Process Parameters Affecting the Production of Charcoal Briquettes from Lignocellulose Waste

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Due to the increasing energy shortages in sub-Sahara Africa, countries are looking for alternative energy sources that are renewable such as the charcoal briquettes solid fuel from agricultural waste. This paper presents the influence of various process factors that affect the performance of charcoal briquettes. The briquettes performance in terms of calorific value can be enhanced by pyrolysing at temperatures of 300 to 400°C for residence times of 4 to 5 hours. Ignition times of 200s are achieved for briquettes with small sizes of 120 g, and they have a burning rate of up to 600 min/kg. A high compressive strength of 400N is achieved after using binder ratios of 1:10 parts of the bio charcoal at a packing moisture content of 5%. Charcoal briquettes if processed optimally can provide eco-friendly energy promoting sustainable development in Africa.

Keywords: Agricultural waste, Charcoal briquettes, Process factors, Renewable energy

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INTRODUCTION

Energy shortage is a major challenge in sub-Sahara Africa, with 50% of the total population living off the grid (Energy Outlook 2014). There is therefore a need for alternative sources of energy that are renewable and eco-friendly. At the same time, sub-Sahara Africa is rich in agricultural waste from its maize, tea, coffee, wheat, animal waste, and sugarcane farming activities (Manyuchi *et al.* 2016). Of late, the production of charcoal briquettes from agricultural waste for use as solid fuel has gained momentum, and the technology has proved to be feasible (Pandey and Dhakal 2013). However, there is still need to understand the process parameters that underpin the quality of the charcoal briquettes, hence the basis of this study.

EXPERIMENTAL

Materials and Methods

Charcoal briquettes production

A sample with 5 kg of blended agricultural waste (cow dung, corn stover, and saw dust) was pyrolysed in a muffle furnace set at different temperatures of 200 to 500 °C, respectively for times between 2 and 5 hours. The cow dung, corn stover, and saw dust were in the ratio 30:30:40, respectively. After pyrolysis, the biochar solid product was obtained.

A number of reactions occurred during pyrolysis, these include: (i) devolatilisation and carbonization of hemicellulose; (ii) de-polymerization and devolatilisation of lignin and cellulose (Chan et al. 1985). The biochar was finely ground using a pestle and mortar. The ground material was then sieved through a 600 µm sieve to attain a size ranging from 0.2 to 0.6 mm. Charcoal briquettes were produced by adding a waste flour as binder at ratios of 1:10 for 10 minutes to the biochar. Water was then added to make a mixture. The mixture was then compressed using a piston press cylinder to densify the biochar/binder mixture increasing the energy per unit volume value. Briquetting was done at a pressure of 1 MPa to 5 MPa in a rectangular briquetting machine. The charcoal briquettes were then dried in the oven at 55 °C for 20 hours.

Gross calorific value

The gross calorific value of the samples of the charcoal briquettes was determined by the ASTM D5865-13 procedures in accordance with (ASTM, 2012). This was done using an adiabatic bomb calorimeter. About 0.4 g of each sample was burnt in the bomb calorimeter until complete combustion was obtained. The difference between the maximum and minimum temperatures obtained was used to compute the gross calorific values of the charcoal briquettes.

Moisture content

A portion (2g) from each of the charcoal briquettes was measured in a watch glass. The samples were placed in an oven for 2 hours at 105°C. The moisture content was determined by using,

$$MC = (W_1 - W_2)/W_1 \times 100 \quad (1)$$

where W_1 is the initial weight and W_2 is the weight after drying.

Ignition time

This is the time taken by each charcoal briquette to catch fire (Mitchual *et al.* 2014). The different samples were ignited at the edge of their bases with a Bunsen burner. The time taken for each charcoal briquette to catch fire was recorded as the ignition time using a stopwatch.

Burning time

This is the time taken for each charcoal briquette sample to burn completely to ashes (Mitchual et al., 2014). Subtracting the time is turned to ashes completely from the ignition time gives the burning time. Burning time = Ashing time – Ignition time.

Compressive strength

Compressive strength is the maximum crushing load a charcoal briquette can withstand before cracking or breaking (Mitchual *et al.* 2014). A single charcoal briquette was placed on the platform of the tensile strength testing machine and, with the machine operating in the compressive mode, a constant load was applied until the charcoal briquette fractured in accordance to a methodology described by Ozbayoglu and Tabari (2003).

The load at fracture can also be converted to a stress by expressing the load as a stress (force per unit area). By this means it is possible to compare briquettes of various sizes and incorporating different binder ratios. For the purpose of this study all charcoal briquettes were of similar size and shape, and therefore only the load force was used. A batch of 20 briquettes was tested at a time. The mechanical strength measured through the compressive strength is determined by the briquetting compaction pressure and the binder ratio (Habib *et al.* 2013).

Ash content

Ash content of the charcoal briquettes was determined in accordance with ASTM D3 174-12 (Mitchual *et al.* 2014). This was done by heating approximately 2 g of oven-dried mass of each charcoal briquette with particle size of 425 μm, in an electric furnace at a temperature of 600˚C for four hours. Thereafter, it was cooled in a desiccator and weighed to represent the ash content of the sample.

Volatile matter

The volatile matter of the charcoal briquettes was determined in accordance with ASTM D3175 (Mitchual *et al.* 2014). Approximately 2 g of each of the biomass materials, particle size 425 μm, was placed in a porcelain crucible then put in the oven. Each sample was first oven-dried and then kept in a furnace at a temperature of 550˚C for 10 min and weighed after cooling in a desiccator.

Organic carbon content

The organic carbon content of the biomass materials was determined in accordance with ASTM D1762 (Mitchual *et al.* 2014). This was done by subtracting the mass (g) of ash from the oven-dry mass of the sample to obtain the mass (g) of organic matter component.

Sulphur composition

The sulphur content was determined by the Turbidimetric method in accordance with ASTM D4239 (Mitchual *et al.* 2014).

RESULTS AND DISCUSSION

Charcoal Briquettes from Agricultural Waste

The charcoal briquettes produced from the blended agricultural waste are shown in Fig 1. A biochar yield of 73% was achieved, and this was briquetted to charcoal briquettes. The charcoal briquettes produced can be used for cooking, heating, boiling purposes in manufacturing industries.

Fig. 1. Charcoal briquettes from agricultural waste

Effect of Pyrolysis Time

The blended agricultural waste had a calorific value of 12 to 16 MJ/kg. The calorific value of the final charcoal briquettes improved by more than 80% directly with the pyrolysis time from 22 to 30 MJ/kg (Fig 2). Increased times from 2 to 5 hours of pyrolysis allows all the carbon content in the agricultural waste to be transferred to the char. Thus, enhancing the briquettes heating value and optimum pyrolysis temperatures were achieved at 5 hours. Slow pyrolysis temperatures allow the slow release of the carbon in the agricultural waste thereby enhancing the energy content (Pandey and Dhakal 2013).

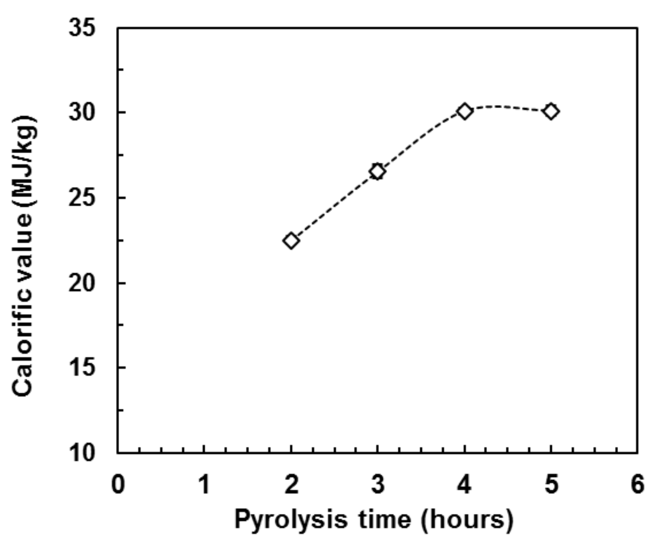

Fig. 2. Effect of pyrolysis time on charcoal briquettes calorific value

Effect of Pyrolysis Temperature

As the pyrolysis temperature increased from 200 to 500 °C, the final calorific value of the charcoal briquettes increased from 22 to 30 MJ/kg (Fig 3).

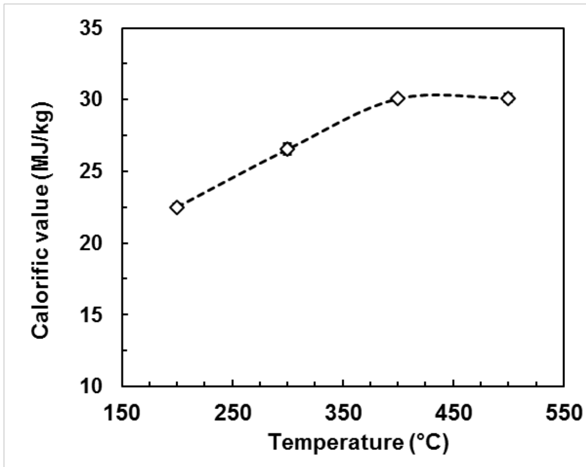

Fig. 3. Effect of pyrolysis temperature on charcoal briquettes calorific value

The calorific value gives the charcoal briquettes its commercial value (Pandey and Dhakal, 2013). Values obtained in this work were comparable to those of coal, indicating that the briquettes were of high energy content.

Effect of Briquette Size

As the size of the briquettes increased from 120g to 180 g, the ignition time of the charcoal briquettes increased from 100s to 200s (Fig 4). Larger charcoal briquettes have lower porosity index. This affects the ignition rate, leading to longer ignition times (Davies *et al.* 2013).

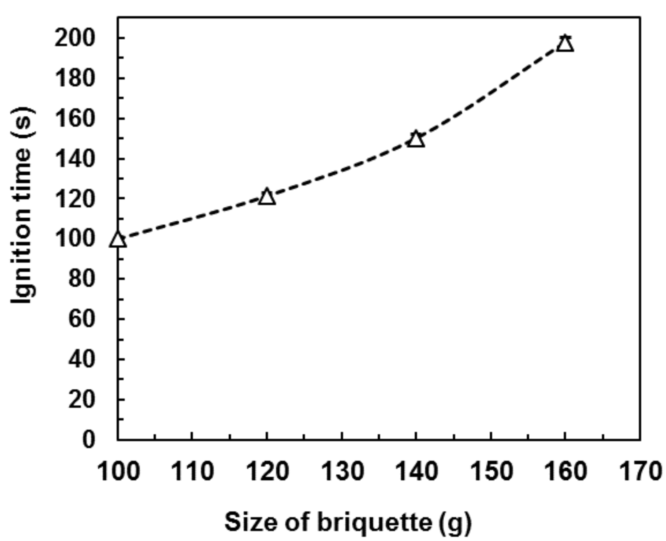

Fig. 4. Effect of briquette size on ignition time

Effect of Binder Ratio

As the binder ratio increased from 1:20 to 1:10 in relation to the biochar added, the compressive strength of the charcoal briquettes significantly increased to 400 N (Fig 5).

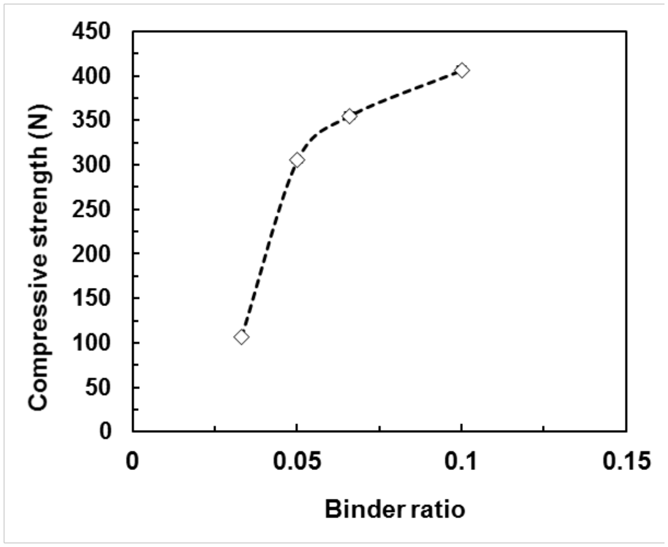

Fig. 5. Effect of binder ratio on compressive strength

Effect of Briquettes Moisture Content

High moisture contents from 5% to 20% in the final product of the charcoal briquettes resulted in increased ignition times of the charcoal briquettes from 100 to 200 s (Fig. 6). Moisture content must be as low as possible; for charcoal briquettes, 5% maximum is recommended because high moisture content has a potential to decrease the combustion efficiency (Pandey and Dhakal 2013).

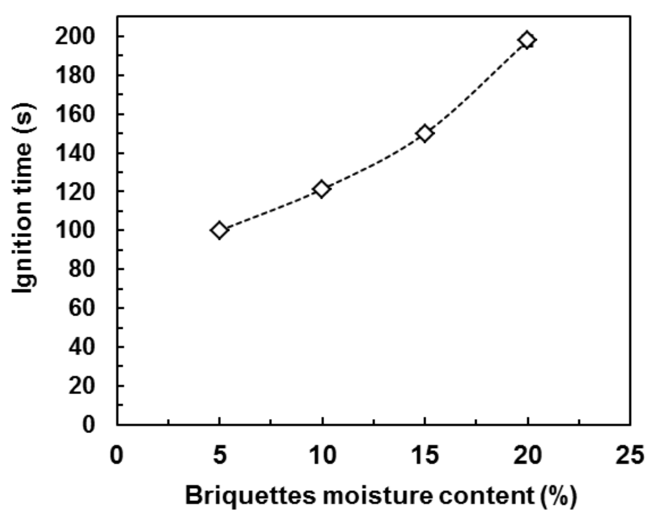

Fig 6. Effect of moisture content on ignition time

Effect of Biochar Compaction Pressure

Mechanical strength of the charcoal briquettes is very critical, as it affects the briquettes quality during storage and transportation to the market (Habib *et al.* 2013). As the biochar compaction pressure during briquetting was increased from 1 to 10 MPa the briquette compressive strength increased from 100 N to 400 N (Fig 7).

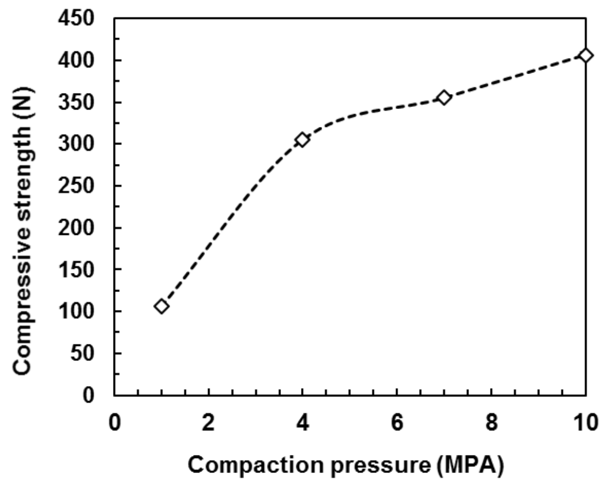

Fig. 7. Effect of compaction pressure on briquettes compressive strength

The overall physicochemical parameters of the charcoal briquettes are in Table 1. The charcoal briquettes have a high heating value of 22 to 30 MJ/kg and minimal sulphur emissions.

Table 1. Summary for Charcoal Briquettes from Agricultural Waste Properties

Parameter	Value
Moisture content	5.00%
Fixed carbon content	68.40%
Ash content	1.80%
Volatile matter	13.30%
Ignition time	100-000 secs
Burning time	200 – 600 mins/kg
Calorific value	22.5-30 MJ/Kg
Sulphur content	0.01%

CONCLUSIONS

1. Charcoal briquettes from agricultural waste are a good alternative source of energy due to their eco-friendliness and high calorific value of 22 to 30 MJ/kg.
2. Due to the high calorific values, the briquettes can be used for cooking, heating, and boiling purposes
3. The ultimate performance of charcoal briquettes from agricultural waste is dependent on the process factors.
4. Controlled pyrolysis time, temperatures, binder ratios, moisture content, and the briquettes' size affect the performance of the briquettes, and these must be controlled.

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