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3 authors:


Joseph Oppong Akowuah
Kwame Nkrumah University Of Science and Technology


Francis Kemausuor
Kwame Nkrumah University Of Science and Technology


Stephen Jobson Mitchual
University of Education, Winneba

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Physico-chemical characteristics and market potential of sawdust charcoal briquette

Joseph O Akowuah[1*], Francis Kemausuor[1] and Stephen J Mitchual[2]

Abstract

In the absence of the widespread distribution of modern cooking fuels in developing countries, efforts are being made to utilise biomass residues which abound in most of these countries. This is intended to replace portions of firewood and charcoal and thereby reduce the cutting down of forests for fuel purposes. Briquettes from agro-residues have therefore been promoted as a better replacement to firewood and charcoals for heating, cooking and other industrial applications in both urban and rural communities. This study sought to assess the physico-chemical properties of charcoal briquettes produced in Ghana and also establish demand for and willingness of potential users to substitute charcoal and firewood with a charcoal briquette. A laboratory experiment was conducted to determine the physico-chemical characteristics of the briquettes. This was done prior to the distribution of the briquette to potential users to collaborate their views or otherwise on the handling and burning characteristics of the charcoal briquette. A survey was undertaken a week later using questionnaires to access the willingness of the potential users to use the briquettes. Sixty respondents were purposively selected from households and the hospitality industry for the survey. Results of the physico-chemical assessment of the briquettes were as follows: length (75 to 120 mm), moisture content (5.7% dry basis), density (1.1 g/cm^3), ash content (2.6%), fixed carbon (20.7%), volatile matter (71%) and calorific value (4,820 kcal/kg). Responses from the survey indicated that the briquette is easy to ignite, has a long burning time and has good heat output. Respondents also observed that the briquettes did not give off sparks and had less smoke and ash content as compared to the regular charcoal they often used. Finally, 93% of the respondents indicated their willingness to use the briquettes if the price was comparable to charcoal.

Keywords: Sawdust charcoal briquettes, Physico-chemical characteristics, Demand and potential user's acceptability

Background

As a result of the growing worldwide concern regarding environmental impacts - particularly climate change - from the use of fossil fuels, the volatile fossil fuel market and the need for an independent energy supply to sustain economic development, there is currently a great deal of interest in renewable energy in general and biomass energy in particular. Biomass is one of the most common and easily accessible renewable energy resources and represents a great opportunity as a feedstock for bioenergy [1–3]. A wide range of biomass resources - crop residues (corn stover, rice husk, etc.), wood wastes from forestry and industry, residues from food and paper industries, municipal solid wastes and dedicated energy crops such as short-rotation perennials - can be utilised to generate electricity, heat, combined heat and power, and other forms of bioenergy.

Traditionally, energy in the form of firewood, twigs and charcoal has been the major source of renewable energy for many developing countries [4]. Fuelwood - firewood and charcoal - forms the most dominant source of energy in Ghana and is used significantly in both rural and urban communities for cooking and many other heating applications. According to [5], about 70% of the total national energy consumption is accounted for by biomass in either direct or processed form. Figure 1 presents the trend of energy consumption by the type of fuel in Ghana from the year 2000 to 2008. It can be seen that since the last decade, there has been consistent dependence on the use of fuelwood for cooking and other

* Correspondence: akowuahjoe@yahoo.co.uk
[1]Department of Agricultural Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
Full list of author information is available at the end of the article

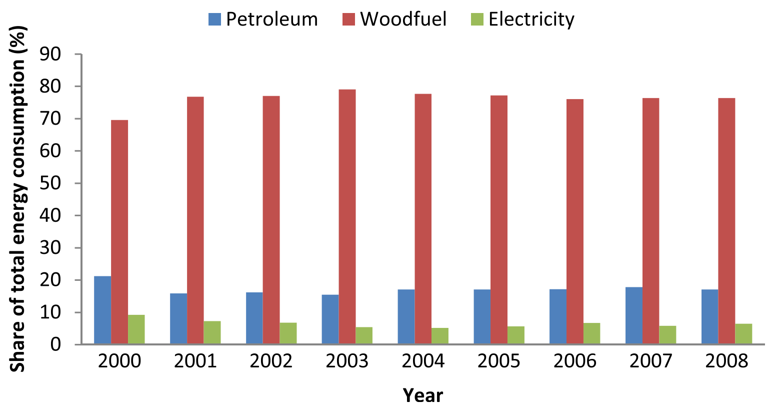

Figure 1 Trend of energy consumption by type of fuel in Ghana (adapted from [6]).

heat applications in Ghana in comparison to other sources of energy [6].

The over-reliance on forest wood in Ghana mainly for charcoal production, firewood and furniture making has resulted in the depletion of forest reserves at a faster rate - estimated at 3% per year [7]. A similar scenario, according to [4], in other sub-Saharan countries has resulted in shortage of fuelwood which has led to the depletion of over 75% of the total forest cover and thus leading to environmental crises. As rightly noted by [8], a transition to a sustainable energy system is urgently needed for developing countries.

Among the several kinds of biomass resources, agricultural residues - sawdust, rice husk, corn stover, cotton stalk, groundnut husk, etc. - have become one of the most promising choices as cooking fuels due to their availability in substantial quantities as waste annually. However, the utilisation of these biomass residues in their natural form as fuel is quite challenging due to their low bulk density, low heat release and the excessive amounts of smoke they generate [9]. All of these characteristics make it difficult to handle, store, transport and utilize biomass residues in their raw form. One of the methods of improving the thermal value of such biomass is the application of briquetting technology [10,11]. This involves the densification of loose biomass to produce fuel briquette which has better handling characteristics and enhanced volumetric calorific value [12] compared to the biomass in its original state. According to [13], briquettes are a key technology for increasing biomass use in both electricity and heat production.

The production of briquettes from sawdust and other agro-residues exemplifies the potential of appropriate technology for the utilisation of biomass residues which abound in large quantities in developing countries. However, compared to developed countries where successful briquette operations are mostly found, briquettes have not been widely adopted in developing countries due to the high cost of production, lack of awareness on its sustainability, lack of ready market and poor packaging and distribution systems for the product [4].

In Ghana, commercial production of sawdust briquette started in 1984. The production could not be sustained due to operational, marketing and standardisation challenges, though the briquettes had high prospect as an alternative to firewood and charcoal. However, according to [12], besides overcoming marketing and operational challenges, if agro-waste briquettes are to be used efficiently as fuel, they must be characterised by determining their physico-chemical parameters such as moisture content, ash content, density, volatile matter and heating value among others. According to [14], moisture content is a very important property which affects the burning characteristics of biomass. Volatile matter content has also been shown to influence the thermal behaviour of solid fuels [15]. This study therefore assessed the physico-chemical properties of charcoal briquettes produced in Kumasi, Ghana. It also sought to assess the market potential of charcoal briquettes in the study area to establish demand for and also the willingness of potential users to substitute charcoal and firewood with the sawdust charcoal briquette.

Methods

Raw material

The samples of sawdust charcoal briquette used for the study were obtained from a briquette-producing company in the Kumasi Metropolis in Ghana. In all, 600 kg of briquettes was acquired for the study. The production of briquette at the company is by the extrusion process through the use of a screw press briquetting machine at a die pressure range of 100 to 200 MPa with no additives such as starch binder. Figure 2 is a sample of the briquette in a carbonized form. It comes in square size

Figure 2 Sample of the sawdust charcoal briquette in a carbonized form.

(0.035 m × 0.035 m) with a concentric hole diameter of 0.01 m.

Determination of physico-chemical properties of sawdust charcoal briquette

The calorific value and density of the briquette were determined while proximate and ultimate analyses were conducted prior to the distribution of the briquettes to sampled potential users. This approach was adopted as a measure of control to collaborate the views or otherwise of the respondents on the handling and burning characteristics of the charcoal briquette after they have used the briquettes.

The calorific value was determined using a bomb calorimeter in accordance with [16]. Density was calculated from the ratio of the mass to the volume of the briquette in accordance with the method used by [2]. Estimations of important chemical elements that make up biomass, namely carbon, hydrogen, oxygen, nitrogen and sulphur, were determined through 'ultimate' analysis. These properties were determined in accordance with ASTM analytical methods as prescribed by [17]. Proximate analysis, which is a standardised procedure that gives an idea of the bulk components that make up a fuel [18], was done to determine the percentage volatile matter content, percentage ash content, moisture content and percentage content of fixed carbon of the briquettes.

Percentage volatile matter

The percentage volatile matter (PVM) was determined by pulverising 2 g of the briquette sample in a crucible and placing it in an oven until a constant weight was obtained. The briquettes were then kept in a furnace at a temperature of 550°C for 10 min and weighed after cooling in a dessicator. The PVM was then calculated using Equation 1:

$$\mathrm{PVM} = \frac{A - B}{A} \times 100 \tag{1}$$

where A is the weight of the oven-dried sample and B is the weight of the sample after 10 min in the furnace at 550°C.

Percentage ash content

The percentage ash content (PAC) was also determined by heating 2 g of the briquette sample in the furnace at a temperature of 550°C for 4 h and weighed after cooling in a dessicator to obtain the weight of ash (C). The PAC was determined using Equation 2:

$$\mathrm{PAC} = \frac{C}{A} \times 100 \tag{2}$$

Percentage moisture content on dry basis

The percentage moisture content (PMC) was found by weighing 2 g of the briquette sample (E) and oven drying it at 105°C until the mass of the sample was constant. The change in weight (D) after 60 min was then used to determine the sample's PMC using Equation 3:

$$\mathrm{PMC}_{(\mathrm{db})} = \frac{D}{E} \times 100 \tag{3}$$

Percentage fixed carbon

The percentage fixed carbon (PFC) was computed by subtracting the sum of PVM, PAC and PMC from 100 as shown in Equation 4:

$$\mathit{Fixed\,carbon} = 100\% - (\mathrm{PAC} + \mathrm{PMC} + \mathrm{PVM}) \tag{4}$$

User perception and potential market survey

Ten kilograms of the sawdust charcoal briquettes was given to each of the 60 potential users sampled purposively from within the Kumasi Metropolis of the Ashanti region of Ghana. The potential users sampled included households and local hospitality industry operators (e.g. restaurants, hotels, wayside food vendors and bakeries). A survey was then conducted among the recipients of the briquette in order to establish their acceptability and willingness to use the briquettes. The survey was conducted through the administration of structured questionnaires a week after the distribution of the briquettes. The results of the survey were analysed using descriptive analysis tools in the Statistical Package for Social Scientists.

Questions of critical importance which the potential users responded to include the effect of the burning rate of the briquettes, heat output, ease of ignition of the briquettes, rate of devolatisation (how fast the briquettes burned), burning time or combustibility rating (how long the briquettes burned before restocking when they are used in cooking and heating), sparking ability (whether or not the briquettes produce sparks when burning), smoke generation and any other effects regarding the burning of the briquettes.

Results and discussions

Physical characteristics of the briquettes

The quality of the sampled briquettes assessed on the basis of their physical condition revealed that their external surface was smooth and the structure of the cross section was compact and homogenous. The density of the sawdust charcoal briquette was found to be 1,100 kg/m^3 and falls within the range recommended by [19] for sawdust briquette produced by screw extrusion process. The hole in the centre helps in combustion because of sufficient circulation of air. It also provides sufficient toughness to withstand exposure and shocks of transportation and storage.

Physico-chemical characteristics

The result of the physico-chemical characteristics of the sawdust charcoal briquette is presented in Table 1 and discussed in this section.

Table 1 Physico-chemical characteristics of sawdust charcoal briquette

Parameter	Value
Proximate analysis	
Volatile matter	71.0%
Ash content	2.6%
Moisture content	5.7%
Fixed carbon	20.7%
Ultimate analysis	
Carbon	53.07%
Hydrogen	4.10%
Oxygen	39.60%
Sulphur	0.302%
Nitrogen	0.28%
Heating value	4,820 kcal/kg

Proximate analysis

The total energy that is needed to bring a briquette up to its pyrolytic temperature is dependent on its moisture content which affects the internal temperature within the briquette due to endothermic evaporation [20]. According to [21], moisture content is one of the main parameters that determine briquette quality. A lower moisture content of briquettes implies a higher calorific value. From Table 1, the as-received moisture content of the sawdust charcoal briquette was determined to be 5.7% db. This is good for the storability and combustibility of the briquettes as recommended by [22]. The value obtained is also corroborated by [21] who reported a moisture content of 5% for durable briquettes of sawdust.

Biomass generally contains a high volatile matter content of around 70% to 86% and low char content. This makes biomass a highly reactive fuel giving a faster combustion rate during the devolatisation phase than other fuels such as coal [15]. As reported by [18], low-grade fuels, such as dung, tend to have low volatile content that results in smouldering which other authors [23] described as an incomplete combustion which leads to a significant amount of smoke and release of toxic gases. However, for the sawdust charcoal briquette, a volatile content of 71% is high and an indication of easy ignition of the briquette and proportionate increase in flame length as suggested by [15]. The high volatile matter content indicates that during combustion, most of the sawdust charcoal briquette will volatise and burn as gas in the cookstove.

Ash, which is the non-combustible component of biomass, was found to be 2.6%. According to [24], ash has a significant influence on the heat transfer to the surface of a fuel as well as the diffusion of oxygen to the fuel surface during char combustion. As ash is an impurity that will not burn, fuels with low ash content are better suited for thermal utilisation than fuels with high ash content. Higher ash content in a fuel usually leads to higher dust emissions and affects the combustion volume and efficiency. According to [15], the higher the fuel's ash content, the lower is its calorific value.

The fixed carbon of the briquette, which is the percentage of carbon (solid fuel) available for char combustion after volatile matter is distilled off, was determined to be 20.7%. Fixed carbon gives a rough estimate of the heating value of a fuel and acts as the main heat generator during burning.

Ultimate analysis

The ultimate analysis indicates the various elemental chemical constituents such as carbon, hydrogen, oxygen, sulphur, etc. It is useful in determining the quantity of air required for combustion and the volume and composition of the combustion gases. The composition of the sawdust charcoal briquette analysed on an 'as-received basis' showed 53.07% carbon, 4.1% hydrogen, 39.6% oxygen, 0.28% nitrogen and 0.302% sulphur. The results agree with the observations made by Chaney [18] who reported that analysis of biomass using the gas analysis procedures revealed the principal constituent as carbon, which comprises between 30% and 60% of the dry matter and typically 30% to 40% oxygen. Hydrogen, being the third main constituent, makes up between about 5% and 6%, and nitrogen and sulphur (and chlorine) normally make up less than 1% of dry biomass.

The amount of carbon and hydrogen content in the sample examined is an indication that they will contribute immensely to the combustibility of the charcoal briquette as suggested by [25]. According to [19], the resulting composition of biomass affects its combustion characteristics as the total overall mass of the fuel decreases during the volatile combustion phase of the combustion process, as the hydrogen to carbon ratio of the fuel increases and, to a lesser extent, as the oxygen to carbon ratio increases. Nitrogen, sulphur and chlorine are significant in the formation of harmful emissions and have an effect on reactions forming ash [18]. The sulphur and nitrogen contents reported which are below 1% is a welcome development as there will be minimal release of sulphur and nitrogen oxides into the atmosphere, thereby limiting the polluting effect of the briquettes [26].

Calorific value

Heat value or calorific value determines the energy content of a fuel. It is the property of biomass fuel that depends on its chemical composition and moisture content. The most important fuel property is its calorific or heat value [21]. The computed calorific value for the sawdust charcoal briquette was 20,175.81 kJ/kg (4,820 kcal/kg). This energy value can produce enough heat required for household cooking and small-scale industrial cottage applications. The results of the calorific value of the charcoal briquettes compare well with the results of the heating value of sawdust briquette obtained by [27] and most biomass briquettes including almond shell briquette (19,490 kJ/kg) [19], corncob briquette (20,890 kJ/kg) [12], cowpea (14,372.93 kJ/kg) and soybeans (12,953 kJ/kg) [26].

Respondents' perception on usage of the sawdust charcoal briquette

As shown in Table 2, the following observations were made in response to the use of the briquettes by potential users.

Table 2 A matrix of user's perception on usage of sawdust charcoal briquette

Parameter	Response (%)		
Usage of product	Cooking	Grilling	Barbecuing
	72	18	10
Ease of ignition	Easy	Difficult	
	97	3	
Convenience	Very good	Good	Poor
	27	68	5
Rate of devolatisation	Fast	Slow	Moderate
	6	85	9
Heat output intensity	High	Moderate	Low
	76	20	4
Burning time	Long	Short	
	78	22	
Ash generated	Low	High	
	100	0	
Smoke/sparks	Yes	No	
	0	100	
Eagerness to use briquette	Willing	Not sure	
	93	7	

With ease to ignite the briquettes, 97% of the respondents indicated that it was easy to ignite the briquette. Also, 78% of the respondents indicated that combustibility rating/burning time was quite long if they compare to the same amount of charcoal they use for their cooking and heating activities. On the heat output from the briquette, 76% perceived that it was quite high compared to other fuels such as charcoal which they have been using. On the rate of devolatisation, 75% responded that though the briquette has high heat output, it burned slowly. The responses imply that the sawdust charcoal briquette ignites more easily and burns with high intensity for a long time.

More importantly, all the respondents indicated that the briquettes burned without sparks and smoke. Low ash content was also observed. This shows that the sawdust charcoal briquette will be a better alternative to charcoal and firewood. This agrees with [4] who reported that briquettes improve health by providing a cleaner burning fuel and also provide a better alternative to firewood (40% more efficient, better and longer burning time), as well as help to protect the environment by reducing the number of trees cut for firewood. Finally, 93% of the respondents indicated their willingness to use the briquettes if available and if the price is comparable to charcoal.

Conclusions

The findings of this study have shown that charcoal briquettes produced from sawdust meet recommended briquette characteristics and have market potential in Kumasi. The physico-chemical characteristics of the briquette assessed in this study showed that briquettes manufactured from sawdust had low moisture content (5.7%), high calorific value (4,820 kcal/kg) and low ash content (2.6%). There is also an indication that the briquette will be environmentally friendly due to the low sulphur (0.302%) and nitrogen (0.28%) contents observed. The survey has revealed that sawdust generated in large quantities and usually burned to pollute the environment can be converted into high-quality and durable solid fuel briquettes that will be suitable for both domestic and industrial energy production for heat generation. Even though a cost analysis was not performed in this study, the user perception survey showed that in terms of acceptability, there is future market potential for biomass briquettes among households and the hospitality industry (hotels, wayside food vendors, restaurants, etc.) in the study area. This is evident from the 93% of the respondents that indicated their readiness to use the briquette if the price is competitive enough.

Competing interests
The authors declare that they have no competing interest.

Authors' contributions
JOA conceived of the study, drafted the manuscript and participated in the sequence alignment. FK participated in the design of the study, performed the statistical analysis and participated in the sequence alignment. SJM was involved in the laboratory analysis and survey and also participated in the sequence alignment. All authors read and approved the final manuscript.

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Author details
[1]Department of Agricultural Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. [2]Department of Design and Technology Education, University of Education, Winneba, Kumasi Campus, Kumasi, Ghana.

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