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THE EFFECTS OF PARTICLE SIZE, COMPACTION PRESSURE, AND TORREFACTION ON QUALITY AND THERMAL PROPERTIES OF PELLETIZED CORNCOB RESIDUES

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ABSTRACT

Torrefaction and biomass pelletization into pellets for solid fuel development are considered sustainable energy solutions to mitigate fossil fuel dependency and environmental challenges. This study investigated the effect of particle size, compaction pressure, and torrefaction on the quality and thermal properties of pelletized corncob residues. The corncob samples were collected, sorted, and pulverized before the torrefaction pretreatment. The torrefaction was achieved by placing the corncob in a furnace at a temperature and residence time of 280 °C and 30 minutes, respectively. The inert atmosphere was attained and maintained by initially purging a nitrogen gas into the torrefying chamber and passing it at 100mL/min during the processes. The raw and torrefied corncob fines were screened to 0.3 mm, 0.5 mm, and 1.0 mm grain sizes. Using starch as a binder (5% wt), pellets were produced employing their respective raw and torrefied fines at compaction pressures of 50 MPa, 75 MPa, and 100 MPa. Though all pellet samples exhibited good quality and thermal properties, the pellets from torrefied corncob are better. Also, the effects of particle size and compaction pressure are significant on the produced pellets. The compressed density varied from 760 to 1,250 kg/m^3 and 637 to 920 kg/m^3 for raw and torrefied corncob pellets. A maximum heating value of 25.8 MJ/kg was obtained from the torrefied pellet sample of 1.0 mm, rendering improvements of 37.2% when compared with 18.8 MJ/kg of raw corncob of the same particle size. The energy values obtained for torrefied corncob for all particle sizes compared favorably with the value obtained in coal. Investigation of particle size, compaction pressure, and torrefaction on quality and thermal properties of pelletized corncob residue proved that it can replace coal and hence could be used for energy applications.

Keywords: *Thar coal; Torrefied pellets; Pelletised particles; Raw corncob.*

1. INTRODUCTION

Fossil fuel plays an important role as the key driver for industrialization. It has the highest percentage in overall energy consumption. However, its proportion in the world energy trend remained almost unchanged until recent years (Nwabunwanne et al., 2021; Krongkaew *et al.,* 2017). With the environmental impact, especially of global warming and the rapid depletion of fuel of this type, it is essential to seek renewable energy for sustainability (Ajimotokan *et al.,* 2019a; Parachwittawin *et al.* 2017; Tumuluru 2015). Biomass, a naturally abundant energy source, is considered a promising renewable fuel due to its renewability, greenish and global availability, and carbon-neutral balance (Ajimotokan *et al.* 2019b). Biomass includes agricultural residues from forestry activities, products, and by-products such as cobs, pods, and shells.

Corncobs are agro-residues abundant in temperate regions such as Nigeria (Anthony *et al*., 2017). In corn mills, empty corn cobs are used as a substitute fuel in convectional boilers (Krongkaew *et al.,* 2017). The thermal efficiency is low due to its poor fuel properties. Compared to low-to-medium grade fuel, corncobs have high moisture content, low fixed carbon, high volatile matter, fibrous and tenacious nature, and low energy value (Hassan *et al.,* 2016). In fact, high

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volumes of empty cobs are needed due to their low energy density. Therefore, the Problems associated with transportation, grinding, storage, and handling become issues at a cogeneration plant (Rabiu *et al.* 2019; Krongkaew *et al.* 2017). One of the crucial steps to circumvent the above limitations is through torrefaction and pelletization. (Adeleke *et al.,* 2020; Ajimotokan *et al.* 2019b). Torrefaction is a thermo-chemical conversion method where biomass is subjected to thermal heating in an inert environment, typically in the temperature range of 200 to 300 at atmospheric pressure (Matali *et al.,* 2016). Torrefied product has a higher mass yield, and energy content is retained with incomplete removal of volatile matters (Tumuluru *et al.,* 2015). The fuel of this type is regarded as an improved version of its raw form. On the other hand, pelletization addresses low bulk density and transportation problems.

Extensive research on the effects of bio-residues pretreatment and densification processes on their quality and thermal properties for energy application has been carried out. However, only a few works are tailored to the pelletization of agro-residue, and in particular, there is no known published or near absent research on torrefied and pelletized corncob residues. For instance, Kanwal *et al.* 2019 examined the physicochemical characteristics of thar coal and torrefied corncob with five distinct torrefaction temperatures and four different residence times. The torrefied corncob was reported to be suitable as a substitute for thar coal. Ibitoye *et al.,* 2021 investigated the combustion properties of corncob biomass via torrefaction for solid fuel applications with varied torrefaction temperature and residence time. The study results revealed that torrefaction improves the thermal and combustion characteristics of the biomass residue. Thus, this study seeks to investigate the effect of particle sizes, compaction pressure, and torrefaction on the quality and thermal properties of pelletized corncob residue.

2. MATERIALS AND METHODS

2.1. Materials

The raw corncobs utilized in this study were obtained from the University of Ilorin farm and the starch from the cassava processing factory within Ilorin, Kwara State, Nigeria. The samples were stored in the University of Ilorin woodwork laboratory (latitude 8.4799 N and longitude 4.5418 E). The equipment used in this study was a set of sieves, muffle furnace, weighing balance, oven, thermometer, the crucible, Venire caliper, compression machine, stopwatch, die, and piston.

2.1.1 *Material preparation and torrefaction*

The stored samples of corncob were sorted by handpicking technique, which involved the removal of every form of dirt and foreign materials. Such as sand, stone, ashes, and plant residue. It was then dried by placing it in an oven at a temperature of 105 °C for 2 hours to minimize the interference of surface water. Torrefaction of the biomass was achieved by placing the biomass in a furnace at a temperature and residence time of 280 °C and 30 minutes, respectively. The inert atmosphere was attained and maintained by initially purging a nitrogen gas into the torrefying chamber and passing it at 100mL/min during the torrefaction processes (see Figure 1). The samples were then crushed to reduce the particle size for better workability and compactness. The sieve analyses based on BS EN 15149-2 (2010) were used for this experiment. Samples were screened into three (3) different sizes (0.3, 1.0, and 1.7 mm). The sieved samples of raw and torrefied corncob were then stored separately in a zip-locked polythene bag.

2.1.1.1 Pelletisation procedure

The pellets were produced at the Department of Civil Engineering, University of Ilorin, Nigeria. Raw and torrefied corncob samples were weighed using an electronic weighing balance. The binder at 5% of the total mass of the samples was used for the respective agglomerate samples (Ajimotokan *et al.* 2019b). The compaction was achieved using a manual hydraulic jack machine (Figure 2), model EL31 072. The aggregates were mixed manually using a manual stirrer. After thorough mixing was achieved, the feedstock was then poured into the mold. Different compaction pressures that were considered were 50, 75, and 100 MPa. After the pellets formed were removed from the molds, the weight and dimensions were taken before sun drying.

2.1.1.2 Density

The compressed density was calculated by dividing the mass of pellet bulk (m) with its volume (V), as depicted in Equation 1: The relaxed density was then determined 30 days after being sun-dried (Ajimotokan *et al.* 2019a).

$$\rho = \frac{m}{v} \qquad \text{(Eq. 1)}$$

ρ denotes the green density, m is the mass of the pellet, and v is the volume.

2.1.1.3 Calorific value

The calorific value (HHV) for the raw and torrefied samples was carried out using an oxygen bomb calorimeter following ASTM standard D-5865.

3. RESULTS AND DISCUSSION:

3.1 Density

Figure 1 shows the effect of variations in compaction pressure and particle size on the compressed density of the produced fuel pellets. The green density of the produced pellets varied from 760 to 1,250 kg/m^3 and 637 to 920 kg/m^{3}for the raw and torrefied pellets, respectively. The density of the torrefied pellets was observed to be lower than the density of the raw pellets produced under the same condition. This may be as a result of the loss of chemically bonded water and low melting point compounds (i.e., volatiles), which would have added to the binding effect during densification.

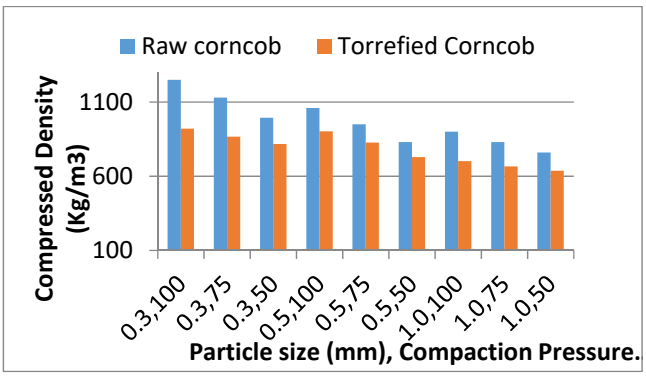


Figure 1: *Effect of particle size and compaction pressure on the compressed density of raw and torrefied corncob pellets.*

3.2 Calorific value

Figure 2 shows the calorific value profiles of raw and torrefied corncob samples. The calorific values varied from 16 to 18.8 MJ/kg and 24 to 25.8 MJ/kg for the raw and torrefied pellets. It depicted that the heating value also increases with an increase in the particle size for both the raw and torrefied corncob residues. A maximum increase was observed at 1.0mm particle size, i.e., 25.8 MJ/kg, which is almost equal to the heating value found in coal, i.e., 24.6 MJ/kg. An increase in heating value could be associated with a decrease in moisture content that resulted due to torrefaction (Kanwal *et al.*, 2014). Torrefaction pretreatment rendered an average improvement of 37.2%. These results revealed that torrefaction has an obvious impact on the rise of calorific values of the torrefied corncob residues.

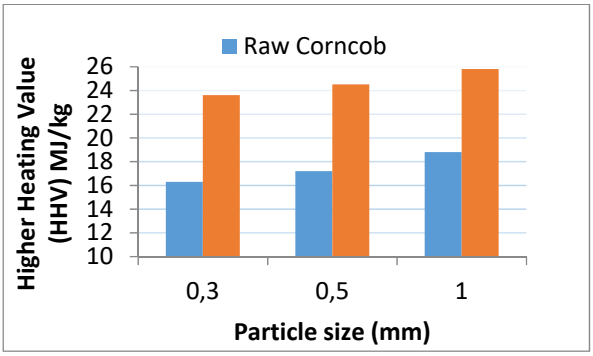


Figure 2*: Calorific values of raw and torrefied corncob samples of different particle sizes*

4. CONCLUSIONS:

The effects of particle size, compaction pressure, and torrefaction on the quality and thermal properties of pelletized corncob residues were examined. The effects of torrefaction were significant on the overall properties of the pellets produced. Particle sizes, compaction pressure, and their combined effect affect the densities and moisture uptake of the pellets produced from both the raw and torrefied corncob residues. In addition, the higher value of the calorific value of torrefied corncob samples depicts that torrefied corncob will produce greater heat of combustion during char burnout. Thus, pellets produced from all categories of particle size of torrefied corncob can be used for energy applications.

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