there was minimal heat lost through conduction from the body of the stoves.

IV. CONCLUSION

From the outcome of the research, it can be concluded that the improve stove is the best in all ramification; as such it is advised that every household should acquire it for fater and economical cooking.

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REFERENCES

[1]. Akolgo, G. A., Essandoh, E. O., Gyamfi, S., et al. (2018) The potential of a dual purpose improved cooking stove for low income earners in Ghana-Improved cooking methods and biochar production. Renewable Sustain Energy Rev 82: 369–379.

[2]. Aliyu, A; Ismaila, B.E; and Samuel, A.M, (2003). Design and Construction of A Two-Hole Kerosene Cooker, Student’s Project, Department of Mechanical Engineering, Niger State Polytechnic, Zungeru.

[3]. Daioglou, V., van Ruijven, B. J. and van Vuuren, D.P. (2012), Model projections for household energy use in developing countries, Energy 37 (1):601-615.

[4]. Evrard, K. E., Latif, A. F., Stephen, J. Z. and Jihane, B.(2020). Energy performance, safety and durability of charcoal cooking stoves commonly used in West Africa: Benin case study.

[5]. AIMS Energy, 9(1): 68–95. DOI:10.3934/energy. 2021005 Received: 13 August 2020 Accepted: 01 December 2020, Published: 15 December 2020.

[6]. Haruna, M. M.and Jibrin, A. (2015).Comparative Performance Evaluation of two Improved Clay – Lined Charcoal Cook Stove. International Journal of Engineering Research andTechnology (IJERT) ISSN: 2278-0181. IJERTV4IS040239 www.ijert.org.

[7]. International energy agency (2017) WEO-2017 special report: Energy access outlook.

[8]. International Energy Agency (2013), World Energy Outlook, Chapter 2 Extract,"Modern Energy for All".

[9]. International Energy Agency, (2006) World Energy Outlook, 2006

[10]. Jagger, P. and Das, I. (2018) Implementation and scale-up of a biomass pellet and improved cooking stove enterprise in Rwanda. Energy Sustain Development 46: 32–41.

[11]. Sunil, M. and Govinda, R. T. (2014). Household Cooking Fuel Choice and Adoption of Improved Cook stoves in Developing Countries", A Review Policy Research Working Paper 6903. The World Bank Development Research Group Environment and Energy Team.