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Energy Efficiency of Briquettes Derived from Three Agricultural Waste's Charcoal Using Two Organic Binders

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Abstract

Waste management could contribute significantly to reducing environmental degradation. Studies showed that briquetting provides with or without binder helps to manage wastes as energy fuels. However, the properties of many binders are not investigated extensively. This work investigated the effect of two organic binders' low rate on energy efficiency of Briquettes produced from charcoals of Tender Coconut Husks (TCH), Palm Kernel Shells (PKS) and Corn Cobs (CC). Bombax Costatum calyx (B) and Cissus Repens barks (C) were used separately as binders to elaborate briquettes. The briquettes were compared based on their energy efficiency parameters with wood charcoal as control. Energy efficiency parameters such as water boiling time (WBT), mass of biomass used (MB), burning rate (BR), temperature rise rate (TR) and maximum temperature in the furnace (T_{max}) were measured from each biomass charcoal briquette and wood charcoal combustion. Water boiling test was applied to determine briquettes thermal properties. The results of WBT, BR, TR and T_{max} were respectively within the ranges 3.4 - 12.3 min, 2.90 - 7.71 g/min, 4.63˚C/s - 16.10˚C/s and 623˚C - 900˚C. Corn Cobs charcoal briquettes with Bombax binder took the shortest time to boil water and also presented a high temperature rise rate and the highest maximum temperature. The lowest burning rates were obtained for Tender coconut husks charcoal briquettes with Cissus binder. They showed good material conservation for bombax bound briquettes. The results of our investigations showed that binders content increasing enhanced the thermomechanical stability and affected negatively the energy efficiency parameters of the studied briquettes.

Keywords

Biomass, Charcoal, Briquette, Binder, Energy Efficiency

1. Introduction

The firewood is the most important source of energy in most of the Sub-Saharan countries, particularly firewood covers a large part of the needs of cooking energy (A. Demirbas, 2008) [1], (J. I. Duruaku *et al.*) [2]. The excessive use of firewood in this area has led to deforestation which accentuates the problems of climate change. To reduce deforestation, massive use of fossil fuels such as petroleum and cooking gas was promoted, but fossil fuels production and use led to environmental pollution. On the other hand agriculture is the main activity of a large part of West African population. Numerous agricultural residues and wastes are generated; however they are poorly used and badly managed, since most of these wastes are left to decompose or are burned in the field resulting in environmental pollution and degradation (Jekayinfa *et al.*, 2005) [3]. In developing countries and in particular in Togo, raw biomass is used mainly in rural and peri-urban areas, while charcoal is used in urban areas (Damgou Mani Kongnine *et al.*, 2018a) [4]. The use of charcoal associated with other uses of firewood increases deforestation. The valorization of biomass for the production of energy has been the subject of many studies in recent decades (Damgou Mani Kongnine *et al.*, 2018b) [5], (Kenchukwu Ugwu *et al.*, 2013) [6]. One important way of limiting the deforestation and protecting the environment is briquetting the agricultural wastes and other biomasses (Muhammad Yerizam *et al.*, 2013) [7], (Bianca G. de Oliveira Maia *et al.*, 2014) [8], (Gabrierl Borowski *et al.*, 2017) [9], (A. O. Akintaroa *et al.*, 2017) [10]. Briquettes are flammable materials obtained from the compression or densification of matter into solid form to be used as fuel. Briquetting is a process of binding together pulverized carbonaceous matters at specific pressing, often using various binders (J.F. Martin *et al.*, 2008) [11], (N. Altun *et al.*, 2003) [12]. The common forms of briquettes are the coal briquettes and the biomass briquettes. The binders can be organic or inorganic agents. The commonly used organic binders are heavy crude oil, starch, molasses and other organic matters (Bianca G. de Oliveira Maia *et al.*, 2014) [8], (Godson Rowland Ana *et al.*, 2016) [13], (Zakari I.Y. *et al.*, 2013) [14]. The inorganic binders include clay, sodium silicate and cement. The binder types, amount of binder agent and water addition, have significant effects on the thermal behavior and combustion characteristics of the briquettes (N. Altun *et al.*, 2003) [12]. J.O Awulu *et al.* [15] have studied the effect of Bombax and Cissus on the briquettes properties of some biomasses. However their rate effect has not been extensively investigated. In this work Bombax Costatum calyx and Cissus Repens barks were used as binders. The influence of low concentration of the two binders was examined from the combustion characteristics of three rates bound briquettes produced from charcoals of Tender Coconut Husks, Palm Kernel Shells and Corn Cobs.

2. Materials and Methods

2.1. Material

The raw materials used in this study were three biomasses collected in Lomé and its surrounds. They were sun dried and then carbonized to produce the three raw charcoals used in this study. Bombax Costatum's calyx and Cissus Repens's bark were used as binder in the present work.

2.1.1. Raw Biomasses and Charcoals

The three wastes used for this work were Corn Cobs (CC), Tender Coconut Husks (TCH) and Palm Kernel Shells (PKS). The raw biomasses were carbonized using a laboratory carbonizer described elsewhere by Damgou Mani Kongnine *et al.*, 2018a) [4].

2.1.2. Binders

The binders used in this work are natural organic binders which, to our knowledge were very little valued as binders. The Bombax calyx and Cissus bark were dried separately until their mass remained constant. The dried products were crushed and sieved. The obtained products are then stored in sealed containers until they were used.

2.2. Experiment

2.2.1. Substrates Processing

The substrates (charcoals of corn cobs, tender coconut husks and palm kernel shells) were sun dried until their weight remain constant. The dried charcoals samples were then shredded and sieved with less than 2 mm pore size sieve. The charcoal powder was then used for briquetting.

2.2.2. Bound Briquettes Preparation

A mass of 10 g, 20 g and 40 g of each dried binder powder is mixed with boiling water for Bombax and cool water for Cissus repens. The Bombax binder mixture is boiled for 30 minutes and then left to air cold. The obtained solutions were mixed with 990 g, 980 g and 960 g of each biomass charcoal powder respectively corresponding to a binder rate of 1%, 2% and 4% in mass.

2.2.3. Briquetting Process

The mixture was introduced into a mold. The contents were manually compacted to a certain compaction rate. The briquettes are then removed from the mold and sun-dried in open air. The briquettes were thus dried to a constant mass. Figure 1 presents some briquettes samples.

2.2.4. Energy Efficiency Test

The energy efficiency test was conducted by realizing the water boiling and

Figure 1. Different charcoal briquettes.

water evaporating tests. A weight of 300 g of each biomass charcoal briquette were introduced in a cylindrical charcoal stove. The ignition was operated using 5 ml kerosene and 10 g of teak wood chips. An aluminum cooking pot containing 0.2 L of water was placed on the stove as soon as charcoal was ignited. A stop watch was used to determinate the times at which the water boiled at 100˚C and the time it completely evaporated. The mass of briquette left when the water is evaporated was also reported. During the water boiling and evaporation tests, a mercury thermometer measuring up to 150˚C was introduced in the water to record it temperature and a K-type thermocouple was introduced in the stove in burning briquettes to record it temperature profile. Figure 2 presents the experimental apparatus used to evaluate the briquettes energy efficiency parameters.

2.2.5. Energy Efficiency Parameters

The following energy parameters were estimated using the results of water boiling and evaporating tests such as Water boiling Time (WBT), Water Evaporating Time (WET), Mass of Briquette used (MB), Burning Rate (BR) and the maximum Temperature achieved in the stove (T_{max}) (Kenchukwu Ugwu *et al.*, 2013) [6] and (Godson Rowland Ana *et al.*, 2016) [13].

WBT: Time necessary to boil 0.2 L of water using an initial weight of 300g of each briquette.

WET: Time required to evaporate completely 0.2 L of water.

MB: The change in the charcoal briquette mass before ignition (300g) and after the total initial volume of water is evaporated.

T_{max}: The maximum temperature achieved in the stove during energy efficiency tests.

3. Results

Table 1 presents the energy efficiency parameters of raw biomass charcoals used in this work. Higher WBT were recorded for PKS briquettes for the two tested binders. TCH-Cissus bound briquettes presented a high WBT and Bombax bound briquettes showed a relative low WBT. The best briquette regarding WBT were respectively CC-Bombax 1%, CC-Cissus 1% and CC-Bombax 2%. The samples which presented a high WBT showed also a high WET. Briquette of CC with 4% Bombax binder had a lower WET than wood charcoal one. Lowest BR

Table 1. Energy efficiency parameters of biomasses charcoals briquettes.

Energy Parameters	CHB	Biomass charcoal substrates												
		Bombax								Cissus				
		TCH			PKS		CC			TCH		PKS		CC
		1%	2%	4%	2%	4%	1%	2%	4%	1%	2%	2%	4%	1%
WBT (min)	5.5	7.1	5.4	5.8	12.3	5.5	3.4	3.8	4.8	10.3	14.0	11.8	5.5	3.8
WET (min)	24.5	31.5	31.0	33.5	-	33.5	25.4	27.0	20.5	47.3	49.2	67.0	30.0	22.5
MB (g)	110	169	154	178	300	253	171	160	158	137	144	258	190	164
BR (g/min)	4.49	5.37	4.98	5.31	-	7.55	6.73	5.93	7.71	2.90	2.93	3.85	6.33	7.29

Figure 2. Experimental apparatus for energy efficiency tests.

were recorded for TCH 1%, 2% and PKS 2% Cissus binder briquettes compare to that of wood charcoal and other briquettes. Higher BR were reported for CC briquettes for the two binders. The lack of data for WET and BR for PKS-Bombax 2% Binder briquettes was due to the fact that these briquettes were damaged during combustion. For a rate of 4%, the briquettes showed a higher stability.

Figure 3 presents the kinetic curve of temperature rise of water and the profile of the temperature in the stove for Tender Coconut Husks with Bambax and Cissus bound briquettes. The curves of water temperature rise are all quite linear. The stove temperature profiles for TCH-Bombax 1% and 2% bound samples are less stable. The temperature profile of TCH-Bambax 4% and TCH-Cissus 2% bound briquettes are stable and lower than that of wood charcoal.

Figure 4 shows the kinetic curve of water temperature rise and the profile of the temperature in the stove for Corn Cobs with Bambax and Cissus bound briquettes. The curves of water temperature rise are all quite linear. As shown in **Figure 4**, the temperature profile of CC-Bambax 4% and CC-Cissus 1% bound briquettes are stable and higher than that of charcoal control.

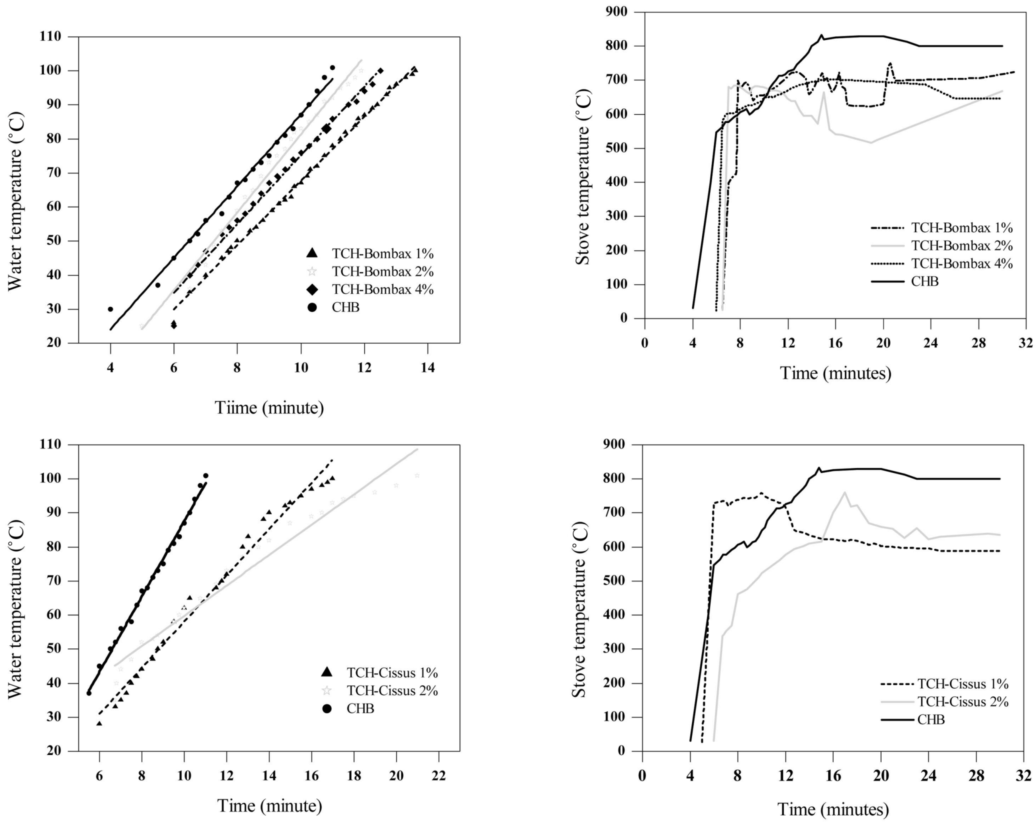

Figure 3. Temperatures profiles for water and in the stove for Coconut chars briquettes.

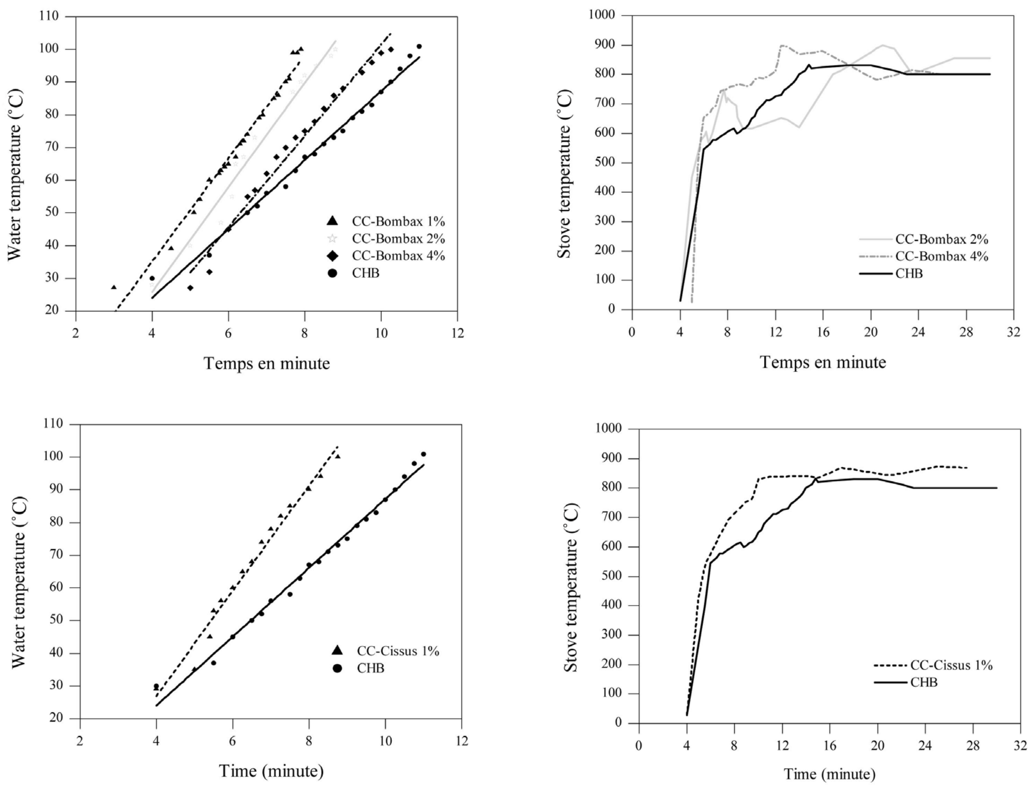

Figure 4. Temperatures profiles for water and in the stove for Corn Cobs briquettes.

Figure 5 presents the kinetic curve of water temperature rise and the profile of the temperature in the stove for Palm Kernel Shell with Bambax and Cissus bound briquettes. The curves of water temperature rise are all approximately linear. The stove temperature profiles for PKS-Bombax 2% Cissus 4% bound samples are less stable. The temperature profile of PKS-Bambax 4% and PKS-Cissus 2% bound briquettes are stable and lower than that of charcoal control.

Table 2 presents the correlation coefficients of water temperature profiles parameters of raw biomasses charcoals briquettes used in this work. The temperature rise coefficient of the CC briquettes were the highest regardless of the nature of the binder. However, this coefficient is higher for binder rates of 1% and 2%. As shown in Table 2 the temperature rise coefficient for all 4% Bambax and Cissus bound briquettes was slightly higher than that of charcoal. The lowest temperature rise coefficient were recorded for TCH 1% and 2% Cissus bound briquettes and PKS 2% Bombax and Cissus bound briquettes.

4. Discussion

The energy parameters such as Calorific value, bulk density and energy density of Tender Coconut Husks, Corn Cobs, and Palm Kernel Shells biomasses charcoals used in this study were investigated in early works [4] [5]. In this paper, the

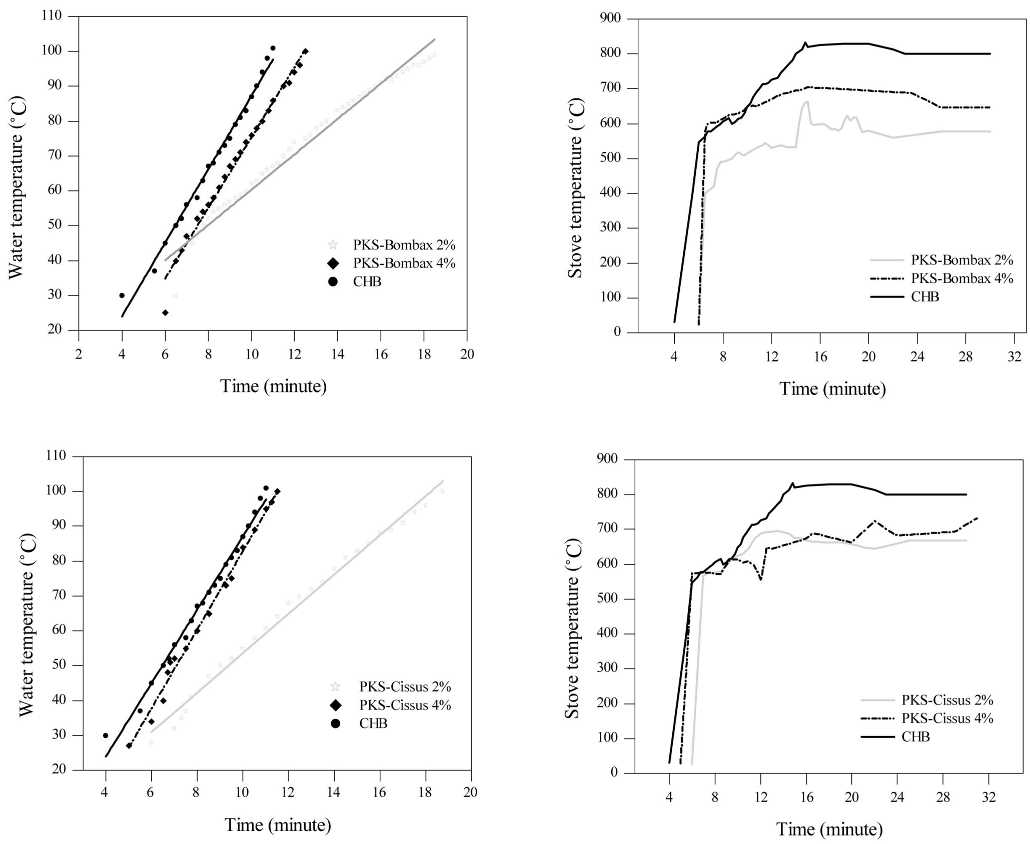

Figure 5. Profiles of temperatures of water and in the stove for Palm Kernel Shell briquettes.

Table 2. Thermal energy efficiency parameters of the briquettes.

Charcoal type	Binder	Rate (%)	a (˚C/s)	b (˚C)	R^2	T_{max} (˚C)
TCH	Bombax	1	9.430	−26.685	0.997	752
		2	11.450	−33.119	0.988	672
		4	10.114	−25.878	0.985	705
	Cissus	1	06.734	−9.030	0.985	760
		2	04.625	+12.617	0.951	760
PKS	Bombax	2	05.026	+10.100	0.963	623
		4	10.778	−16.582	0.982	798
	Cissus	2	05.643	−2.793	0.989	734
		4	11.289	−29.935	0.991	695
CC	Bombax	1	15.824	−28.227	0.979	-
		2	15.998	−38.190	0.977	900
		4	13.951	−38.045	0.980	900
	Cissus	1	16.097	−37.461	0.977	870
Chacoal (control)			10.533	−18.099	0.989	833

energy efficiency parameters of the three charcoals briquettes were investigated. The results obtained showed that there are slight difference between briquettes-binders type and briquettes-binder rate for all the charcoals briquettes samples examined.

Among TCH-binders briquettes samples, TCH-Bombax briquettes presented the highest temperature rise rate, burning rate and the lowest water boiling time, the better BR, WBT and the highest temperature rise rate were achieved for TCH-Bombax 2%. However for briquettes conservation, TCH-Cissus briquettes showed a lower burning rate than that of the wood charcoal used as control.

For PKS-binders briquettes, (PKS-Bombax and PKS-Cissus)—4% briquettes showed the lowest WBT and the highest temperature rise rates while a low BR was recorded for PKS—Cissus 2% briquette. PKS-Bombax-2% briquettes were disintegrated during combustion tests, resulting in an incomplete water evaporation. The early degradation did not make possible to record the values of WET and BR for these briquettes.

Among CC-binders briquettes, the lowest WBT was reported for CC-Bombax 1% briquette, the lowest BR was recorded for CC–Bombax 2% and the highest temperature rise rate was obtained for CC-Cissus-1%. The butter energy efficiency parameters were recorded for CC-Bombax-2%. Mani Kongnine *et al.* have established that CC charcoal presented a lower ash content than TCH [4]. The good heat characteristics of CC briquettes could be explained by their low ash content as Obi *et al.* have observed [16].

The energy efficiency parameters (WBT and BR) of TCH and CC briquettes were observed to decrease with increasing binders concentration such results were in contradiction to those obtained by R. M. Davies *et al.* [17] and A.O Akintaro *et al.* [10]. The discrepancy between our results and those of the authors mentioned above could be due to the fact that they used much higher binder concentration, ranging from 10% to 50% by mass. Binder levels ranging from 1% to 4% would differently affect the properties of the briquettes. However, the briquettes analyzed in this work must be compacted under higher pressure to provide them with better breaking strength. Overall of the briquettes examined in this work the CC-Bombax and CC-Cissus bound briquettes exhibited the best thermal efficiency. Similar result was obtained by J. O. Awulu *et al.* [15].

Generally across the briquettes types, while Corn Cobs briquettes had the best WBT, T_{max} and temperature rise rate, Tender Coconut Husks briquettes presented the lowest briquette burning rate.

5. Conclusions

This study investigated the energy efficiency of tender coconut husks, palm kernel shells and corn cobs briquettes elaborated with two organics binders (bombax calyx and cissus barks). The results show that increasing the binder content enhances the thermomechanical stability and on the other hand decreases their energy efficiency. The CC briquettes showed the best WBT whereas TCH briquettes presented the best material conservation (lowest BR). The highest water boiling time was recorded for PKS briquettes. However, this parameter decreased strongly from 2% bound briquettes to 4% ones. The binder concentration increase affected negatively the energy efficiency parameters for a low rate (lower than 10%).

The current results showed the potentiality to use low binders rates in biomasses charcoal briquettes elaboration, although further works and investigations need to be performed in order to determine the optimal binder rate for each biomass charcoal. In addition preliminary studies should be carried out in order to characterize the binder, to make approximate and ultimate analysis of the elaborated briquettes as well as their thermomechanical properties. The final objective is to develop low binder rate briquettes with a competitive price and comparable properties to wood charcoal.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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