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Development of Biomass Fuel Briquettes from Waste Rice Husks in Ebonyi State Nigeria

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ABSTRACT: Rice husks from a rice milling plant in Afikpo Local Government Area of Ebonyi state Nigeria were processed into cylindrical briquettes. The received sample was divided into two batches. One batch was torrefacted at 210ºC for 30 minutes before being extruded into briquettes. The other batch was extruded into briquettes without torrefaction. Cassava starch was used as binder for the two batches. Water boiling test was used to evaluate the combustion performance of the two batches and also to compare them against each other as well as against wood charcoal. The firepower recorded for the torrefacted batch were 1867.23 watts, 4462.42watts and 1189.6 watts for phases one, two and three of the test respectively. The firepower recorded for the non-torrefacted batch were 1296 watts, 2441.93 watts and 871.67 watts for phases one, two and three of the test respectively. The firepower recorded for wood charcoal were 3322.9 watts, 8817.02 watts and 1737.85 watts for phase one, two and three of the test respectively. The specific power of the three batches of fuel were 7.67 watts per gram, 5.60 watts per gram and 18.06 watts per gram for the torrefacted rice husk briquettes, non-torrefacted rice husk briquettes and wood charcoal respectively. Torrefaction increased the firepower of rice husk briquettes by 44%, 82.89% and 36.47% during phases one, two and three of the water boiling test, respectively. The weight loss due to torrefaction was 17.8% and indicates an increased energy density. The improved specific power due to torrefaction and briquetting is a promising indication that processed rice husk has the potential to replace wood charcoal products for domestic and industrial heating.

KEYWORDS: rice husk, torrefaction, briquette, firepower, specific power, energy density.

I. INTRODUCTION

The use of firewood and wood charcoal for cooking has been an essential anthropogenic activity since pre-historic era, (Deforce et al. 2013). The continuous felling of trees to sustain the production of wood based biomass leads to deforestation and forest degradation.

Some agricultural wastes, such as rice husks are rich in carbon bearing compounds, like cellulose and lignin. However, the fibrous nature of rice husks, as well as poor combustion efficiency, low energy density and high smoke emission, poses a limitation to their use as an alternative biomass energy source. van der Stelt *et al.* (2011), reported that the properties of raw biomass, such as its high oxygen content, high moisture, low calorific value, large particle size, and grinding difficulty, have limited the further development of biomass application to technology.

According to Bergman et al. (2005), biomass is expected to play a major role in the transition to renewable or sustainable energy production. Bioenergy can be generated in many ways. It can be converted to value added liquids and gaseous products, such as ethanol, synthesis gas, or bio-oil, or it can generate electricity via direct combustion or gasification, (Aytenew et al 2018).

Currently, energy sources for cooking in most urban and sub urban homes in Nigeria include electricity, kerosene, liquefied petroleum gas, charcoal and fire wood. Most rural dwellers depend largely on charcoal and firewood for their cooking. Rising costs of kerosene and LPG, as well as poor electricity supply means that increasing numbers of urban and semi urban households are also turning to wood derived biomass fuels.

Wood charcoal usage has been an essential anthropogenic activity since pre-historic era, (Deforce et al 2013). The attraction towards wood charcoal is due to its unique characteristics of affordability and availability, (Mensah et al 2020).

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Vol. 9, Issue 9 , September 2022

Also according to Nyako et al (2020), wood charcoal has more energy density and emits less smoke than firewood. However, the indiscriminate felling of trees to sustain the production of wood charcoal poses a grave danger to the environment.

The environmental impact of wood charcoal production includes, long term and accelerated deforestation and forest degradation, (Olorunnisola 1999). In the decade (2010 -2019), 4,314,708 tonnes of wood charcoal were produced in Nigeria, (Nyako et al 2020).

Complete substitution of wood fuel by other sources such as electricity, solar, gas and kerosene would yet take a few decades to materialize. It is therefore quite reasonable to explore the development and utilization of agro-residue briquetts as an interim measure, (Ikelle et al 2017).

Rice is an increasingly important crop in Nigeria and rice husks are the by-products of threshing paddy. In 2015, 3,000,000 tonnes of rice paddy was produced in Nigeria. About 20% of the dry mass of harvested paddy is husks, (Chukwudebelu et al 2015). Rice husks belong to a class of lignocellulose biomass because the major organic mass fraction consists of cellulose, hemicellulose and lignin, (Chen et al 2011). Rice husks are readily available around rice milling plants in rice producing areas of Nigeria. The only limitation to its utilization as a biomass fuel source is its fibrous nature, poor combustion characteristics and smoke emission.

Briquetting is a densification process whereby loose organic materials such as rice husks, cassava stalk, saw dust, corn cob, coal, etc, are converted into a more dense material aimed at improving handling and combustion characteristics for domestic and industrial use, (Ogbuagu et al 1999). Kaliyan et al 2009 stated that the main purpose of briquetting a raw material is to reduce the volume, thereby increasing the energy density.

Another treatment that improves the quality of biomass fuels is torrefaction. Torrefaction is a thermo-chemical treatment of biomass in a non-oxidizing or inert environment within a narrow temperature ranging from 200^{O}C to 300 ^{O}C, (Aytenew et al 2018). Torrefaction leads to reduction in moisture content, superflous volatiles as well as partial decomposition of biopolymers such as cellulose, hemi-cellulose and lignin, (Nhuchhen et al 2014). Torrefaction changes the properties of biomass to provide better fuel quality for combustion and gasification applications. It produces a relatively dry product which reduces or eliminates the potential for organic decomposition.

Torrefaction combined with densification, (briquetting or pelletizing), is a promising solution to logistic challenges associated with developing a large scale renewable energy system from agro wastes. Torrefacted agro-waste pellets or briquetts are easier to transport and store because they have higher density, contain less moisture and are more stable in storage than the original loose biomass they are derived from, (Umair et al 2019). Briquettes also burn at a more steady and controlled rate, compared to loose biomass, (Chaney 2010).

This research work aims to improve the energy density and combustion characteristics of waste rice husks in Ebonyi state, by torrefactional processing into biomass briquettes.

II. DESCRIPTION OF STUDY AREA

The rice husks used for the research was collected from a rice milling plant in Afikpo, Ebonyi state of Nigeria. The drying, orrefaction, briquetting and combustion performance tests were done at the Ceramic Research Workshop of Akanu Ibiam Federal Polytechnic Unwana, Ebonyi state.

III. MATERIALS AND METHODOLOGY

The rice husks was washed thoroughly in ample distilled water to remove dirt and other contaminations from the mill. The washed specimen was then spread out on a nylon mat to dry in open air for 14 days. The mass of washed rice husk was intermittently turned over with a rake to enhance a more uniform drying.

ISSN: 2350-0328
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Vol. 9, Issue 9 , September 2022

The dried rice husk was then divided into two batches. One batch was extruded into briquettes without further processing, while the other batch was processed by torrefaction and then extruded into briquettes. 2300 grams of the dried rice husk was then loaded into a cylindrical metal tube, filling the tube completely and the cover was screwed into place.
The metal tube filled with rice husk was then placed in an oven and heated to a temperature of 210°C and held at that temperature for 30 minutes. After cooling the screw cover was removed and the toreffacted rice husk was poured into a pan and weighed. The mass loss due to torrefaction was determined as,

$$Mass\ loss = initial\ mass\ before\ torrefaction - final\ mass\ after\ torrefaction$$

The torrefacted and non torrefacted batches of rice husk were separately mixed with suitable amounts of prepared cassava starch as binder and then separately extruded into cylindrical briquettes using a manual hydraulic briquette extruder. The extruded briquettes were then allowed to dry in the sun for 14 days and monitored for any signs of organic decomposition or deterioration.
After drying, the water boiling test was used to evaluate the combustion performance of the torrefacted and no-torrefacted batches, as described by Smith et al. (2007) and Osonwa et al. (2020).

The test consists of three phases:
1. Cold Start (high power): Using a cold stove and a cold pot, 1 liter of water at
room temperature was brought to a boil. This simulates rapid cooking tasks like making tea, boiling milk etc.

2. Hot Start (high power): Immediately following the cold start, the water is replaced with a new batch of 1 liter of water at room temperature and brought to a boil.

3. Simmer (low power): Immediately following the hot start, the already boiled water is maintained at a simmer for 45 minutes. In this phase, the stove, pot and water remain hot from the second phase of the test. This simulates slow cooking tasks like cooking rice, beans or hard grains.

For any phase of the test, firepower is the energy released by the burning fuel per unit time. Firepower can be calculated as

$$P_{(W)} = \frac{(M_i - M_f)\ x\ H_c}{t}$$

Where,

P = fire power in watts (w)
M_i = initial mass of fuel in the stove (g)
M_f = final mass of fuel in the stove (g)
H_c = energy content of fuel, 12552J/g for rice husk, according to Zafar (2022) and 29000J/g for charcoal.
t = time spent during the test phase in seconds (s), (Smith et al 2007)

The power to mass ratio, also known as specific power is a measure of how much power a fuel material can deliver per unit mass of fuel consumed. According to Yang et al (2002), it enables comparison of one type of power source to another. The power to mass ratio (specific power) of the three batches were determined as,

$$Specific\ power = \frac{Total\ power\ output\ for\ the\ three\ stages\ of\ test\ (P_{Total})}{Total\ mass\ of\ fuel\ consumed\ (M_{Total})}$$

Total amount of fuel consumed during the entire test duration was calculated as

$$M_{Total} = Initial\ mass\ in\ phase\ one - Final\ mass\ in\ phase\ three$$

ISSN: 2350-0328
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Vol. 9, Issue 9 , September 2022

IV.RESULTS AND DISCUSSION

Initial mass of rice husk before torrefaction = 2300g
Final mass of rice husk after torrefaction = 1869g
Mass loss due to torrefaction = 2300 – 1891 = 409g
%mass loss = 17.8%
The readings obtained from the various phases of the water boiling test are shown in tables 1, 2 and 3. Table 4 shows the total amount of fuel consumed for each batch during the entire test duration, while table 5 shows the comparison of the combustion performance of the three fuel batches.

Table 1. Results for phase one of the water boiling test.

Batch	Initial mass (M_i) grams	Final mass (M_f) grams	Time (seconds)
Torrefacted	1120	736.2	2580
Non-torrefacted	1220	842	3660
Charcoal	1400	1180	1920

Table 2. Results for phase two of the water boiling test.

Batch	Initial mass (M_i) grams	Final mass (M_f) grams	Time (seconds)
Torrefacted	736.2	394.6	960
Non-torrefacted	842	585.2	1320
Charcoal	1180	671.6	1140

Table 3. Results for phase three of the water boiling test.

Batch	Initial mass (M_i) grams	Final mass (M_f) grams	Time (seconds)
Torrefacted	394.6	138.7	2700
Non-torrefacted	585.2	397.7	2700
Charcoal	833.4	671.6	2700

Table 4. Total amount of fuel consumed (M_{Total}) during entire test duration.

Batch	Initial mass in stage one (grams)	Final mass in stage three (grams)	M_{Total} (grams)
Torrefacted	1120	138.7	981.3
Non-torrefacted	1220	397.7	822.3
Charcoal	1400	671.6	768.4

Table 5. Comparison of the combustion parameters of the three batches.

Batch	Stage one Firepower - P (Watts)	Stage two Firepower – P (Watts)	Stage three Firepower – P (Watts)	Specific Power (Watts/gram)
Torrefacted	1867.23	4466.42	1189.6	7.67
Non-torrefacted	1296	2441.93	871.67	5.60
Charcoal	3322.9	8817.02	1737.85	18.06

From the results obtained in this work, it can be seen that torrefaction of the rice husk improved the firepower of the biomass fuel by 44% during phase one, 82.89% during phase 2 and 36.47% in phase 3. The remarkable improvement in firepower of the torrefacted batch in phase 2 of the test is a clear indication of better combustion performance over the non torrefacted batch.

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Vol. 9, Issue 9 , September 2022

Torrefaction also imcreased the specific power by 37%. This implies that it will be more cost effective to process agro wastes like rice husks close to the point of generation and then transport the more energy dense torrefacted briquettes or pellets to the points of usage.
These results agree with the findings of Chen et al (2014) and Umair et al (2019), that torrefaction process enhanced the fuel characteristics of rice husk.

V.CONCLUSION AND RECOMMENDATIONS

From the results of this research, it can be concluded that torrefaction of rice husk and subsequent briquetting improves the combustion performance of the agro waste, as measured by the firepower and specific power of the material.
The weight loss resulting from torrefaction, typically above 15% implies increased energy density of the torrefacted bio-waste while briquetting improves handling and storage capabilities, compared to non-torrefacted batches and loose biomass.
The improved specific power due to torrefaction and briquetting is a promising indication that processed rice husk has the potential to replace wood charcoal products for domestic and industrial heating.
It is recommended to increase torrefaction temperature to about 250 -300^oC and holding time to about 60 minutes to further increase the combustion performance of the product. However the gains from such increased toreffaction temperatures and holding time need to be weighed against the increased cost of heating.

VI.APPRECIATION

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Plate 1. The extruded biomass briquettes after drying. Notice the color difference between the non-torrefacted batch on the left and the torreffacted batch on the right.


Plate 2: Combustion performance test of the briquetts – torrefacted briquettes on the left and non-torrefacted briquettes on the right.

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Vol. 9, Issue 9 , September 2022

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