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Energy Efficiency Evaluation from the Combustion of Selected Briquettes-Derived Agro-waste with Paper and Starch Binders

Godson Rowland Ana, Victor Tolulope Fabunmi

Department of Environmental Health Sciences, Faculty of Public Health, College of Medicine, University of Ibadan, Ibadan, Nigeria

Email address:
victorfabunmi@yahoo.com (V. T. Fabunmi)

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Abstract: A lot of agricultural residues and wastes generated in the country are improperly utilized and poorly managed. The bulk is left to decompose or blazed, resulting in environmental pollution and degradation. Studies have shown that briquetting provides a means of managing this waste as fuels however, energy efficiency of this process has not been investigated extensively. This study investigated the energy efficiency associated with combustion of selected briquettes-derived agro-waste. An experimental design was adopted that involved comparing the energy efficiency from the combustion of biomass briquettes of sawdust (SD) from different trees, rice husk (RH), coconut shell (CS) and corncob (CC) with paper (p) and starch (s) binders with wood (control). Energy parameters which include calorific value (CV), bulk density (BD), and energy density (ED) were measured. Energy efficiency parameters such as water boiling time (WBT), Mass of biomass used (MB), Burning Time (BT), Burning rate (BR) and Recoverable energy (RE) from the combustion of 0.5kg mass of each of the briquette treatments in comparison with the wood was obtained. The energy parameters of the biomass briquettes ranged 12.3 – 19.6 kJ/g, 0.27 – 0.75 g/cm^3 and 3.9 – 13 KJ/cm^3 for CV, BD and ED respectively. The ranges of the thermal properties based on the water boiling test carried out included water boiling time, mass of biomass used and burning time were 7.75 – 62.5 min, 150 – 390 g and 53.5 – 143 min respectively. Although sawdust briquettes took least time to boil water, coconut briquettes burned efficiently in terms of material conservation and duration of burning. Therefore coconut and sawdust briquettes are both viable alternative fuel sources to firewood.

Keywords: Agrowaste, Biomass Briquettes, Energy Efficiency, Water Boiling Test

1. Introduction

Energy serves as the major driving force of any country's economic growth and development. Its importance cannot be overemphasized as it is essential for the production of goods and services in various sectors viz: industries, transport, agriculture, health and education sectors, as well as instrument for politics, security and diplomacy (Sambo, 2009; Ohunakin, 2010). Nigeria, with a population of 170,123,749 in 2012, an annual growth rate of 2.55%, has over 95% of foreign income earnings and about 80% of budgetary allocation come from oil (CIA, 2012), national income from energy measured up to 25.24% of the GDP between 2002 and 2006 (Sambo, 2009).

However, her sole dependence on oil and gas as the major source of revenue and the uncertainty in governance has opened the nation to global energy crisis (Iwayemi, 2008). Electricity demand for instance, decreases with increase in population. It is evaluated that about 40% of the population and as low as 18% in the rural areas is connected to the national grid system and they lack power supply for more than 60% of the time. It was further stressed that even connection on the grid experiences regular outage that can span for 20 hours daily (Okoye, 2007; Simoyan and Fasina, 2013; Akande and Olurunfemi, 2009).

Of 4.6 EJ or 111MTOE evaluated energy consumed in Nigeria in 2009, biomass had the largest share of about 85%, followed by crude oil with 9.3%, natural gas and hydropower sources had 5.4% and 0.4%, respectively (IEA, 2012). Moreover, despite the contribution of 70% of the Oil and gas industry to national GDP, it is fairly low as compared with the biomass utilization. Table 1 explains total energy demand at 10% GDP growth rate at million tonnes of oil equivalent (mtoe) between 2005 and 2030. It was found highest at the household level in 2005 while projected to be highest at this progression in industry in 2030. Hence, there is need to exploit the nation's energy potential (ECN, 2008).

A lot of agricultural residues and wastes are generated in the country, but poorly utilized and inappropriately managed, since most of these wastes are left to decompose or burned, resulting in environmental pollution and degradation (Jekayinfa and Omisakin, 2005).

Table 1. *Total Energy demand based on 10% GDP growth rate (Mtoe).*

Item	2005	2010	2015	2020	2025	2030	Average Growth Rate (%)
Industry	8.08	12.59	26.03	39.47	92.34	145.21	16.2
Transport	11.7	13.48	16.59	19.7	26.53	33.36	4.7
Household	18.82	22.42	28.01	33.6	33.94	34.27	2.6
Services	6.43	8.38	12.14	15.89	26.95	38	8.7
Total	45.03	56.87	82.77	108.66	179.76	250.84	8.3

(Energy Commission of Nigeria, 2008)

It has been proposed that the conversion of agro-wastes through briquetting process will go a long way in reducing waste disposal problems. Moreover, this provides an alternative use to agrowaste as fuel source thereby a considerable reduction in the burden on deforestation for energy purpose.

Agricultural biomass waste through briquetting can substantially displace fossil fuel, reduce emissions of greenhouse gases and provide renewable energy to people in developing countries. Scientific studies have concluded that a lot of potential energy abounds in agricultural residues/wastes (Jekayinfa and Scholz, 2009). These residues could be used to generate heat for domestic and industrial cottage applications (Oladeji, *et al*., 2009). A briquette is a block of compressed biomass or charcoal dust that is used as fuel to start or maintain fire (Grainger *et al*., 1981). The shredding, binding and compacting of the biomass into briquettes helps to reduce the surface area, air pollution from particulates and improves mobility, storage, heat and usage of the biomass (Martin *et al.,* 2008; Olorunisola, 2007).

Briquettes of agricultural wastes through the extrusion process have been studied considerably (Grover and Mishra, 1996; Chin and Siddiqui, 2000; Ndiema *et al*., 2002; Husain *et al*., 2002). Densification of rubber wood, corn cob (Medhiyanon *et al*., 2006), rice husk (Maiti *et al*., 2006) and cotton stalk (Onaji and Siemons, 1993) were studied experimentally. It was discovered that mechanical and physical characteristics of charcoal briquettes were influenced by several parameters such as: die pressure, dwell time, binder type and content and particle size.

More researches have been recently conducted that reported that combination of biomass can improve the material mechanical strength and durability of the briquettes produced compared with the use of a type of biomass for instance, sawdust and wheat straw briquettes (Wamukonya and Jenkins, 1995), Yaman *et al*., 2000; Demirbas and Sahin, 1998). Generally, some common binders used are starch, paper, animal dung, clay, gum Arabica, ash and coal. Cassava starch and paper binders were selected for this study because of their relative availability and abundance.

2. Materials and Methods

2.1. Material

Generally, the raw substrates used were sourced from farmers and traders in Ibadan except rice husk from Kastina State.

2.1.1. Sawdust

A heterogeneous blend of sawdust from wood of three different tree species was used. They are; *Terminalia superba,* (*Afara*), *Terminali ivorensis* (*Idigbo*) and *Erecta caribaea* (*Ogungun*). The sawdust was collected at Bodija Sawmill located beside the Bodija Abattoir off UI – Secretariat Road.

2.1.2. Coconut Shell (Cocos Nucifera)

Coconut shell was collected from coconut flesh vendors at the Sabo – Mokola, Ibadan.

2.1.3. Corn Cob (Zea Mays)

The corncob was purchased from corn sellers at Oja Oba Market opposite Mapo Hall.

2.1.4. Rice Husk (Oryza Sativa)

A link was created from Bodija market to a local rice mill factory at Funtua, Kastina state from where the rice husk was purchased from.

2.1.5. Wood (Celtis Zenkeri) Local Name - Ita

The wood was sourced from local wood vendor

2.1.6. Paper

Old and rejected newsprints were collected from paper vendor

2.1.7. Cassava Starch (Manihot sp)

Cassava starch was purchased from local cassava (*Fufu*) processing factory in Ibadan.

2.2. Experiment

2.2.1. Substrate Processing

The substrates (rice husk, sawdust, coconut shell, corncob, paper and starch) were dried to a reasonable extent. Coconut shell, corncob and paper were shredded at local food mill at Oja Oba opposite Mapo hall.

Following the shredding process, the substrates were sieved with less than 2 mm pore size sieve ready for briquetting.

2.2.2. Paper Bound Briquettes Preparation

0.6 kg of the sieved paper was soaked overnight to produce paper slurry. The paper slurry was mixed with 2.4 kg of the substrate thoroughly.

2.2.3. Starch Bound Briquettes Preparation

A mixture of 1:8 of binder to substrate by mass was prepared. 0.4 kg of oven dried starch was measured into a bowl. The bowl content was mixed with water about 10 ml of water till a homogeneous mixture was achieved. Boiling water was mixed with the content of the boil to form porridge. This starch porridge was mixed with the substrate.

2.2.4. Briquetting Process

The mixture was loaded into the briquette machine in batches. Manual compaction was done till a reasonable extent of compaction was achieved. Through the lever action, the briquettes were ejected from the machine. These briquettes were air-dried for two days and oven dried overnight to desirable moisture content.

Eight kinds of briquettes were produced four with each binder type. For instance for starch binder, corncob (CCs), coconut shell (CSs), rice husk (RHs), sawdust (SDs) and for paper binders, CCp, CSp, SDp, RHp for corncob, coconut shell, sawdust and rice husk respectively. The physicochemical parameters of the briquettes were taken before and after briquetting using standard procedures.

2.2.5. Physicochemical Characterization

The physicochemical characterization which includes moisture content, volatile matter, fixed carbon and ash content were carried out using standard methods (AOAC, 1990).

2.2.6. Determination of the Moisture Content

A ceramic crucible of known weight was put in a drying oven for 3 h at 105°C. The ceramic crucible was put in a desiccator to cool down. It was reweighed and the weight was noted. Then 1 g of the sample was measured out. The sample and ceramic crucible were put in a drying oven set at 105°C and was left for 6 h. The crucible and its contents was removed and put in a desiccator, allowed to cool to room temperature and reweighed. This was repeated until the weight after cooling was constant within 0.3 mg. This was recorded as the final weight.

$$\text{Moisture content } (\%) = \frac{Initial\ weight - final\ weight\ of\ the\ sample \times 100}{Initial\ weight\ of\ the\ sample} \quad (1)$$

2.2.7. Determination of the Volatile Matter

Volatile matter is defined as those products, exclusive of moisture, given off by a material as gas or vapour. The volatile matter of the sample was determined using the Meynell method. The residual dry sample from moisture content determination was preheated at 300°C in a furnace for 2 h to drive off the volatiles. The resulting sample was further heated at 470°C for 2 h (just before the materials turns black i.e. before it ashes).

$$\text{Volatile matter} = \text{weight of dry sample} - \text{weight of dry sample after heating (470°C for 2 h)} \quad (2)$$

$$\text{Volatile matter } (\%) = \frac{loss\ in\ weight\ due\ to\ removal\ of\ volatile\ matter \times 100}{Weigt\ of\ dry\ sample} \quad (3)$$

2.2.8. Determination of the Ash Content

1 g of a 105°C dried test sample was measured and heated in a furnace at 590°C, and left in a desiccator to cool down to room temperature, and weighed. This was repeated for 1hr interval until the weight was constant. This weight was recorded as the final weight of the ash.

$$\text{Ash content } (\%) = \frac{Weight\ of\ ash \times 100}{Weight\ of\ dry\ sample} \quad (4)$$

2.2.9. Determination of the Organic Carbon

Carbon content refers to the percentage of carbon present in a particular sample. The carbon content was determined using the Walkey-Black method. About 0.1 g of the sample was weighed into a 500 ml conical flask. 15 ml of 1 M $K_2Cr_2O_7$ was added into the flask, followed by 20 ml of concentrated H_2SO_4 (this is to digest the sample so that the organic component in the sample would be breakdown). The mixture was allowed to cool down for about 20 minutes. 45 ml of distilled water was added to dilute the mixture. 1, 10 phenantrolin and Iron II salt (ferroin indicator) was also added into the flask. The mixture was shaken thoroughly, and titrated with 1 M Ferrous ammonium sulphate. The colour changes from purple to dirty green.

2.2.10. Determination of the Fixed Carbon

Fixed carbon represents the quantity of carbon that can be burnt by a primary current of air drawn through the hot bed of a fuel (Moore and Johnson, 1999). The fixed carbon content of the samples was calculated using the following relation:

$$\text{Fixed carbon } (\%) = 100 - [Moisture\ content\ (\%) + Volatile\ Matter\ (\%) + Ash\ content\ (\%)] \quad (5)$$

2.3. Energy Determination (AOAC Official Method 2003. 09)

Apparatus: Gallenkamp ballistic bomb calorimeter

Reagents: Benzoic acid

Procedure: 0.25 g of each of the substrate was weighed in a steel capsule. A 10 cm thread was attached to the thermocouple torching the capsule. The bomb was closed with oxygen up to 30 atm. The bomb was fixed by depressing the ignition switch to burn the sample in excess oxygen. The maximum temperature rise was measured with the thermocouple and galvanometer system. The rise in temperature was compared with that obtained for 0.25 g of the benzoic value of each of the substrate was determined as shown below.

Calculations:

- Mass of benzoic acid = W_1 g
- Calorific value of 1gm Benzoic acid = 6.32Kcal/g

2.4. Bulk Density

$$\text{Bulk density} = \frac{mass\ of\ biomass}{Volume\ of\ biomass} \quad (6)$$

The mass (g) of the biomass was measured using OHUAS weighing (sensitivity of 0.0000)

The volume of briquettes were measured using $V = \pi r^2 h,$

Where

r= radius of the briquette (cm)

h= mean height of the briquette (cm)

2.5. Energy Density

$$\text{Energy Density}\left(\frac{\text{KJ}}{\text{cm}^3}\right) = Calorific\ value\left(\frac{Kj}{g}\right) \times Bulk\ density\ (g/\text{cm}^3) \quad (7)$$

2.6. Energy Efficiency Test

The energy efficiency test was done by carrying out a water boiling test. 0.5 kg of the briquette were measured into the coal stove and ignited with about 5 ml of kerosene to facilitate ignition. A Kettle containing 1L of water was placed on it as soon as it ignited. Using a stop watch, the time at which the water boiled at 100°C was noted, the mass left at that point was also noted and the time it took the biomass to finally burnout was also documented.

2.7. Calculations of Energy Efficiency Parameters Which Include

1. Water boiling time (WBT): the time required to boil 1l of water using 0.5 kg of the different briquettes types and wood (control).
2. Mass of biomass used (MB): the change in the mass of biomass before ignition (0.5 kg) and after the water is boiled.
3. Burning Time (BT): the total time taken to burn out 0.5kg biomass solid fuel.
4. Burning rate (BR): $the\ mass\ of\ briquette/Burning\ time$ formula 8
5. Recoverable energy: $MB\ X\ Calorific\ value$ formula 9

3. Data Management and Statistical Analysis

Data were entered into the computer and analyzed using descriptive and inferential statistics. Statistical Packages for Social Sciences (SPSS version 20) software was used for data analysis. Data were summarized using means and standard deviation. Some were displayed using bar charts. Analysis of Variance (ANOVA) was done to compare means of the physicochemical parameters among the raw substrates and briquettes and the energy efficiency parameters. Independent T Test was used to compare the mean difference of the energy efficiency parameters between paper and starch binder. Correlations between physicochemical parameters and energy efficiency parameters were established.

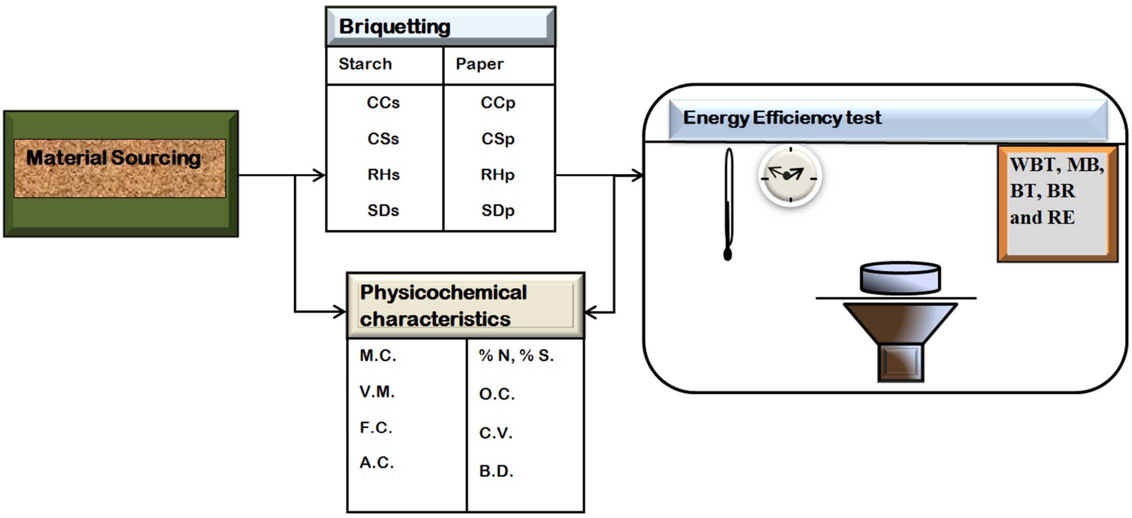

Fig. 1. Schematic representation of the Experimental set up for the Briquettes energy efficiency evaluation.

4. Result

As shown in table 1, the energy property of the raw substrate was measured in terms of calorific value. The values across the various substrates were very close. It ranged between 16.1 - 21.3 kJ/g. The highest mean value of 21.03 ± 0.04 kJ/g was obtained in rice husk while, coconut shell had the least mean value 16.1 ± 0.04 kJ/g.

Among paper bound briquettes, as shown in table 2, a range between 14.25 and 17.95 KJ/g was obtained in the calorific values with significant difference across the substrates with p= 0.00. Highest value of 17.95 ± 0.04KJ/g was seen in RHp while, 14.25 ± 0.03KJ/g (lowest value) was discovered in CSp. The mean bulk density (g/cm^3) were also significantly different at p= 0.00 p<0.05and ranged between 0.27 - 0.61. While CSp had the highest value of 0.61± 0.01, the lowest (0.27±0.02) was found in SDp. Besides, the energy density also showed disparity relative to the bulk density and calorific values. It ranged between3.94KJ/cm^3 and 8.68KJ/cm^3)). The highest value of 8.868 ± 0.2KJ/cm^3 was found in CSp while SDp had the lowest with 3.94 ± 0.29KJ/cm^3.

By and large, the energy properties were all significantly different at p<0.05. A range of 12.28 - 19.58 was observed in the calorific values (KJ/g). Highest value of 19.58 ± 0.02KJ/g was observed in SDs while, 12.3 ± 0.03KJ/g (lowest value) was discovered in RHs. The mean bulk density (g/cm^3) also varied between 0.27- 0.51. CSs had the highest mean of 0.747± 0.01 while, the lowest (0.27±0.02) was found in SDs. And, the energy density also showed disparity relative to the bulk density and calorific values. It ranged between 3.99KJ/cm^3 and 12.96KJ/cm^3. The highest value of 12.96±0.23KJ/cm^3 was found in CSp while SDp had the lowest with 3.94±0.29KJ/cm^3).

4.1. The Relationship Between the Physicochemical Characteristics and the Energy Parameters

As shown in table 3, there was significant positive correlation between MC and BD, ED, ER, BR, OC, and AC with r= 0.769, 0.907, 0.326, 0.279, 0.284 and 0.316 respectively. While, WBT and VM were negatively correlated with MC with r= -0.296 and 0.319 and (p<0.05). The VM recorded at p=0.00 was negatively correlated with BD, ED, MB, WBT, AC and BT with r= -0.444, -0.383, -0.437, -0.763, -0.769 and -0.332 respectively with (p<0.05). While, there were significant positive correlations between VM and BR, OC, FC and CV with r = 0.407, 0.336, 0.569 and 0.569 at (p<0.05). There were significantly positive correlation between FC and VM with r = 0.569. While significantly negative correlation exists between FC and WBT, MB, RE, and AC with r= - (0.507, 0.586, 0.633, 0.494) respectively. Recorded Ash Content (AC) negatively correlated with CV, BR, ER and OC with r = (0.614, 0.555, 0.273, 0.503) but positively correlates MB, BT, and WBT with r = 0.506, 0.531 and 0.977 respectively. The OC positively correlated CV but ED negatively with r = 0.369 and -0.341 respectively at p<0.05.

At p<0.05, the CV negatively correlated WBT, BT, and BD with r = -(0.639, 0.908, 0.289) respectively. While, it positively correlated BR, RE and ER with r = 0.88, 0.30 and 0.31 respectively. Bulk Density positively correlated ED and BT with r = 0.95 and 0.38. But negatively correlated BR with r = -0.330. The MB recorded positively correlated WBT with r = 0.46 at (p<0.05). There was positive correlation between WBT recorded and BT but BR and ER negatively with r = 0.56 and -0.564 and -0.287, respectively, at p<0.05. The BT recorded positively correlated BR at p=0.0 and r = 0.98. But, negatively correlates ER with r = 0.329.

4.2. Comparison of Energy Parameters Between the Binders

Generally as shown in table 3, higher WBT was recorded among starch bound briquettes compared to that of paper. Other energy parameters showed significant mean differences at p<0.05 that were non directional across the substrates. These parameters cannot be attributed to the type of binder. In the bulk density recorded, starch bound briquettes had higher BD compared with paper bound ones for CC, CS and RH (p=0.05) except SD. This is due to the more adhesive ability that starch has over paper binder to compact the substrate to form briquettes. Briquettes of paper binder recorded higher MB compared with starch binder across CC, RH and SD but, the reverse was recorded for CS substrate. Higher BT were recorded among briquettes of starch binders compared with that of paper binders for CS, RH and SD. But, paper bound CC briquettes recorded higher BT compared with starch bound briquettes. Moreover at p<0.05 BR values of starch bound briquettes were higher compared with paper bound CS, RH and SD. Unlike CC, the reverse was the case.

The CV and ED recorded among paper bound briquettes were higher compared with that of starch for CC and RH whereas, the CV recorded among paper bound compared with that of starch for CS and SD (p<0.05.

Table 2. *Energy parameters of the raw substrates.*

Parameter	Substrate	Mean	Std Dev	P value
Calorific value (KJ/g)	Wood (control)	18.3	1.84	<0.05
	Corncob	16.85	0.01	
	Coconut shell	16.10	0.04	
	Rice husk	21.03	0.04	
	Sawdust	19.35	0.06	

Table 3. *Mean energy parameters of the substrates.*

Energy parameters	**Biomass substrate (Mean ± SD)**								
	Wood	**CCp**	**CSp**	**RHp**	**SDp**	**CCs**	**CSs**	**RHs**	**SDs**
BD (g/cm^3)	0.894 ± 0.01	0.29 ± 0.04	0.44 ± 0.03	0.267 ± 0.02	0.325 ± 0.02	0.5 ± 0.33	0.75 ± 0.013	0.269 ± 0.02	0.32 ± 0.28
CV (KJ/g)	18.30 ± 1.84	16.28 ± 0.14	14.25 ± 0.03	17.95±0.04	14.74 ± 0.06	12.28 ± 0.03	17.34±0.07	12.34 ± 0.06	19.58 ± 0.02
ED (Kj/cm^3)	16.36 ± 1.53	4.69 ± 0.11	8.68 ± 0.2	7.9 ± 0.53	3.94 ± 0.29	3.99 ± 0.23	12.92 ± 0.23	6.28 ± 0.13	5.27 ± 0.42
WBT (min)	10 ± 1.4	9 ± 1.4	11 ± 1.4	52 ± 5.67	7.75 ± 2.48	11 ± 1.4	12 ± 1.4	62.5 ± 3.54	12.5 ± 2.12
BT (min)	56 ± 4.24	70 ± 4.24	130 ± 7.07	107 ± 2.8	58 ± 2.8	53.5 ± 3.54	135 ± 1.4	143 ± 2.83	60 ± 4.24
MB (g)	300 ± 10	390 ± 40	150 ± 10	370 ± 10	300 ± 20	200± 40	250 ±40	340 ± 40	220 ± 30
BR (g/min)	9.07 ± 0.47	7.16 ± 0.43	3.85 ± 0.21	4.67 ± 0.12	8.6 ± 0.42	9.37 ± 0.62	3.7 ± 0.4	3.5 ± 0.07	8.35 ± 0.59
RE (kJ)	5.57 ± 0.16	6.35 ± 0.75	2.1 ± 0.2	6.6 ± 0.27	4.35 ± 0.33	2.46 ± 0.53	4.34 ± 0.75	4.2 ± 0.54	4.31 ± 0.55

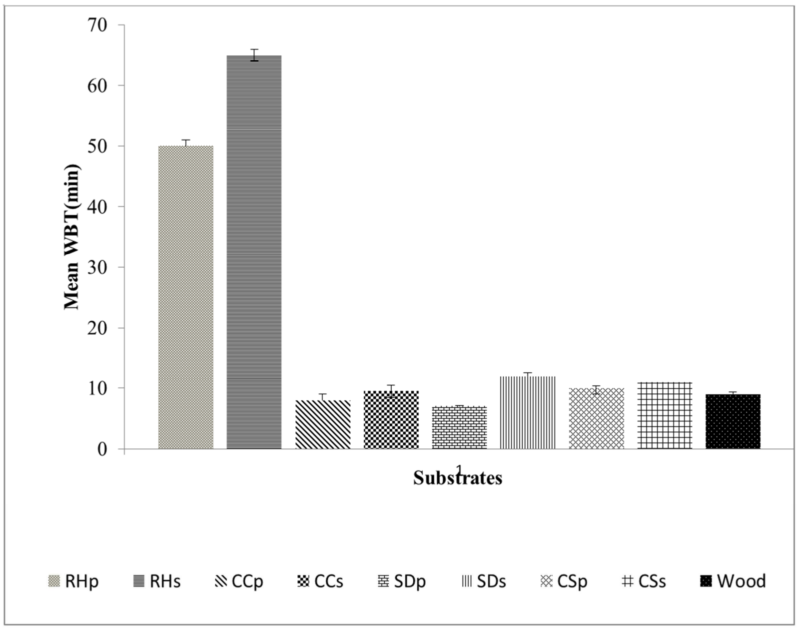

Fig. 2. *Mean Water Boiling Time (min) among the briquettes in comparison with wood.*

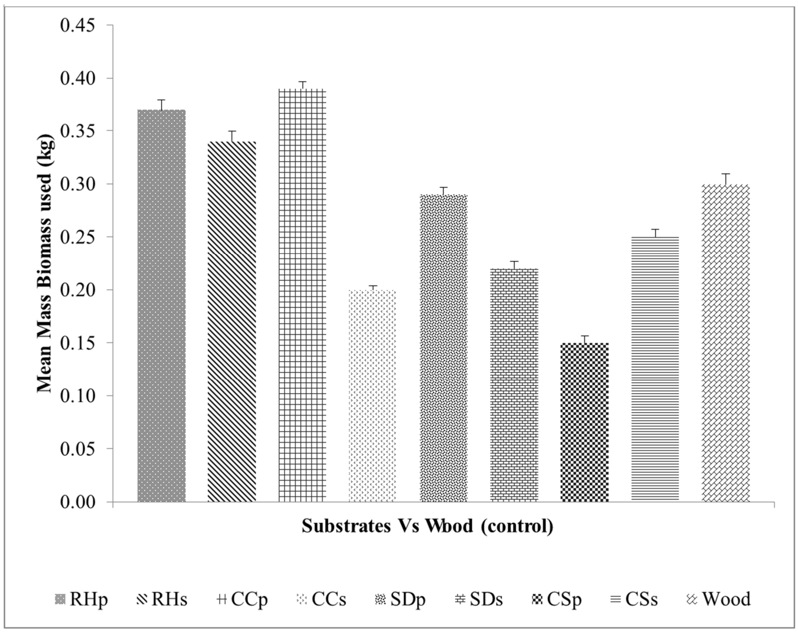

Fig. 3. *Mean mass of biomass substrate burnt among the briquettes in comparison with wood.*

Table 4. *Comparison of energy parameters between different substrate binders.*

Substrate	Energy Parameter	M. D. between paper and starch binders	P value	Substrate	Energy Parameter	M. D. between Paper and starch binders	P value
CC	CV	4.00	0.00	CS	CV	-3.9	0.00
	BD	-0.04	0.00		BD	-1.38	0.00
	ED	0.70	0.00		ED	-4.24	0.00
	MB	0.19	0.00		MB	-0.10	0.00
	WBT	-2.00	0.00		WBT	-1.00	0.00
	BT	16.50	0.00		BT	-5.00	0.00
	RE	3.90	0.00		RE	-2.2	0.00
	BR	-2.21	0.00		BR	0.15	0.00
RH	CV	5.6	0.00	SD	CV	-4.8	0.00
	BD	-0.69	0.00		BD	0.02	0.00
	ED	1.61	0.00		ED	-1.33	0.00
	MB	0.03	0.00		MB	0.08	0.00
	WBT	-10.28	0.00		WBT	-1.57	0.01
	BT	-36.14	0.00		BT	-2.28	0.02
	RE	2.43	0.00		RE	0.08	0.54
	BR	01.18	0.00		BR	0.32	0.00

Table 5. *The Relationship between the physicochemical characteristics and the energy parameters.*

	MC	VM	FC	AC	OC	CV	BD	ED	MB	WBT	BT	RE	BR	ER
MC	1	-.319*	-.117	-.316*	-.284*	.256	.769**	.907**	.056	-.296*	-.249	.214	.279*	.326*
		.019	.400	.020	.038	.062	.000	.000	.689	.030	.070	.120	.041	.016
VM		1	.569**	-.769**	.564**	.407**	-.444**	-.383**	-.437**	-.763**	-.332*	-.218	.336*	.098
			.000	.000	.000	.002	.001	.004	.001	.000	.014	.113	.013	.481
FC			1	-.494**	.344*	-.240	.176	.074	-.586**	-.507**	.265	-.633**	-.224	-.151
				.000	.011	.080	.204	.596	.000	.000	.053	.000	.104	.277
AC				1	-.503**	-.614**	-.036	-.199	.506**	.977**	.531**	.165	-.555**	-.273*
					.000	.000	.795	.150	.000	.000	.000	.234	.000	.046
OC					1	.369**	-.422**	-.341*	-.497**	-.444**	-.425**	-.340*	.469**	-.161
						.006	.001	.012	.000	.001	.001	.012	.000	.246
CV						1	-.289*	.002	-.161	-.639**	-.908**	.303*	.884**	.313*
							.034	.988	.244	.000	.000	.026	.000	.021
BD							1	.953**	-.109	.007	.384**	-.202	-.330*	.019
								.000	.432	.958	.004	.144	.015	.894
ED								1	-.110	-.167	.096	-.066	-.050	.129
									.430	.229	.488	.636	.717	.354
MB									1	.464**	-.014	.886**	-.071	.039
										.000	.917	.000	.608	.779
WBT										1	.563**	.101	-.564**	-.287*
											.000	.466	.000	.036
BT											1	-.431**	-.983**	-.337*
												.001	.000	.013
RE												1	.330*	.209
													.015	.129
BR													1	.329*
														.015
ER														1

*. Correlation is significant at the 0.05 level (2-tailed), **. Correlation is significant at the 0.01 level (2-tailed).

5. Discussion

Generally, the recorded calorific values (CV) were high and adequate for domestic and small scale industrial heating needs (Oladeji, 2012). Moreover, calorific value (KJ/g) was found highest in rice husk with 21.03 ± 0.04 while coconut shell had the lowest of 16.1 ± 0.04. However, briquetting impacted negatively on the calorific value to a certain degree. Many of the substrate dropped in their CV (for instance, rice husk dropped from 21.03 to 17.95). Nevertheless among the paper binder briquettes, CSp and RHp maintained the lowest and highest values with 14.25 ± 0.03 and 17.95 ± 0.04, respectively. And in comparison with wood, it was found higher than all the paper binder briquettes. Among the starch briquettes, SDs had the highest value of 19.58 ± 0.02 but the lowest was found in CCs with 12.28 ± 0.03. Sharma *et al.* (2006) supported stating that there is no significant effect of material, binder and binder concentration on calorific values briquettes.

The bulk density (g/cm^3) was found highest 0.89 ± 0.01 in wood. This may be due to the high moisture content (30%) found in the wood compared with the briquettes. Generally across the briquette types, while coconut shell briquettes had highest values, sawdust briquettes had lowest value across the binders. Just as CSs and CSp were 0.75 ± 0.01 and 0.6 1± 0.01, SDp and SDs were 0.27 ± 0.02 and 0.27 ± 0.02, respectively. Bulk density is a measure of mass per unit volume of the particles and their compactness. Low densities may lead to crumbling of the briquettes. This would in turn influence the transportation of the briquettes. From field experience, for the basis of comparison, the same binder ratio was used for all the substrates to produce the briquettes. This was adequate for some and not for others depending on the density of the raw substrate. Adequate binder and compaction pressure could have enhanced the bulk density of the briquette (Oladeji and Enweremadu, 2012).

Energy density is the product of the bulk density multiplied by the calorific value. Hence, it indicates the amount of energy per volume of the substance. While it was found highest in wood 16.4 ± 1.53 kJ/cm^3, SDp recorded the lowest value of 3.94 ± 0.29. This implies that the SDp briquettes would burn volatilely and readily burning out. This reflected in its water boiling time of 7 min. Hence larger quantity would be required for cooking compared with others with higher energy density. Moreover, briquettes with high energy density that result from high calorific value and bulk density without confounding moisture content are good for fuel.

6. Energy Efficiency Parameters

While the major energy properties of biomass include CV, BD and ED (Energy per volume), energy efficiency entails doing the work without wasting fuel and time.

The time required by the briquettes and wood respectively to boil 1 l of water varied significantly at $p<0.05$. The lower the time required for boiling water the more efficient the fuel. While, briquettes of SDp required the lowest time of 7 ± 0.45 min to boil 1l of water, RHs took the highest time 65 ± 2.37 min.

Moreover, there was negative correlation between WBT and CO ($r= -0.29$) but positive with CO_2 ($r= 0.505$) concentrations (Fabunmi *et al*, nd). This is an indication that the more complete combustion is the more efficient the fuel is. The emission ratio of CO_2 to CO varies with the efficiency of combustion (Andreae and Merlet, 2001).

There are relationship between WBT and volatile matter, fixed and organic carbon with r = -0.763, 0.507 and 0.44, respectively, as shown in table 3. This indicates that they play a positive role in facilitating combustion efficiency. This assertion was supported by McKendy (2001) in his report on effect of proximate analysis on combustion efficiency that VM and FC contents significantly provide a degree of the ease of biomass ignition, gasification and oxidation. However, there a strong positive correlation between WBT and ash content with $r=0.977$ at $p<0.05$. This conforms to Obi *et al* (2013) that explained that low ash content of biomass results in higher heating value of briquettes. Water boiling time also correlated negatively with the calorific value with r = - 0.64. This affirms that the heating value or calorific value of a burning fuel would reflect on the amount of heat emitted. On the other hand, WBT positively correlated with that mass of briquette required to boil water with r = 0.46.

7. Conclusion

From the study, energy efficiency parameters showed that SDs possesses the highest calorific value followed by SDp > CCs > CCp > RHp > CSs > CSp > RHs respectively. Also in terms of the Water Boiling Time took this order SDp < CCp < CCs < CSp < CSs < SDs < RHp < RHs respectively. This implies that SDp is the best with respect to time conservation and volatility. With regards to the mass of briquette used, the findings of the study revealed CSp < CCs < SDs < CSs < SDp < RHs < RHp < CCp. Therefore, with reference to MB and WBT using a scoring model, CCs and CSs are both the most fuel efficient briquettes. The burning time was highest in RHs.

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