Sospoly Journal of Engineering, Entrepreneurship & Environmental Studies,
Vol. 5, Issue 1, July. 2023, ISSN: 2536-7183
Available Online At http://uaspolysok.edu.ng/sospolyjeee/

COMPARATIVE STUDY ON THE EFFICIENCY OF CHARCOALS DERIVED FROM TWO TYPES OF TREES USING IMPROVED STOVE

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ABSTRACT

Considering the country's situation today, it is not easy to figure out any commodity that one can say is cheap. At least you can get Charcoal today in Sokoto is ₦100, which is not enough to cook food for a moderately large family. As such, seeking an alternative efficient cooking stove is necessary. The research is designed to identify the best charcoal cooking between two charcoals in terms of energy performance, safety and sustainability and recommend that domestic application cook meals at a cheaper rate and safe conditions effectively. A representative sample of types of Charcoal from two different trees in Nigeria that are commonly used in the Sokoto metropolis will be tested according to the requirements of the ISO 1986 standard. These are charcoal from Shear-Butter (Kade/Ukopi) tree and Mahogany (Madaci/Nze) charcoals. The process that was used in the execution of the research will be to obtain two different types of Charcoal from vendors and carry out the proximate and ultimate analyses and Calorific values of the different charcoals bought. To boil water and cook some quantity of Rice using the two different types of charcoals to compare their heating rate and suggest the best Charcoal to be used by every household for economic purposes. The charcoals were acquired and tested using proximate and ultimate analyses, and the Calorific value was found. After this, water heating and rice cooking tests were performed using each Charcoal. The research results show that charcoal B is better for fast and economical cooking than sample A. The least Charcoal burning rate is 0.0021 for B and 0.0023 for A, the least time for cooking of 28 minutes for B and 30 minutes for A in water heating and 43 minutes for B and 44 for A in rice cooking, and the highest Efficiency is 24.67 for B as against 24.42 for A.

Keywords: *Calorific, Cooking, Charcoal, Efficiency, Energy, Heat, Sustainable, Thermal*

INTRODUCTION

Energy is at the heart of all human development. To this end, Sustainable Development Goal 7 (SD Goal 7) ensures access to all reliable, sustainable and modern energy services at an affordable cost as defined by the United Nations. However, millions worldwide live in energy poverty, marked by a lack of access to modern energy sources and clean cooking energy (IEA, 2017). About 40% of households worldwide cook on open or inefficient biomass cooking stoves. A World Bank study conducted in 2015 indicates that 81% of households in Sub-Saharan Africa 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 million people in Sub-Saharan Africa still use wood energy as their primary energy source.

The existence of cookers and other domestic heating equipment dates back to ancient times. Since the dawn of humanity, he has been faced with the problem of how to cook and warm his environment efficiently, which has yet to be elusive. In this quest, a man of the Stone Age gathered stones from a tripod stove, using wood as the energy source. Firewood was the first fuel to be used for cooking and heating because of its accessibility and ready availability, especially in rural areas (Haruna and Jibril, 2015 Aliyu *et al.*, 2003).

According to Sunil and Govinda (2013), about half of the world's population has continued to depend on biofuels, fuel wood, Charcoal, crop residue and dung- to provide energy requirements for cooking. However, households in industrialized countries have shifted to petroleum fuel and electricity; these options will likely be limited to rural areas.

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. Under a baseline scenario, the number of people without clean cooking facilities could remain almost unchanged in 2030 (Haruna and Jibril, 2015 IEA, 2013). Household cooking consumes more energy than other end–use services in low-income developing countries (Daioglou *et al.*, 2012 and IEA, 2006).

Statement of Problem

Economics 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 wood today. Knowing the best stove or Charcoal or wood to use will save much cost for cooking. This research will recommend the best Charcoal for economical cooking in rural homes.

Objectives of the Research

The objective of the research is to:

- ✓ Acquire charcoal samples from two types of trees.
- ✓ Carry out proximate and ultimate analyses on the two samples of Charcoal bought from the market.
- ✓ Tests the two samples of charcoals in boiling water and cooking Rice.
- ✓ Compare the efficiencies and performances of the two stoves.

LITERATURE REVIEW

There are 2.8 billion people, or 38% of the world's population and nearly 50% of the population in developing countries who live without access to modern sources of cooking energy to cook food (IEA, 2017). In Africa, the number of people without access to modern sources of cooking energy exceeded 900 million in 2018. This situation forces people to rely mainly on traditional solid fuels (firewood and Charcoal) (IEA, 2019). Household cooking stoves are only sometimes efficient and pose serious environmental and health problems. Indeed, traditional three-stone cooking stoves are primarily used in rural areas. Low-income households must use traditional cooking stoves. 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 bare ceramic, clay or metal stove. It is characterized by very low Efficiency, unlike improved cooking stoves, which perform better. 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 the economy. Many cooking stove models have been implemented in many countries worldwide (Akolgo *et al.*, 2018). These different programs have had mixed but generally unsatisfactory results. These authors recommend that cooking stove designers consider smoke, heat removal, and fuel availability before other factors in cooking stove design. Several studies show that improved cooking stoves save not only wood or Charcoal but also cooking time and cooking drudgery (Guzman *et al.*, 2020; Tigabu, 2017; Adkins *et al.*, 2010). Some studies suggest "rocket" technologies for cooking stove design (Adkins *et al.*, 2010). The improved cooking stove is a cooking appliance with higher energy efficiency than the traditional cooking stove. There are different types of improved cooking stoves in different countries and regions. It is known by different names taken from local languages (such as Sakkanal and diambar in Senegal, sewa in Mali, Kenyan Jiko in Kenya, Nansu in Benin, Ouaga métallique in Burkina, etc.). Different materials are used to design improved cooking stoves, including clay, cow dung, sheet metal, and ceramic materials (IFDD, 2011).

The real problem in developing countries is that some cooking stoves come onto the market and are marketed as improved cooking stoves without prior testing and studies having been carried out on these Cooking stoves. The other problem often encountered is that cooking stoves improved for energy performance are not durable and need to offer sufficient safety to users and are therefore not economically viable. Energy performance should not be separated from safety and durability. Therefore, this study fills this gap by studying the performance (safety, energy efficiency and durability) of the different cooking stove technologies available on the Beninese market (Evrad *et al.*, 2020).

The study of the energy performance and safety of cooking stoves has been addressed in previous research work. Although these studies still need to address the combined analysis of the two parameters of energy performance and cooking stove safety, they have attempted to study them separately. The energy performance of cooking stoves has long been a concern for the various researchers in the field because of the close link between them and the consumption of solid fuel, the preservation of the environment and the household economy. In Benin, for example, the performance of cooking stoves has been evaluated by the water boiling technique (Anjorin *et al.*, 2009). This study revealed that losses are higher for metal and clay stoves. Another study reveals that in Benin, fossil fuel stoves have the best economic performance, but the meager cost of wood fuels gives them an advantage (Anjorin *et al.*, 2014). A comparative study of two traditional improved cooking stoves (clay and Malagasy) indicates that the clay-improved cooking stove performs better than the Malagasy cooking stove (Sagbefia *et al.*, 2018). Chica and Pérez (2019) designed and evaluated a biomass-improved cooking stove for developing countries. The actual cooking stove is a rocket stove. Water boiling tests conducted on this cooking stove revealed an average energy efficiency of 20.9% with a boiling time of 31.6 minutes. The thermal and emission performance of biomass stoves is being tested in Nigeria (Okafor, 2019), and water boiling tests (WBT) and food cooking tests (Rice and beans) have been carried out. The results indicate that of the 15 charcoal stove samples tested, 62% met the minimum Tier 2 standard, while 51% of the ten 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. Water boiling tests conducted on aluminum stoves in Ghana indicate that the thermal Efficiency of the stove compared to the traditional stove is much improved (Otoo, 2018). According to another study in Ghana (Obeng *et al.*, 2017), wood-burning stoves have an energy efficiency of 12.2 ± 5.00%, charcoal stoves 23.3 ± 0.73%, and Gyapa charcoal stoves 30.00 ± 4.63%. These authors recommend switching to and adopting Gyapa charcoal cooking stoves to increase efficiency and reduce emissions.

As seen above, much work is being done to improve the energy efficiency of cooking stoves and reduce solid fuel consumption. However, the safety and durability of cooking stoves have long been overlooked. Thus, for developing countries, Johnson and Bryden (2015) sought to reduce injuries and other incidents created by the use of cooking stoves on household members by proposing ten (10) safety guidelines for solid fuel cooking stoves (Johnson & Bryden, 2015). The authors' Cooking Stove Safety Rating Grid will serve as a reference or decision support tool for designers of improved cooking stoves and users. Other authors have evaluated cooking stove safety protocols in low-income and middle-income countries (Gallagher *et al.*, 2016). These authors sought to assess whether the ten tests proposed by the biomass stove safety protocol (BSSP) are reliable and meet the requirements. They sought to determine whether this test would produce repeatable safety scores over a series of tested cooking stoves. The results show that significant differences are obtained for each tester. It is concluded that the BSSP is an important starting point for evaluating safety tests but that some of its aspects need improvement. The different cooking stoves commonly used in households in Benin and the West African sub-region have yet to be the subject of a scientific study considering the combined analysis of these cooking stoves' energy performance, safety and durability. Therefore, this study fills this gap by focusing initially on the most commonly used charcoal cooking stoves in the Sokoto metropolis (Evrad *et al.*, 2020).

METHODOLOGY

To perform the tests, the following equipment will be required:

(1) A cooking pot; (2) Charcoal (two samples); (3) The vernier caliper and the ruler; (5) an anemometer; (6) An electron ic scale; (7) Charcoal cooking Stove; (8) Water; (9) Rice

Acquisition of Charcoal

Two Bags of Charcoals were bought from two different sellers: Malam Nura Abdullahi and Zayyanu Yakubu, prepared from different types of trees. However, the sellers did not identify the trees, as they both bought them. Though according to Nura, the Charcoal obtained from him seemed to be that of a Mahogany (Madaci/Nze) tree from his observation, while Zayyanu thought the Charcoal bought from him should be from a Shear-butter (Kade/Ukopi) tree. The two are designated as A and B, respectively.

Type A **Type B**

Plate 1: Samples of the two different types of Charcoal used

Proximate Analysis of the Two Different Charcoals

Proximate analysis was carried out according to 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. It involves determining moisture content, volatile matter, fixed carbon, and ash content. It was carried using an XD-1200N Muffle Furnace.

Moisture Contents of the Charcoal Samples

The Charcoal samples were crushed and pulverized into powder form. The crucible was weighed using a weighing balance and was 2g. 1g of the pulverized charcoal samples was fetched, placed inside the crucible, and closed. The content kept inside the silica crucible and the crucible was measured to be 3g. It was then heated in a muffle furnace at a temperature of 110°C for 45 min. The crucible was taken out, allowed to cool in a desiccator, and weighed. The percentage of moisture content is given by:

$$\mathbf{MC\%} = \frac{W_{S1} - W_{S2}}{W_{S1}} \quad \mathbf{(1)}$$

Where: W_{S1} = weight of the sample of pulverized Charcoal before heating.
W_{S2} = weight of the sample pulverized Charcoal after heating.

Volatile Matters of the Charcoal Samples

Samples of pulverized were dried and rendered moisture free, and 1g was inserted into a crucible and weighed to be 3g. The sample was further heated in a crucible fitted with a cover in a muffle furnace at a temperature of 1000°C for 5 min. The content was removed, cooled and weighed again, and the percentage of volatile matter in the combustible components of the sample was determined.

Ash Content of the Charcoal Samples

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

Fixed Carbon of the Charcoal Samples

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

%Fixed Carbon = 100 - (moisture content + volatile matter content + ash content) % **(2)**

Total carbon

The sample's total carbon percentage was determined directly by adding the volatile matter and the fixed carbon together.

%Total Carbon = Volatile matter + Fixed Carbon **(3)**

Calorific Values of the Charcoal Samples

This was carried out in accordance with ISO, ASTM, UNE and EN standards, using an XRY-1A Model of Calorimeter. The outer bucket of the Bomb calorimeter was filled with water and stirred for an 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 and fix two ends of the ignition wire on the two conductive poles, with the ignition wire touching the pulverized Charcoal. Oxygen was filled into the Bomb Calorimeter until the pressure in the oxygen bomb was 2.8MPa to 3.0MPa through the oxygen pipe. The oxygen bomb was placed on its seat in the inner bucket. The ignition wire was connected to the control case, the instrument was 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 the buzzer alarmed after 30 seconds, and the indicated temperature was recorded. The end button was to end the test. The exact process was repeated for sample B of the Charcoal. The results of the two tests show that:

- The calorific value of Charcoal **A = 30,000 kJ/kg**
- The calorific value of Charcoal **B = 31,000 kJ/kg**

Ultimate Analyses of the Charcoal Samples

The ultimate analysis was carried out according to ASTM D5373 and D3176 to determine the carbon (C), hydrogen (H), oxygen (O), Nitrogen (N) and sulphur (S) contents of the Charcoal (Fuel). This was done by EN using the Thermo-Flash 1112 Microanalyser.

Table 1: American Standard of Testing and Measurement

S/N	Elements	Methods	Version
1	Carbon	ASTM D5373	ASTM, 1993
2	Hydrogen	ASTM D5373	ASTM, 1993
3	Oxygen	ASTM D3176	ASTM, 1989
4	Nitrogen	ASTM D5373	ASTM, 1993
5	Sulphur	ASTM D5373	ASTM, 1993
6	Ash	ASTM D3174	ASTM, 2012

Source: Evrad *et al*, (2020)

Water Boiling Test of the various Stoves

The water was boiling on Thursday, 15th September 2022, at 10 am. The stoves were weighed, the 1kg each of the two samples of Charcoal was also weighed, so also the PotPot was weighed, and 3kg of water was weighed and poured into the PotPot 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 PotPot and water were placed on it. The system was monitored until the water started boiling, and the temperature was taken. The water was allowed to cool, and then the water was reweighed, and the final mass was taken. The Charcoal was quenched, dried in the Muffle Furnace, and reweighed. The process continued in that format with other stoves. The average wind speed of the day was 64m/s.

Plate 1: The PotPot used for the cooking test

Rice Cooking Test of the Various Stoves

The rice cooking test was conducted on Saturday, 17th September 2022, at 10 am. The process was similar to the water boiling test, only that in this stage, one mudu (1.25kg) of Rice was measured and added to the PotPot, and 1.5kg of water was added to the Rice. The contents and the PotPot were placed on the fire for the cooking test. As in the water boiling test above, the stoves were used one after. After the Rice had been tested to be cooked, the contents and the PotPot were brought down. The Charcoal was quenched and dried using the Muffle Furnace and reweighed. The average wind speed was 67m/s.

Plate 2: Improved Stove

RESULTS AND DISCUSSIONS

This section display, analyze and discuss the results of the experiment done in the research.

Experimental Results

Below are the tables of readings obtained from the experiments done in the research.

Table 2: Proximate Analyses of the Two Charcoal Samples

S/N	CONTENT (%)	SAMPLE OF CHARCOAL	1ST READING	2ND READING	AVERAGE
1	Moisture	A	6.8	6.5	6.7
		B	6.2	5.9	6.1
2	Volatile matter	A	12.7	13.4	13.1
		B	15.2	16.0	15.6
3	Ash	A	2.4	2.3	2.4
		B	2.0	1.8	1.9
4	Fixed Carbon	A	78.1	77.4	77.8
		B	76.6	76.3	76.5
5	Total Carbon	A	-	-	90.9
		B	-	-	92.1

Source: Laboratory Analysis

Table 3: Ultimate Analyses of the Two Charcoal Samples

S/N	CONTENT (%)	SAMPLE OF CHARCOAL	1ST READING	2ND READING	AVERAGE
1	Carbon	A	53.6	52.5	53.1
		B	53.9	53.9	53.9
2	Hydrogen	A	5.7	6.0	5.9
		B	5.6	5.6	5.6
3	Oxygen	A	39.9	40.8	40.4
		B	39.8	39.6	39.7
4	Nitrogen	A	0.8	0.7	0.8
		B	0,7	0.7	0.7
5	Calculative value of LCV (kJ/kg)	A			32,528.31
		B			33,238.32
6	Experimental Value of LCV (kJ/kg)	A			30,000
		B			31,000
7	Error (%)	A			8.43
		B			10.45

Source: Laboratory Analysis

From the above table, the lower calorific values (LCV) of the charcoals can be calculated using Dulong's formula below:

$$\mathbf{HCV} = \frac{1}{100}\left[8080C + 34500\left(H + \frac{0}{8}\right) + 2240N\right] \text{ kcal/kg} \quad (4)$$

$$LCV = \left[HCV - \frac{9H}{100}\ x\ 587\right] kcal/kg \quad (5)$$

With the data obtained from the ultimate analyses, S is replaced with N and taking 1kcal = 4.184kJ:

Table 4: 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)
5	Improved Stove	25	50 (Dia)	7.82	0.196	39.90

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

S/N	Test Parameter	Value
1	Mass of Pot, Mp (kg)	0.42
2	Specific heat capacity of PotPot, C_p (kJ/kg^{o}C)	0.50
3	The initial mass of Charcoal, M_{C1} (kg)	1
4	The final mass of Charcoal, M_{C2} (kg)	0.90
5	Mass of Charcoal burnt, M_{C3} (kg)	0.10
6	Specific heat capacity of water, C_w (kJ/kg^{o}C)	4200
7	The initial mass of water in the PotPot, M_{w1} (kg)	3
8	The final mass of water in the PotPot, M_{w2} (kg)	2.92
9	Mass of water loss from the PotPot, M_{w3} (kg)	0.08
10	The initial temperature of water in PotPot, T_{w1} (^{o}C)	30
11	The final temperature of water in PotPot, T_{w2} (^{o}C)	93
12	Time for water to boil, t_b (min)	30
14	Burning Rate of Charcoal (kg/min)	0.0023
15	The calorific value of the Charcoal, LCV (kJ/kg^{o}C)	32,528.31
16	Latent Heat of vaporization of water, Q.L., (kJ/kg)	7,056
17	Useful Heat Delivered by Charcoal, Q_C (kJ)	794,364
18	Thermal Efficiency of the stove, η_S (%)	24.42

Source: Laboratory Test Results

Table 6: Water Boiling Testing Results with sample B of the Charcoal

S/N	Test Parameter	Value
1	Mass of Pot, Mp (kg)	0.42
2	Specific heat capacity of PotPot, C_p (kJ/kg^{o}C)	0.50
3	The initial mass of Charcoal, M_{C1} (kg)	1
4	The final mass of Charcoal, M_{C2} (kg)	0.88
5	Mass of Charcoal burnt, M_{C3} (kg)	0.12
6	Specific heat capacity of water, C_w (kJ/kg^{o}C)	4200
7	Initial mass of water in the PotPot, M_{w1} (kg)	3
8	Final mass of water in the PotPot, M_{w2} (kg)	2.90
9	Mass of water loss from the PotPot, M_{w3} (kg)	0.10
10	Initial temperature of water in PotPot, T_{w1} (^{o}C)	30
11	Final temperature of water in PotPot, T_{w2} (^{o}C)	95
12	Time for water to boil, t_b (min)	28
14	Burning Rate of Charcoal (kg/min)	0.0021
15	Calorific value of the Charcoal, LCV (kJ/kg^{o}C)	33,238.32
16	Latent Heat of vaporization of water, Q.L., (kJ/kg)	9,100
17	Useful Heat Delivered by Charcoal, Q_C (kJ)	845,138

18	Thermal Efficiency of the stove, η_S (%)	24.67

Latent Heat of vaporization of water can be determined using the following formula:

$$M_{W1}C_W(T_{W2} - T_{W1}) = M_{W1}Q_L + M_{W2}C_W(T_{W2} - T_{W1}) \qquad \textbf{(6)}$$

Where: M_{W1} = Initial mass of water in pot; M_{W3} = mass of water evaporated; C_W = specific heat capacity of water; L_V = latent heat of water; T_{W1} = initial temperature of water; T_{W2} = final temperature of water

From which the latent Heat, Q.L. will be made the subject of the formula to be able to calculate it.

The thermal Efficiency of the charcoal samples can be calculated from Table 4 using the formula (7):

$$\eta_{stv} = \frac{M_{W1}C_W(T_{W2} - T_{W1}) + M_{W3}Q_L}{M_{C1}Q_C} \qquad \textbf{(7)}$$

Where: η_{stv} = Efficiency of the stove; M_{W1} = initial mass of water in the PotPot; C.W. = specific heat capacity of water; M_{C3} = Mass of Charcoal burnt; Q.C. = Useful energy delivered by Fuel; Q.L. = Latent Heat of vaporization of water; T_{W1} = Initial temperature of water; T_{W2} = Final temperature of water.

Table 7: Rice Cooking Testing Results with sample A of the Charcoal

S/N	Test Parameter	Value
1	Mass of Pot, Mp (kg)	0.42
2	Specific heat capacity of PotPot, C_p (kJ/kg^{o}C)	0.50
3	Initial mass of Charcoal, M_{C1} (kg)	1
4	Final mass of Charcoal, M_{C2} (kg)	0.60
5	Mass of Charcoal burnt, M_{C3} (kg)	0.40
6	Mass of Rice Added to the PotPot (kg)	1.25
7	Specific heat capacity of water, C_w (kJ/kg^{o}C)	4200
8	Initial mass of water in the PotPot, M_{w1} (kg)	1.5
9	Final mass of water in the PotPot, M_{w2} (kg)	2.92
10	Mass of water loss from the PotPot, M_{w3} (kg)	0.08
11	Initial temperature of water in PotPot, T_{w1} (^{o}C)	30
12	Final temperature of water in PotPot, T_{w2} (^{o}C)	93
14	Time for Rice to cook, t (min)	44
15	Burning Rate of Charcoal (kg/min)	0.0091
16	Calorific value of the Charcoal, LCV (kJ/kg^{o}C)	32,528.31
17	Latent Heat of vaporization of water, Q.L., (kJ/kg)	7,056
18	Useful Heat Delivered by Charcoal, Q_C (kJ)	794,364

Source: Laboratory Test Results

Table 8: Rice Cooking Testing Results with sample B of the Charcoal

S/N	Test Parameter	Value
1	Mass of Pot, Mp (kg)	0.42
2	Specific heat capacity of PotPot, C_p (kJ/kg^{o}C)	0.50
3	Initial mass of Charcoal, M_{C1} (kg)	1
4	Final mass of Charcoal, M_{C2} (kg)	0.58
5	Mass of Charcoal burnt, M_{C3} (kg)	0.42
6	Mass of Rice Added to the PotPot (kg)	1.25
7	Specific heat capacity of water, C_w (kJ/kg^{o}C)	4200
8	Initial mass of water in the PotPot, M_{w1} (kg)	1.5
9	Final mass of water in the PotPot, M_{w2} (kg)	2.90
10	Mass of water loss from the PotPot, M_{w3} (kg)	0.10
11	Initial temperature of water in PotPot, T_{w1} (^{o}C)	30
12	Final temperature of water in PotPot, T_{w2} (^{o}C)	95
14	Time to cook Rice, t (min)	40
15	Burning Rate of Charcoal (kg/min)	0.0097
16	Calorific value of the Charcoal, LCV (kJ/kg^{o}C)	33,238.32
17	Latent Heat of vaporization of water, Q.L., (kJ/kg)	9,100
18	Useful Heat Delivered by Charcoal, Q_C (kJ)	845,138

Source: Laboratory Test Results

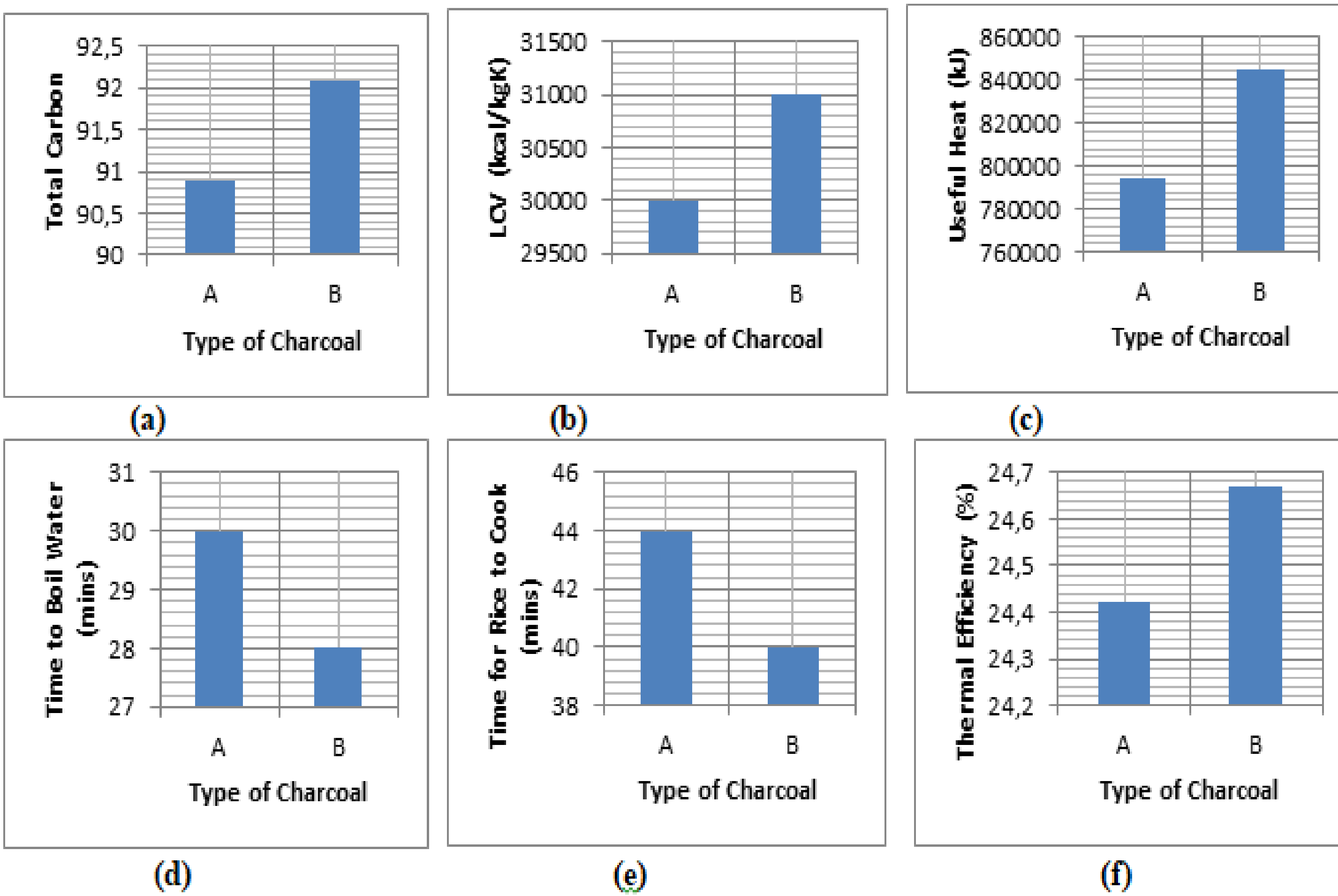

Fig. 1: Chart showing the Comparative behaviors of the Two Charcoals used
(a) is the total carbon in each of the Charcoals, (b) is the Lower Calorific Values of the two Charcoals, (c) is the Useful Heat delivered by each Charcoal, (d) is the time taken to boil water used, (e) is the time taken to cook the amount of Rice used and (f) is the Thermal Efficiency of each Charcoal.

DISCUSSION OF THE RESULTS

From the research, it was found that the results of proximate analyses of the two Charcoal samples differed, as well as the Ultimate analyses. This was due to the difference in the species of the trees obtained. This resulted in the difference of their total carbon, where in Table 2, Charcoal A has 90.9, and B has 92.1 and also their theoretical lower calorific values, as shown in Table 3, indicated that A has 32,528.31kJ/kg^{o}C, while B has 33,238.32kJ/kg^{o}C. The Experimental values of the calorific values were slightly different from those of calculative values, as stated in Table 3, as 30,000 vs. 32,528.31 for sample A and 31,000 vs. 33,238.32 for sample B, resulted in an error of 8.43 for A and 10.45 for B. These results affected the performances of the two samples of Charcoals. According to Table 4, the thermal efficiencies of the two Charcoal shows that A is 24.42% and B is 24.67%. Their proper Heat delivered in boiling water is 792,36kJ for the Charcoal sample A, while the B value is 845,14kJ. The proper Heat delivered in cooking rice is 794,36kJ for Charcoal sample A, while sample B has 845,14kJ. The two helpful Heat delivered are affected by their thermal efficiencies.

CONCLUSION

From the results, it can be concluded that sample of Charcoal B from the Shear-Butter (Kade/Ukopi) tree is better than that of sample A from Mahogany (Madaci/Nze) for economic purposes based on the variation in their LCV, applicable Heat delivered, time to boil water and to cook Rice and the thermal efficiencies. Therefore, it is advised for a household to purchase Charcoal made from Shear-Butter for efficient cooking.

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