Original Research Article

Assessment of combustion properties of briquettes produced from three different biomassessourced from Tarkwa, Ghana

Abstract

The demand for sustainable fuel/energy due to the global Sustainable Development Goals (SDGs) agenda, climate change issues and population growth has necessitated the need for alternative and environmentally friendly fuel/energy sources. This study aimed to produce alternative fuel source using agro-waste biomass such coconut husk, wood sawdust and waste charcoal residue. Particularly, the influence of the type of agro-waste biomass on resulting briquette combustion properties (% volatile matter, fixed carbon and ash content) was examined. Locally designed reactor was employed for briquettes production using cassava starch as a binder. Briquettes of sizes ranging between ~ 40 - 60 mm with varying residual moisture contents (8 – 12%) were produced from the various biomass. In terms of thermal characteristics, the results showed that the briquettes produced from coconut husk yielded highest volatile matter content of 36% followed by fine charcoal particles' briquettes (33%) and those from saw dust (3%). The Ash contents for the various briquettes produced from coconut husk, charcoal and sawdust were 2, 21 and 31%, respectively. In terms of the fixed carbon contents, briquettes produced from coconut husk had 34% whilst charcoal and sawdust ones had 46 and 96%, respectively. The calorific values of briquettes produced from coconut husk, charcoal and sawdust were 3531, 4047 and 5085 kcal/kg, respectively. Generally, the results showed that briquettes produced from saw dust had superior combustion characteristics (Calorific value, ash content, volatile content) than those produced from coconut husk and charcoal. Overall, the work has demonstrated the possibility of producing quality briquettes which could serve as alternative sustainable fuel/energy for various households who are dependent of unstainable fuels such as charcoal produced from trees. Moreover, the outcome can also serve as key alternative manner of managing abundant agro-waste in various communities, especially in the developing countries.

Keywords: Briquettes, Saw dust, Calorific value, Biomass, Coconut husk

1. Introduction

Currently, there is an increase interest in alternative renewable energy sources (such as biomass energy) for sustainable economic development. This is due to the great concern of negative environmental impact, particularly climate change (green gas emissions) issues, from the extraction and utilisation of fossil fuels (Senneca, 2011; Ujjinappa and Sreepathi, 2018). Biomass (e.g., coconut, riceand coffee husks, nut shells, wood shavings, sugarcane bagasse, charcoal fines and sawdust) is one of the readily and easily accessible renewable energy resources with great opportunity as raw material for bioenergy (Salman, 2023).Several reports have shown that developing countries produce large volumes of biomass annually as as by-products from agricultural, forestry and industrial sectors (Njenga et al., 2009, Sugumaran and Seshadri, 2010). Statistically, it is estimated that about 1 billion metric tonnes and 140 million metric tonnes of biomass are produced annually from the forestry and agricultural sectors, respectively,in

Sub-Sahara Africa (Dasappa, 2011). Unfortunately, these biomasses are usually regarded as waste and hence are either burnt without heat recovery or left to rot in-situ, subsequently emitting greenhouse gasses (GHG) leading to other environmental issues(Dasappa, 2011).

Interestingly, most of these biomass resources (such as municipal solid wastes, crop residues, wood wastes from forestry and agricultural industry, dedicated energy crops, residues from food and paper industries) can be utilised to generate electricity, heat, combined heat and power, and other forms of bioenergy (Akowuah et al., 2012). Thus, some of these biomasses can beused directly or indirectly as fuel hence utilizing them for this purpose prevents unnecessary burning, or buryingthat create environmental nuisance. For example, sugarcane bagasse,sawdust,coconut and rice husks can be used directly to fire brick kilns or boilers for producing electricity through steam, or can be converted to gas (Bingh, 2004; Kontor, 2013; Pode et al., 2015; Mwampamba et al., 2013). The direct usage of any biomass for fuel is economically justifiable when the source of waste is in close proximate to the point of energy generation or use. This implies that as distances between sources and sites of end-use increase, densification/compaction of these waste into uniformmaterials (e.g. as briquettes or pellets) facilitates easy handling and storage, lowers transportation costs and increases access to more distant markets. Additionally, it has been reported that the utilisation of these biomass residues (e.g., saw dust, coconut and rice husks) 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 (Akowuah et al., 2012).These characteristics make it difficult to handle, store, transport and utilize biomass residues in their unprocessed form. Briquetting technology has been identified as one of the methods for improving the thermal value of several biomasses (Akintaroa et al., 2017; Pallavi et al., 2013).

The briquetting method is the process of transforming low bulk density biomass into high density and energy-concentrated fuel. In other terms, the process “involves the densification of loose biomass to produce fuel briquette which has better handling characteristics and enhanced volumetric calorific value compared to the biomass in its original state” (Suhartini et al., 2011).Generally, the briquetting process consisttwomain stages, namely carbonisation/charring and compaction/cohesion.The carbonization process involves pyrolytic conversion of biomass into high carbon content material (biochar),by subjecting the biomass to high temperature, low oxygen conditions to remove volatile compounds and moisture (Alula et al., 2015; Ferguson, 2012).Notably, carbonization of the biomass residues is often noted to double the energy value per unit of weight with resulting bio-char having a calorific value of 25–30MJ/kg compared to that of unprocessed biomass (~15MJ/kg)due to the removal of volatile compounds and moisture (Meyer, 2009; Alula et al., 2015; Ferguson, 2012). Compaction/Cohesion of biochar can either be achieved by low pressure agglomeration with the use of binders (e.g. molasses, starch), medium pressure compaction with a lower binder percentage, or high-pressure compaction with little or no binder (Oladeji, 2015; Celestino et al., 2023;Mwampamba et al., 2013). Primarily, compacting of biomass increases its energy density (the amount of useful energy per unit of volume). Additionally, the energy density can be increased further by carbonizing the biomass before or after compaction (Ding et al., 2017; Reza, 2011).

As noted in various studies, the production of briquettes from agro-wastes (such as saw dust and rice husk) typifies the potential of suitable approach or technology for the usage of biomass which abound in large quantities in developing countries ((Rajabu and Ndilanha, 2013;Madukasi, 2023). However, the adoption of this technology in the utilisation of vast quantity of biomass in the developing countries (like Ghana) is very low due to relatively high cost of production, inadequate knowledge about its sustainability, lack of ready market and poor packaging and distribution systems for the product (Emerhi, 2011; Akowuah et al., 2012; Chen et al., 2014; Lohri et al., 2015).For example, it is reported that commercial production of sawdust briquette which had high prospect as an alternative to firewood and charcoal in Ghana started in 1984 but the production could not be sustained broadly due to operational, marketing and standardisation challenges(Akowuah et al., 2012)Thus, briquettes produced had poor thermal behaviour or characteristics primarily influenced by their physico-chemical properties such as moisture content, ash content, bulk density, volatile matter and heating value among others. Notably, the type and nature of the biomass aside operating conditions and binder type, mainly influences the resulting thermal performance of the resulting briquettes. Hence, there is a need to always select the suitable biomass type for the fuel briquette production to obtain an optimal performance, high yield, and energy content. This study therefore assessed thermal characteristics of briquettes produced from three different biomass type (sourced from Ghana). Particularly, the physico-chemical properties (residual moisture content, ash content, fixed carbon and volatile matter) of briquettes produced from three different biomasses (coconut husk, saw dust and fine charcoal particles) was examined.

2.Experimental Methods and Materials

2.1. Materialsand equipment

2.1.1. Materials

Three different materials; Coconut husk (Figure 1A), Sawdust (wood chippings) (Figure 1B), and fine charcoal particles (Figure 1C) were used as feedstocks for the study. The coconut husk, sawdust and fine charcoal particles were sundried to reduce the moisture content to approximately 12%, which is within the acceptable operating limit for briquetting and storage (Olaoye and Kudabo, 2017).Starch produced from cassava (sourced locally)(Figure 1D) was also used as binding agent in the briquette production.

Table 1. Raw materials and their sources

Raw Material	Sources
Sawdust	Carpentry Workshop,
Coconut Husk	Coconut Sellers
Charcoal Particles	Charcoal Sellers

Fig. 1. Biomass feedstocks used as raw materials **(A)** Coconut husk **(B)** Saw dust **(C)**Charcoal particles and **(D)** Cassava starch as binding agent

2.1.2. Equipment

Figure 2A and B are the two main equipment employed in this study for moulding and carbonization/charring, respectively. The equipment was built locally using locally sourced materials. Notably, carbonisation reactor (Figure 2b) is designed to have low oxygen environment within but able to withstand high temperature. Thus, the bottom of the carbonisation reactor is perforated to regulate the flow of oxygen into the reactor since it is closed system.

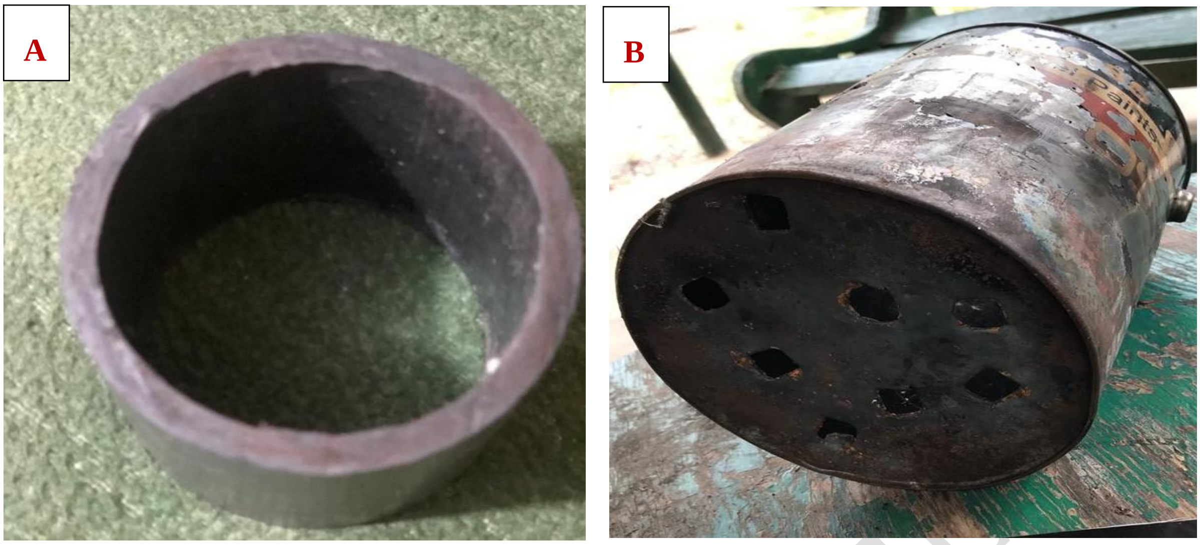

Fig. 2. Locally designed (A) moulding equipment and (B) Carbonisation/Charring reactor

2.2. Experimental methods

2.2.1.Briquetteproductions

The production of briquettes was done via three stages: Feedstock sourcing/preparation, charring and moulding.

Stage 1: Feedstock preparation

The stage involved sourcing and sun-drying of the feedstock for a week. Notably, the coconut husk (Figure 1A) was cut/shred into pieces prior to sun-drying.

Stage 2: Charring of biomass feedstocks

The sun-dried coconut husks and saw dust were charred in a carbonization reactor (Figure 2B). The biomass materials were fed into the reactor and covered. The reactor containing the biomass was fired on traditional stone stove with firewood for about 5 min (wood saw dust) and 10 min (coconut husk). The wood saw dust was charred for only 5 min since its ashes quickly. The charred biomass was then taken out of reactor and spread on a pan to cool down. Notably, the fine charcoal particles were already charred hence were used as received for the study.

Stage 3: Briquette moulding / production process

The charred biomass was grounded and sieved through a 1.18 mm sized screen to ensure uniform feed particle sizes in manner similar to that reported by (Ogwu et al., 2014). About 400 g of the sieved product of each charred biomass (coconut husk, wood saw dust and fine charcoal particles) was mixed with 250 g of binder (cassava starch).The mixture was handfed into a pipe and compacted to obtain uniform briquettessizes.The compacted briquettes were then dried in an oven at a temperature of 120^{o}C for 12 h.

2.2.2. Briquette characterisation

The properties of the compacted briquettes produced from the coconut husk, wood saw dust and fine charcoal particles were assessed. Particularly, the residual moisture content, volatile matter, ash content, fixed carbon and specific heat combustion of the briquettes produced from the various biomass were examined in the manner similar to the methods reported by Egbewole et al. (2009), Tembe et al. (2011) and Fuwape et al. (1998).

Moisture content (% Mc): The moisture content of the briquette produced for each biomass was measured. It is worth noting that the residual moisture impacts the overall durability, strength and calorific value of the briquettes. This was achieved by weighing the fresh briquette before (w1) and after oven- dried at 105^{o}C (w2) (Alula et al., 2015)for 3 hours(Ogwu et al., 2014). The moisture content was calculated using Equation 1.

$$\%Mc = \frac{wet\ weight\ (W1) - oven\ dry\ weight(W2)}{wet\ weight\ (W1)} \times 100 \qquad \text{Eq.1}$$

Volatile Matter (% Vm): The amount of volatile matter was determined byweighing and placing oven-dried briquette (W_2) in a furnace for 10 min at 550^o C to obtained weight (W3) after the escape of its volatile matter. The percentage volatile matter (%Vm) was estimated using |Equation 2 (Ogwu et al., 2014).

$$\%Vm = \frac{W2 - W3}{W3} \times 100 \qquad \text{Eq.2}$$

Where W2 is the oven dry weight and W3 is the weight of sample after 10 mins in the furnace at 550 °C

Ash Content (% Ash): About 5 g of crushed oven-dried briquette was placed in a furnace for 4 h at 550^{o}C to obtain the ash weight (W4)(Ogwu et al., 2014). The percentage Ash Content (% Ash Content) was calculated using Equation 3.

$$\text{Ash Content (\%)} = \frac{\text{Weight of Ash (W4)}}{\text{Oven Dry weight (W2)}} \times 100 \qquad \text{Eq. 3}$$

Fixed Carbon (% Fc): The percentage fixed carbon was calculated by subtracting the sum of percentage of volatile matter and percentage ash content from 100 % as shown in Equation 4(Falemara et al., 2018).

$$\text{Fixed Carbon (\% Fc)} = 100\,\% - (\%\,\text{Vm} + \%\,\text{Ash}) \qquad \text{Eq.4}$$

Specific Heat of Combustion (Hc): The Specific Heat of Combustion (Calorific Value) of the briquettes was calculated using Equation 5 (Falemara et al., 2018).

$$Hc = 0.35(147.6 \times \% Fc) + (144 \times \%Vm) + (\%Ash) \quad \text{Eq. 5}$$

3. Result and Discussion

3.1. Physical characteristics of the briquettes

Figure3 (A-D) shows the photomicrographs of the briquettes produced from wood sawdust (Figure 3A), coconut husk (Figure 3B) and charcoal dust (Figure 3C), respectively. It is worth noting that the sawdust briquette looked brownish because the feedstock was slightly charred/carbonised before moulding since it turns into ashes quickly. The size of briquettes produced ranged within ~ 40 – 60 mm with varying residual moisture contents as highlighted in Table 2.

Fig.3. Photomicrograph of Briquettes with cassava starch as binder produced from charred (A) wood Sawdust (B) coconut husk and (C) fine charcoal material

In terms of the residual moisture content, briquettes produced from coconut husk had the highest (12%) followed by those obtained from charcoal particles (10%) and the saw dust (8%). The differences can be attributed to the variations in the feed properties (e.g., particle size, moisture content, surface area), and the binder content (Demisu and Muluye, 2023). Evidently, the particle size distribution of the coconut appeared finest hence required most binder to wet the surface of the particles followed by charcoal and sawdust hence contributing to the difference in moisture content among the materials. Generally, the residual moisture contents of the various briquettes are consistent with standard residual moisture content of 5- 10% (Pallavi et al., 2013). The variations in the residual moisture contents observed is expected to affect the general performance of briquettes in terms of their calorific value, ash content, fixed carbon content and volatile matter content (Akintaroa et al., 2017). Thus, briquettes with low moisture content are expected to ignite easily yielding higher energy/calorific values (Akowuah et al., 2012). Therefore, it is expected that briquettes produced from saw dust with lowest moisture content would ignite easily and yield higher calorific value followed by those produced from charcoal and coconuts.

Table 2. Residual Moisture content of briquettes produced from sawdust, coconut husk and fine charcoal particles.

Briquette type	Residual moisture (%)
Sawdust	8
Coconut Husk	12
Charcoal Particles	10

3.2 Combustion/thermalproperties of briquettes

3.2.1. Volatile matter (%)

The volatile matter content representing the gaseous phase formed from the thermal degradation of the briquettes produced from coconut husk, charcoal and saw dust was examined. Notably, high volatile matter content is an indication of the readiness of briquettes to ignite and burn easily (Loo and Koppejan, 2008; Akintaroa et. al., 2017 (10)). Fig.4 shows the percentage of volatile matter of the briquettes produced from coconut husk, charcoal particle and saw dust under similar thermal degradation testing conditions. The results indicate that the volatile matter content that was distilled off from coconut husk, charcoal particles and sawdust were 36, 33 and 3%, respectively. The differences in volatile matter can be attributed to the variations in the residual moisture contents and the number of combustible-incombustible materials present in the briquette. In terms of quality, the results show that briquettes produced from coconut husk with the high volatile matter would readily ignite with a high proportionate flame during combustion compared with those from charcoal and saw dust.

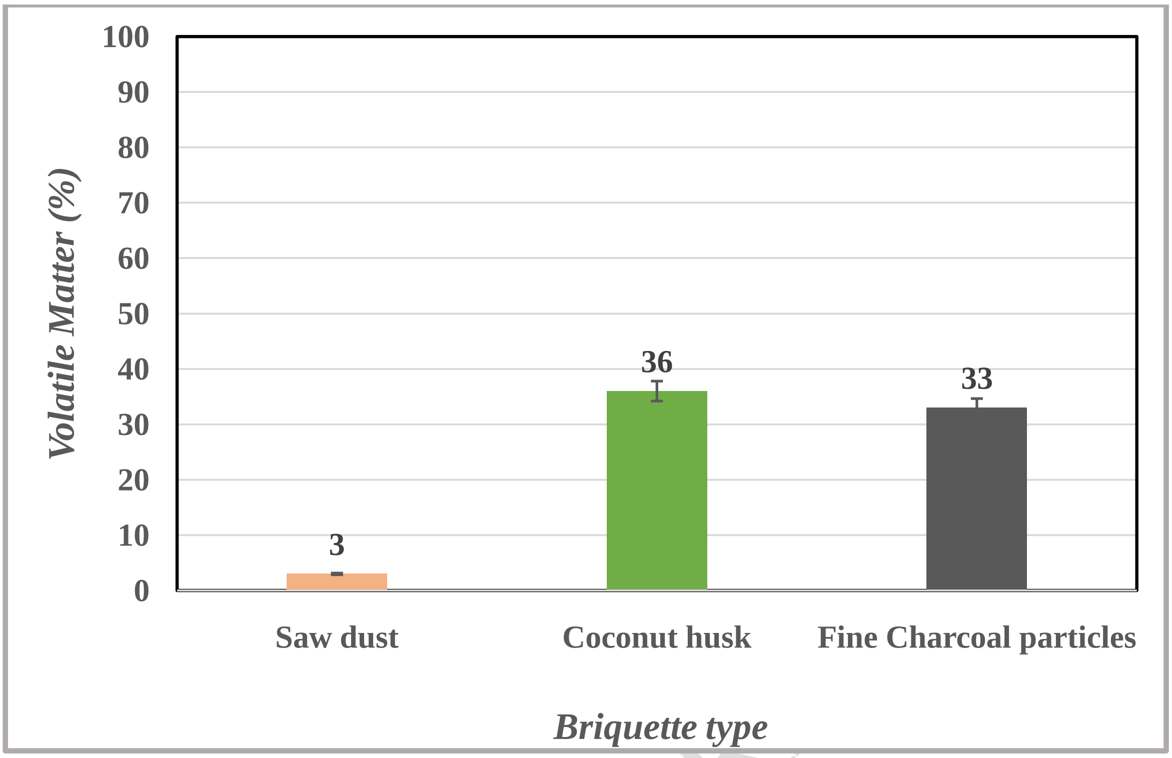

Fig.4. Volatile Matter (%)of briquettes produced from sawdust, coconut husk and fine charcoal particles.

3.2.2. Ash Content

The ash content representing the mass of non-combustible component obtained from briquette produced from the biomass was examined.Figure5shows the ash contents of the briquettes produced from coconut husk, charcoal particles and sawdust. The ash content for the briquettes produced ranged from 2 wt% to 31 wt.%. The highest ash content of 31 wt.% was obtained from the coconut husk briquettes whilst the lowest ash content of 2wt% was obtained from sawdust briquettes. The difference in the ash contents can be linked to the amount of char left after the volatile matter is distilled off (Deepak et al., 2019). The ash content of the briquettes produced from the coconut husk (31 wt%) and charcoal particles (21wt%) were found to be within the acceptable ash limit (5–40 wt%) for a solid biomass briquette (UNEP, 2006).Generally, high ash content of briquette means the combustion remnant of such fuel was high but with a low heating value. High ash content also results in dust emissions that may lead to air poulltion during combustion (Inegbedion, 2021; Dalkhsuren et al., 2023). Ash content has a significant effect on heat transfer and oxygen diffusion to the surface of fuel during combustion (Chou et al. 2009). Therefore, the excessive ash content of solid fuel affects its combustion volume and efficiency (Kuswaet al., 2023;Chaney, 2010). Hence, the produced briquettes from the coconut husk, charcoal particles and sawdust would perform well based on the ash contents.

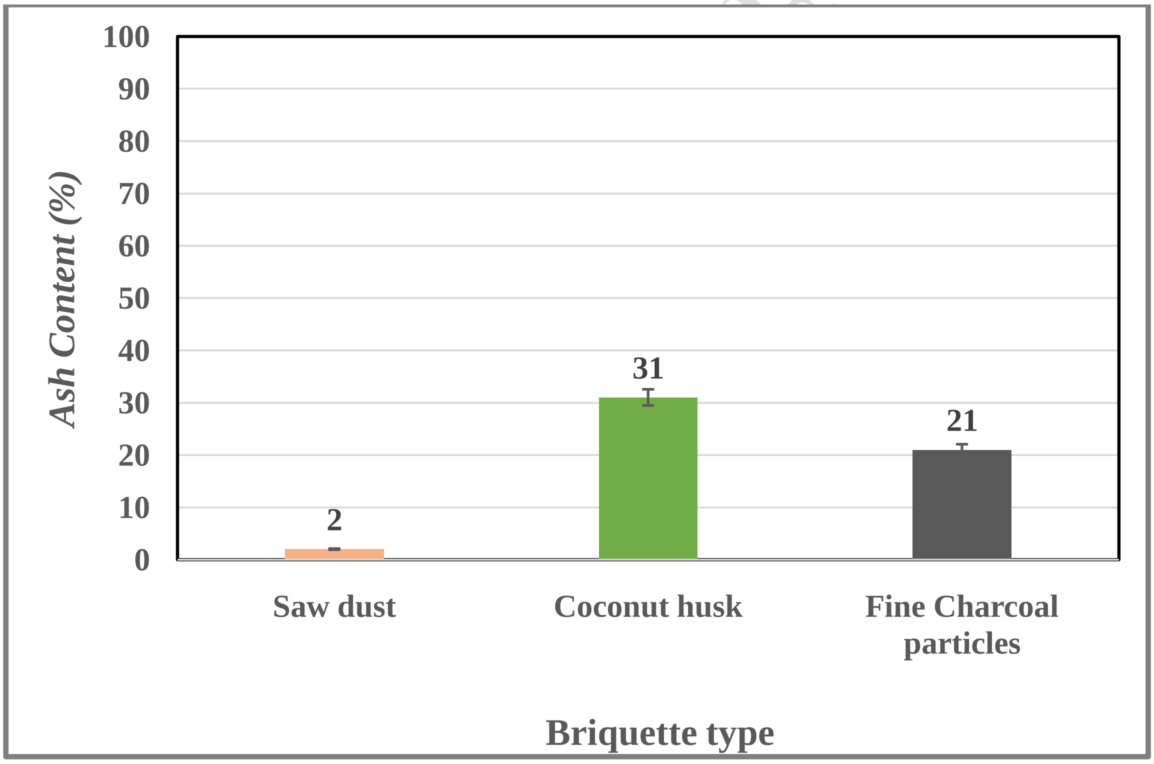

Fig.5. Ash Content (%)of briquettes produced from sawdust, coconut husk and fine charcoal particles.

3.2.3. Fixed Carbon

The fixed carbon which represents the percentage of carbon available for char combustion of the briquettes was examined.Figure6 shows the fixed carbon contents for the briquettes produced from coconut husk, sawdust, and fine charcoal particles. The results revealed that briquettes produced from the sawdust exhibited highest fixed carbon content of 96% followed by fine charcoal particles briquettes (46%) and coconut husk briquettes (34%). The result of fixed carbon contents demonstrated by the various briquette was much expected due to the variations in their residual moisture content as shown in Table 2 (discussed in section 3.1). Thus, increasing residual moisture of briquettes often leads to decreasing fixed carbon content. Evidently, coconut husk briquettes with highest residual moisture yielded lowest fixed carbon content whilst sawdust briquettes with lowest residual moisture content exhibited the highest fixed carbon content, relatively. Generally, low percentage fixed carbon is an indication of a low heating value of the briquette and the vice versa. Hence, it is expected that the heating values of the briquettes produced in this study will increase in the order of Sawdust > Fine charcoal particles > coconut husk.

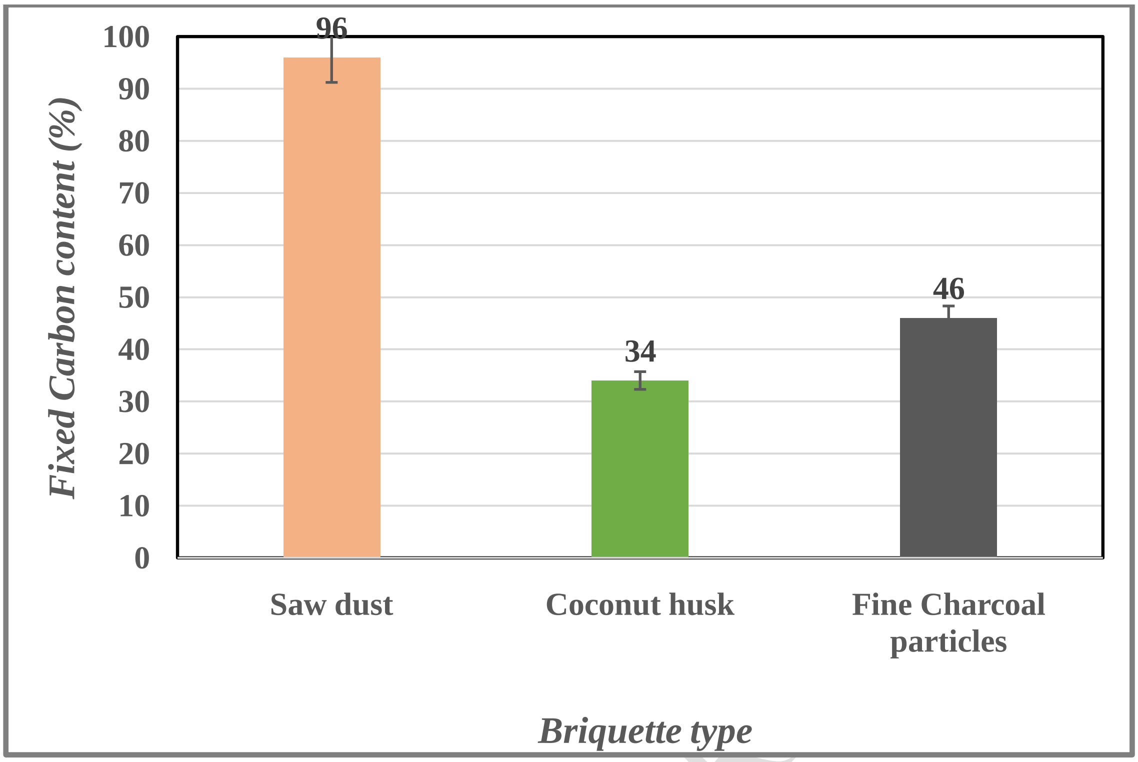

Fig.6. Fixed Carbon contents of briquettes produced from sawdust, coconut husk and fine charcoal particles.

3.2.5 Calorific Value

The main thermal property of any fuel is its calorific value which refers to the amount of heating value of the fuel per unit volume or the amount of heat obtained when the fuel/briquette is burnt (UjjinappaandSreepathi, 2018). The heating values for the briquettes produced from coconut husk, fine charcoal particles and sawdust were also examined. The results showed that briquettes from sawdust yielded highest heating value of 5085 kcal/kg followed by fine charcoal particles briquettes (4047 kcal/kg) (Figure 7). Those obtained from the coconut husk yielded the lowest heating value 3531kcal/kg. The differences in calorific value can be linked the variations in properties of the briquettes such as residual moisture, volatile matter, fixed carbon content and ash content (as discussed in sections 3.2). Notably, the differences in the properties of the raw feedstock/biomass and the binder formulation (type and amount) underpin the variations in the briquettes' properties.

It is worth mentioning that a higher heating value is a great indication of a good and efficient briquettes (Ríos-Badrán et al., 2020). This implies briquette performance in terms of heating value/caloric value, those produced from sawdust is superior that those obtained from fine charcoal particles and coconut husk.

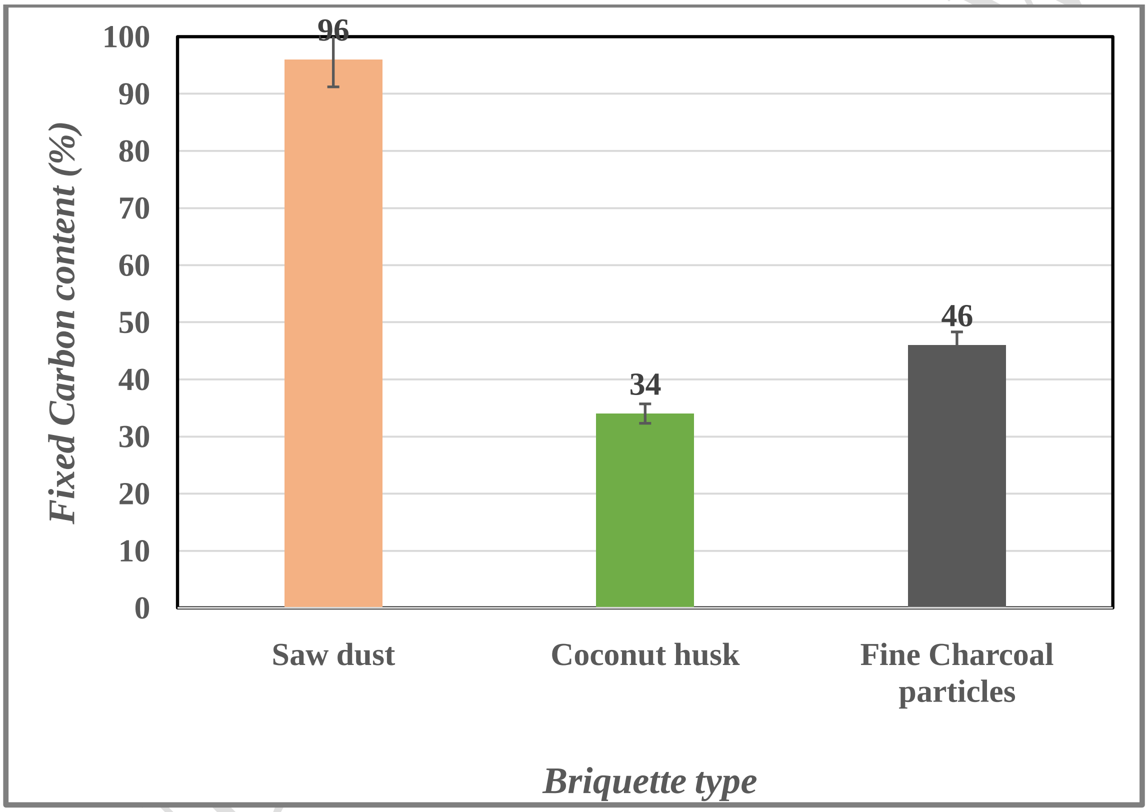

Fig.7. Calorific/Heating valuesof briquettes produced from sawdust, coconut husk and fine charcoal particles

4. Conclusions

The outcomes of the study to investigate the properties of briquettes produced from different biomass sourced from Ghana are:

- Briquettes of sizes ranging between 40 – 60 mm were produced from coconut husk, fine charcoal particles and saw dust using cassava starch as binder.
- The briquettes produced had varying residual moistures with those produced from coconut husk containing the highest (10%) followed by fine charcoal particles (10%) and sawdust (8%).
- The volatile matter content that was distilled off from coconut husk, charcoal particles and sawdust briquettes were 36, 33 and 3%, respectively.
- The ash content for the briquettes produced ranged from 2 wt% to 31 wt.% with coconut husk briquettes yielding the highest ash content of 31 wt.% followed by fine charcoal paricles (21wt%) and sawdust briquettes (2wt%).
- For the fixed carbon content, the briquettes produced from the sawdust exhibited highest fixed carbon content of 96% followed by fine charcoal particles briquettes (46%) and coconut husk briquettes (34%).
- In terms of heating values or calorific values, the briquettes from sawdust yielded highest heating value of 5085 kcal/kg followed by fine charcoal particles briquettes (4047 kcal/kg) and the coconut husk (3531 kcal/kg).

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