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Utilization of Thermoplastic as a Binder for Producing High Quality Charred Biomass Briquettes from Agricultural Residues

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ABSTRACT

The present study aims to investigate the effect of using thermoplastic (polypropylene, PP) as a binder for producing high quality charred biomass briquettes from different agricultural residues. The experiments were conducted under conditions of four different pressing temperatures (150, 200, 250 and 300 ^{0}C) and three different concentrations of thermoplastic ratios (5, 10 and 15 %) with the use of three different agricultural residues (saw dust, okra stalks and corn cobs). The produced charred biomass briquette samples were evaluated in terms of combustion properties (fixed carbon, volatile matter, calorific value, ignition time and burning time), mechanical properties (compressive strength and briquettes durability) and physical properties (moisture content and bulk density). The experimental results revealed that high quality charred biomass briquettes were obtained from okra stalks under a 15 % of thermoplastic concentration ratio and 250 ^{0}C pressing temperature. Under these conditions, the following indicators were achieved: 86.9 % fixed carbon, 38.9 MJ/kg calorific value, 23 min burning time, 10.8 MPa compressive strength, 94.9 % briquettes durability and 510 kg/m^3 bulk density.

Keywords: pressing temperatures, residues, thermoplastic, charred biomass briquette, durability, compressive strength.

NTRODUCTION

Energy shortage is a major challenge in Egypt. Therefore, there is a need for environmentally friendly and renewable alternative energy sources. In addition, Egypt is full of agricultural residues. The production of briquettes produced from agricultural residues use as solid fuel has gained advantages (Pandey and Dhakal, 2013). Intergovernmental Panel on Climate Change (IPCC) (2019) found that tackling the issue of climate change by using biochar as a carbon - neutral material. Due to the maximizing demand for fossil fuels and increasing the pollution of environment, resources of biomass have been used mostly as a major source of renewable energy for all countries (Roy and Corscadden, 2012 and Anupam et al., 2016). Agricultural residues can be turned into green energy at low-cost through various methods. There are different processes to turn them in to an energy source as anaerobic, gasification, pyrolysis, fermentation and digestion. These processes are capable of converting agricultural wastes into more valuable products; however, different processes produce various outputs and kinds of energy (Binod et al., 2010). Although biomass resources have low bulk densities and high moisture content and show degradation during storage, Nowadays, different methods, such as pyrolysis and pelletization are used to overcome these demerits and other problems (Lee et al., 2013 and Anupam et al., 2016). The thermal breaking of biomass in the absence of air/oxygen is called pyrolysis (Ozbay and Ayrilmis, 2017).The pyrolysis technology is the most popular for converting various biomass sources such as household organic, industrial waste and agricultural wastes into biochar, biogas and bio-oil (Vieira et al., 2013 & Ihsanullah et al., 2022). Studies have reported that a pyrolysis temperature is greater than 500 ^{0}C removes all the organic components from the biochar resulting in a high surface area of biochar (Akhtar and Sarmah, 2018 & Mu'azu et al., 2021). The minimum pyrolysis temperature 200 ^{o}C and then set at 450-500 ^{o}C. Pyrolysis of biomass leads to producing gas, liquid and solid/ char, which the product relies on the type of the process (Sheth and Babu, 2006). The large molecules in biomass decompose into small particles in a form of liquids, gases and solids in the pyrolysis process (Basu, 2013). Biomass has a lower calorific value than Bio-briquettes (Tamilvanan, 2013). Millions of tons of plastic waste have poured into oceans, causing threats to many forms of life in the form of microplastics. According to previous results, it appears that plastics are suitable binding for making briquettes with biomass and offer many advantages (Bhoumick et al., 2016 & Emadi et al., 2017). Firstly, Adding plastics as fuels improves the combustion efficiency and calorific value of biomass since many plastics have low oxygen content, high heating values and low ignition points (Song and Hall, 2020), secondly, enhancing the weathering ability of briquettes and mechanical durability by using thermoplastics as binders. Thirdly, using thermoplastic such as PP and LLDPE as a fuel source is the solution for thermoplastic that is better than landfilling (I˜niguez et al., 2019 & Chamas et al., 2020).

The bio-briquettes can create using organic waste from the agricultural industry and the pyrolysis process. It is a technique for converting large molecules into smaller ones under no oxygen at the highest temperature (Shafizadeh, 1982). Crushing, screening, mixing with a binder, and pressing are typical steps in the briquetting process (Zulaika et al., 2020). The binder and charcoal must be combined before being pressed to create briquettes. In order to make the briquettes sturdy enough to hold in the fire, the binder helps

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firmly hold the coal together in place. The binders including tar, asphalt, starch, resins, molasses, and clay, have been evaluated for use as binders and should be combustible. However, several reports have claimed that starch is the most efficient binder (Zubairu and Sadiq, 2014). A binder may be solid or liquid that creates a matrix, film, bridge, or starts a chemical process to firmly tie particles together. There has been many researches done to explain how different adhesive additives affect the manufacture and quality of charcoal briquettes. They employed molasses, wheat starch, cassava starch, gum Arabic, and other forms of binders (Sen et al., 2016). Compared to clay, briquettes made of starch burn more quickly, create less ash and are more effective (Olorunnisola, 2007). Additionally, Gachuri (2015) demonstrated that cow dung, sugarcane molasses, cassava starch, and maize starch are the most widely utilized binders. The coal briquettes took longer to ignite than the composite sawdust-feces briquettes, which ignited in 4.8 minutes, and charcoal took longer to ignite than the briquettes of water hyacinth, which ignited in 1-2 minutes (Rotich, 1998 & Davies, 2013). (Emerhi 2011) examined how different organic binders affected the combustion and physical characteristics of briquettes made from the sawdust from three species of hardwood (Terminalia superba, Afzelia africana and Melicia elcelsa) (cow dung, ash, and starch). The results indicated that the calorific values of the biomass briquettes ranged from 10.03 to 13.04 MJ/kg. The incorporation of waste polyethylene plastics into biomass briquettes is one of the crucial approaches to deal with the scenario of growing global energy demand. Zannikos et al., (2013) and Saad et al., (2014) plastic wastes led to an increase in the calorific values of the briquettes. In addition, the emission of nitrogen oxide and carbon monoxide from the burning of briquettes containing such a mixture was found to be competitive with 100% sawdust briquettes. When the ratio of polyethylene plastics to biomass was set to 30: 70

As to the advantages of using Briquettes compared to other solid fuels, Abimbola and Yekin (2017) stated that biomass briquettes have a higher calorific value. Coal is more expensive than briquettes. Oil or coal cannot be replaced once it has been used. Briquettes don't pollute the environment because there is no sulfur in them. So briquettes increase boiler efficiency due to lower moisture and higher density. Coal has much higher ash content (20-40 % compared to 2-10 % in briquettes). Combustion in coal is less uniform compared to briquettes. A good briquette should meet certain standards, such as not leaving black imprints on the hands and having a smooth surface. Additionally, charcoal briquettes need to be waterproof, easy to light, emit no hazardous gases during combustion, and not smoke. They also need to be mold-free when properly burned and kept for a long period.

Referring to the mentioned literature review, It is of great importance to investigate the possibility of recycling agricultural residues by using thermoplastic as a binder for producing high quality charred biomass briquettes. So the main objectives of the present work are to:

- Recycle agricultural residues to produce high quality charred biomass briquettes using thermoplastic as a binder.
- Optimize some different operating parameters (pressing temperatures, concentrations of thermoplastic ratio and types of agricultural residues) affecting the combustion, mechanical and physical properties of the produced charred biomass briquettes.

MATERIALS AND METHODS

Experiments were carried out in 2022 at a workshop of Zifta, Gharbia Governorate, Egypt, for producing high quality charred biomass briquettes from agricultural residues using thermoplastic as a binder.

Materials

Agricultural residues (Raw materials)

A wide choice of biomass was available to produce biochar briquettes. The raw materials such as saw dust, okra stalks and corn cobs were used in this study. Corn cobs and okra stalks residues were collected from a farm at Zifta, Gharbia governorate.100 kg of each of corn cobs and okra stalks were collected and dried open in sunlight.

Some characteristics of the used residues were shown in Table (1).

Table 1. Some characteristics of residues

Characteristics	Biomass residues		
	Saw dust	**Corn cobs**	**Okra stalks**
Cellulose, %	41.58	41.5	46.4
Hemicellulose, %	31.81	13	29.3
Lignin, %	18.16	33.63	15.3
Bulk density, kg/m^3	100-150	160-210	220-350
Moisture content, %	8.45	11.87	9
Ash content, %	2.20	1.33	3.9
Volatile matter, %	73.4	66.1	67.1
Fixed carbon, %	15.95	20.7	20
Heat calorific value, MJ/kg	18	18.9	30

Binder materials

Thermoplastic (polypropylene, PP) was used as a blending material in the present study (Fig. 1). This plastic was chosen because polypropylene, PP has the most demand and isn't recycled. The virgin plastic was used directly when obtained without drying. The raw material of plastic/ blends was set with concentrations of 5, 10 and 15 wt % per 10 kg of crushed char and 3 liters of water. Properties of pp plastic were illustrated in Table (2).

Table 2. Properties of polypropylene

property	value	unit
Tensile strength	3200-5000	psi
Water absorption, 24h	0.01	%
Density	0.91-0.94	g/cm^3
Specific volume	30.4-30.8	cm^3/Ib
Melting point, T_m	160-166	c°
Softening point, T_g	140-150	c°
Thermal expansion	5.8-10	10-5in./in. c°
elongation	3-700	%

Fig. 1. Thermoplastic

Carbonizer

MIT's D-Lab (2012) devised a process for carbonizing raw materials in order to create briquettes. This process involves turning a 55-gallon (208 l) oil barrel into a carbonizing furnace (Fig. 2); a sizable opening in the barrel's top and a number of smaller holes in its base permitted airflow during the first combustion of the biomass. It was putting on three stones. Biomass is burnt from below and suspended 30 cm from the ground to allow air to pass through the barrel. During the first phases of combustion, the majority of the material's volatile organic components are burned off (Banzaert, 2013). When the raw material reached carbonization temperature (450 °C), the furnace was closed to produce an anaerobic environment that produce charcoal powder. To remove oxygen, the metal plate was placed over the upper hole and the stones removed from under it.

Fig. 2. The carbonizer

Crusher

In the next step of preparing briquettes, a hammer mill was used to cut the charred biomass materials into small pieces and the sample was sieved in order to remove large particles to make uniform briquettes.

Binder machine

The compositions were homogeneously blended with water and coal powder using the binder machine shown in Figure 3 at concentrations of 5, 10, and 15% of PP plastic per 10 kg of crushed char and 3 liters of water. The machine's specifications were as follows: steel material, 0.25 hp (0.18 kW) power, agitator rotating speed of 100-500 rpm, and manual feed intake (Wasfy and Awny, 2020)

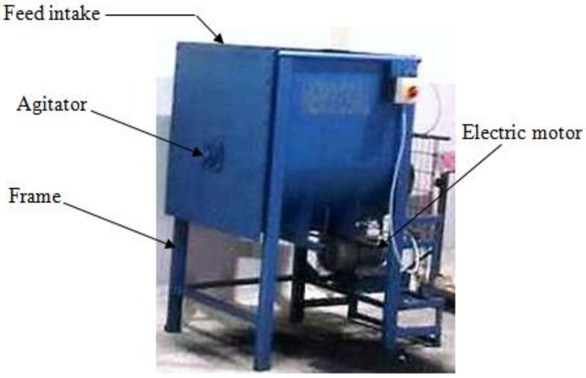


Fig. 3. The binder machine.

Heat Die extrusion screw press

A device used to make briquettes is the heat die extrusion screw press (Fig. 4). It mainly consists of a hopper, a die warmer, an 18.5 kW electric motor, and the screw that compresses the raw material. A configuration of a V-belt and pulleys allows the electric motor to drive the screw, which is located inside the die. Through the hopper, raw biomass material is supplied to the screw. The raw materials lignin and the polypropylene that acts as a binder are frequently heated in the die using an electric die-heater.

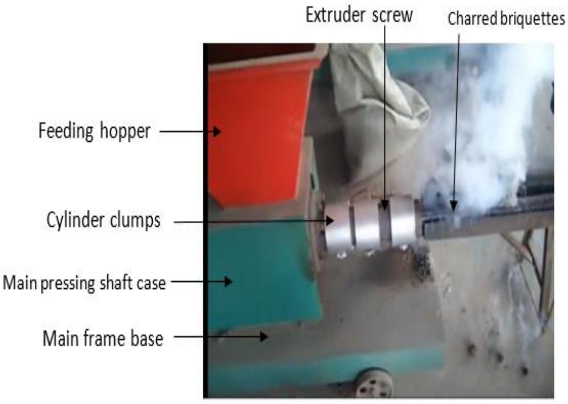


Fig. 4. The heat die extrusion screw press

Methods

Briquetting operation

Fig. 5 shows the briquetting process in the preparation stage. Raw materials received a pre-treatment that included sorting, size reduction, and four days of sun-drying in an ambient environment (32–34 °C) before carbonization. By employing the traditional process, the raw material biomass was carbonized at 400 °C is the temperature at which carbonization occurs. For the next phase, crushing, the completely carbonized material was collected. The material is subsequently processed to a particle size of less than 5 microns to provide high-quality mixing and compaction. Therefore, the binder and charcoal particles must be combined during mixing. The mixing was carried out by using a motorized mixer that rotated for 20 minutes to make the mixture homogeneous. It is then combined with a binder and water to create powdered charcoal. Because of its physical and thermal properties, availability, and affordable price, polypropylene was chosen as the binder in this case (Sawadogo et al., 2018). To create the mixture in a dried form, the charred material mixed with pp was crushed in an extrusion screw press. The briquettes were then put on clean aluminum trays and dried for three days at room temperature (32–34 °C).

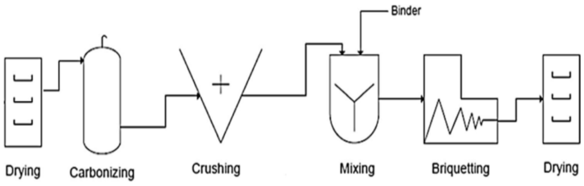


Fig. 5. The briquetting operation (source: Bot, et al 2021)

Experimental conditions

Experiments were performed under the following parameters:

- Three different biomass agricultural residues (saw dust, okra stalks and cob corn).
- Four different pressing temperatures (150, 200, 250 and 300 ^{0}C).
- Three various concentrations of thermoplastic ratios (5, 10 and 15%) by mass.

Measurements and determinations

The produced charred biomass briquettes samples were evaluated according to the following indicators:

- **Volatile matter content**

According to ASTM D3175, the volatile matter in the produced briquettes was measured (Mitchual et al. 2014). A ceramic crucible containing around 2 g of each biomass material was placed in the oven. After being oven-dried, each sample was placed in an oven at 550°C for 10 minutes, cooled in a dryer, and weighed. The loss percentage in mass of the sample, or volatile matter (Vm%), was then calculated.

$$V_m\ (W_t\,\%) = \frac{B - C}{B}\ x100\ \%$$

Where: B - mass of the dried sample
C - Mass of the sample a furnace at 550 ^{0}C after 10 min

- **Fixed carbon**

Using ASTM E711-87, Standard (2004), each sample of briquettes' fixed carbon % was calculated.

$$F\,c\ (\text{wt}\ \%) = 100 - (V\,m + M\,c + A\,c)$$

Where: F c - Fixed carbon for the sample,
V m - Volatile matter for the sample,
M c - The moisture for the sample,
A c - The ash content for the sample.

- **Calorific value**

A model created by Nhuchhen and Afzal in 2017 was used to estimate the calorific value (HHV) of each sample of biochar briquettes. This model has a decent prediction accuracy within the error bar of 10%.

HHV (MJ/kg) = 0.1846 Vm + 0.0352 Fc

- **Ignition time**

Each charcoal briquette's ignition time is the time to ignite (Mitchual et al. 2014). A Bunsen burner was used to ignite each sample. The ignition time was measured using a stopwatch as the amount of time to ignite each charcoal briquette.

- **Burning time**

The burning time measures how long it takes for each sample of charcoal briquettes to burn entirely to ashes (Mitchual et al., 2014). It can be calculated from the following relation

Burning time = Ashing time – Ignition time.

Mechanical properties

- **Compressive strength**

Each specimen was placed between two sheets on a universal testing machine, which then subjected it to compression action at an accelerated speed of 10 mm/min. It can be calculated from the following relation (Navalta et al., 2020).

$$\sigma_c = \frac{F_c}{A}$$

Where: σ_c - Compressive strength, N/ mm^2,
Fc - fracture force of the specimen, N,
A - Area of the briquette, mm^2.

- **Durability**

Briquette durability enables the mechanical manipulation of solid fuel (Chou, 2009). The ASAE S269.4 standard technique (Kaylyan et al) is used to measure this. For the durability test, 100 g of the sample is used, and it is stirred for 10 minutes under 50 rpm. After being tumbled, crushed briquettes are retained using metal fabric with a 4mm aperture size.

Briquettes durability % =

$$\frac{weight\ of\ briquette\ sample\ left\ after\ tumbling}{original\ weight\ of\ briqueette\ sample}\ x100$$

Physical properties

- **Moisture content**

Moisture content (%) was calculated according to BS EN 14,774-1 standard (2009).

$$M_c\ (W_t\%) = \frac{W_o - W_d}{W_o} x100\ \%$$

Where: W_0 - weight the original sample
W_d - weight the sample after drying

- **Bulk density**

According to (Rabier et al., 2006) briquette density values can be calculated by diving mass by volume.

RESULTS AND DISCUSSION

The experimental results will be explained under three different items:

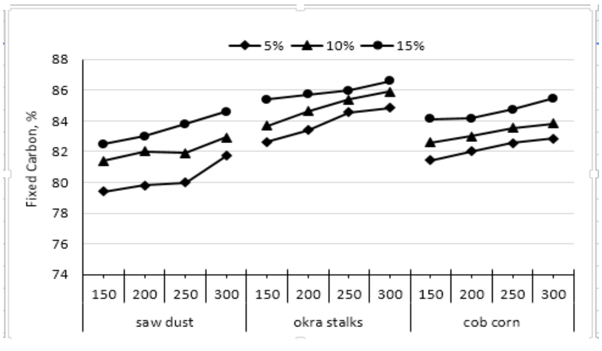
1. Combustion properties

The fixed carbon of the charred biomass briquettes

Fig. (6) Explain the effect of various factors on the fixed carbon. In general fixed carbon of briquette increased with increasing pressing temperatures and increasing concentrations of thermoplastic ratios for all used agricultural residues. The results revealed that the maximum fixed carbon of 86.6% was observed for the charred biomass briquette made of okra stalks under a 15 % concentration of thermoplastic ratio and 300 ^{0}C pressing temperature. This is because the increase in pressing temperature decreased moisture content led to increase fixed carbon and volatile matter. Similarity, the lowest fixed carbon of 79.4% was observed for the briquette made of saw dust at 5% concentration of thermoplastic ratio and 150 ^{0}C pressing temperature. The percentage of fixed carbon in okra stalks briquette may be a good binding and uniformity in particle size that helps to maximize the fixed carbon percentage of the produced briquettes.

The volatile matter of the charred biomass briquettes

The variation of volatile matter of charred biomass briquettes produced from different residues as shown in Fig. (6). the results showed that values of volatile matter of briquettes were difference among residues. In addition the high pressing temperatures could break down the lignocellulose, so the volatile matter content increased, therefore, degraded the briquette. The highest value of volatile matter of briquettes was 9.42 % found in sawdust under 300 ^{0}C of pressing temperature and 15 % concentration of thermoplastic ratios. While the lowest value of 5.9 % was registered in cob corn under 150 ^{0}C pressing temperature and 5% concentration of thermoplastic ratio.



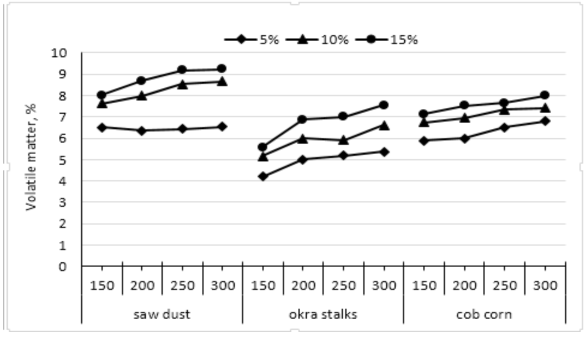


Fig. 6. Effect of different pressing temperatures and concentrations of thermoplastic ratios on fixed carbon and volatile matter of charred biomass briquettes

The calorific value of charred biomass briquette

The effect of the experimental parameters on calorific value was explained in Fig. (7). It is one of the fuel characteristics. It can be defined as the energy per kg it expends when it is burnt. The increase in the concentration of thermoplastic ratio increased the compaction of briquette which caused an increase in the calorific value. The results proved that utilization of the PP plastics as energy source, improve the calorific value of the manufactured briquettes. The results indicated that the calorific value increased from 38.18 to 38.57, from 38.3 to 38.9 and from 38.4 to 38.8 MJ/kg, by increasing the concentration of thermoplastic ratio from 5 % to 15 % under 250 ^{0}C pressing temperature for saw dust, okra stalks and cob corn respectively. This is due to the increasing PP plastic ratio helping to increase the inter lock between the biomass particles causing an increase in the compaction which in turn increases the calorific value. By increasing pressing temperature from 150 to 250 ^{0}C, the calorific value increased significantly that is agreed with (Zannikos et al., 2013). They stated that the calorific values of the briquettes are mostly increase due to adding the plastics waste, while, increasing pressing temperature from 250 to 300 ^{0}C, calorific values increased slightly. It can be noticed that the maximum calorific value of 38.9 MJ/kg was achieved under okra stalks. This is due to that okra stalks containing higher amount of fixed carbon, causing an increase in calorific value of charred biomass briquettes.

The ignition and burning time of the charred biomass briquettes

The ignition and burning time of the charred biomass briquettes are measured and the result is shown in Fig. (8). Ignition time is the time demanded to ignite the manufactured briquettes. Ignition time is influenced by the content of volatile matter. It can be noticed that biomass with higher volatile matter value is lower in fixed carbon and is also easier to ignition. This result agreed with (Shukla and Vyas, 2015) who indicated that briquettes with the less volatile matter had good quality parameters including smooth burning and easy ignition. The results indicated that by increasing concentrations of thermoplastic ratios, ignition time decreased where burning time increased. By increasing concentrations of thermoplastic ratios from 5 to 15 %, the ignition time decreased from 80 to 50, from 98 to 62, from100 to 65 and from 110 to 74 s, for saw dust while 128 to 78, from 140 to 95, from 160 to 118 and from 170 to 125 s for okra stalks. The decreasing values were from 110 to 60, 122 to 76, 150 to 85 and 160 to 100 s, for cob corn under pressing temperatures of 300, 250, 200 and 150 ^{0}C, respectively. On the other hand burning time values under okra stalks were 14.5, 18, 21 and 23 min for pressing temperatures of 150, 200, 250 and 300 ^{0}C, respectively. It is due to that bulk density for cob corn was high. This results matches with (Peter et al., 2018) who said that an increasing in density led to increasing in mass that led to the formation of more ash during the combustion, which prevents the leaching of oxygen into the fuel.

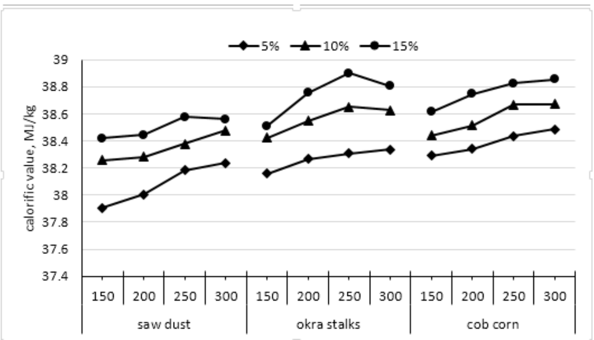


Fig. 7. Effect of different pressing temperatures and concentrations of thermoplastic ratios on calorific values of charred biomass briquettes

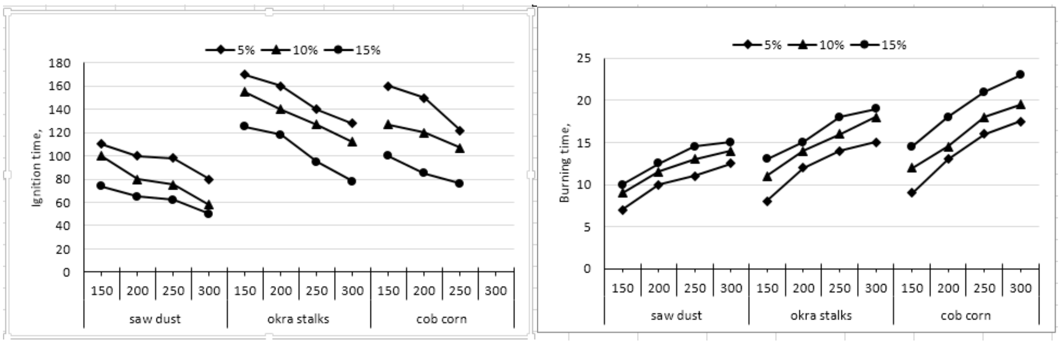


Fig. 8. Effect of different pressing temperatures and concentrations of thermoplastic ratios on ignition and burning time of the charred biomass briquettes

2. Mechanical properties

The compressive strength of the charred biomass briquettes

Briquette's compressive strength is one of the indicators used to evaluate whether can be handled, packed and transported without fracture. It was seen from Fig. (9), that as concentrations of thermoplastic ratios increased, the compressive strength increased. The results stated that by increasing concentrations of thermoplastic ratios from 5 to 15 % compressive strength increased from 2.9, 4.15, 5.69 and 5.5 MPa to 6, 8.5, 9.39 and 9 MPa for saw dust under pressing temperatures of 150, 200, 250 and 300 ^{0}C respectively and increased for okra stalks from 3.4, 5.76, 7.08 and 7 MPa to 7.1, 9.8, 10.83 and 10.7 MPa under the same previous pressing temperatures. While, increased for cob corn from 2.73, 3.4, 4.6 and 4.3 MPa to 4.96, 6.9, 7.8 and 7.5 MPa under the same previous temperatures. It can be noticed that by increasing temperature from 150 to 250 ^{0}C, the briquette's compressive strength increased. This is because the plastic was melting and flowing at higher pressing temperatures, which allows the substance to bond as a binder with other ingredients. On the other hand increasing, temperature to 300 ^{0}C, the briquettes compressive strength decreased this is due to high pressing temperatures which result in burnt briquettes with visible crack defects due to non-uniform expansion as the produced briquettes contact with the ambient temperature around 70 ^{0}C. This result is inverse with (Bello and Onilude, 2021) who said that temperatures in the range of 290 to 310 ^{0}C is the optimal temperature range which is suitable for compressive strength briquetting.

The durability of the charred biomass briquettes

The effect of pressing temperatures and concentration of thermoplastic ratio on the briquette durability was studied. From Fig. (9), the concentration of thermoplastic ratio was increased, the durability was increased. Weak physical durability leads to the production of fine particles and mass loss in it, which poses a threat to the environment and human health (Feng et al., 2018). Adding PP plastic to residues enhances mechanical durability of the produced briquettes and their resistance to humidity and weather. It was found that okra stalks and 15 % concentration of thermoplastic ratio, briquettes had the highest durability of 85, 91, 94.9 and 97 % under pressing temperatures of 150, 200, 250 and 300 ^{0}C, respectively. The results of the durability of the produced briquettes met the standard requirement of LY/T 2552-2015, but the lowest values of durability were 56.68, 63.1, 69.9 and 72.3 for saw dust and 5% concentration of thermoplastic ratio under the same previous pressing temperatures. It can noticed that by increasing pressing temperature briquette durability increased. This is because of the briquette has a greater ability to withstand stress due to mechanical handling, thereby increasing the durability also influences the dimensional stability of the briquettes. The results showed that the highest durability percentage was 97 % achieved under 15% concentration of thermoplastic ratio and 300 ^{0}C pressing temperature for okra stalks. It because of, the lignin contained in the okra was softened when, the temperature increased. which played a strong role as a natural binder during manufacturing the briquettes (Wang et al., 2019).

3. Physical properties

The moisture content of the charred biomass briquette

The variance of moisture content for charred biomass briquettes made from various residues is illustrated in Fig. (10). the moisture content values affected on the quality of briquettes manufactured. The moisture content decreased when increasing pressing temperatures and increasing in adding PP plastic ratios. It can be noticed that the range contained moisture content of charred biomass briquettes 4.6 to 7.3 %, 3.91 to 5.67 % and 4.4 to 8.13% for saw dust, okra stalks and cob corn respectively. This outcome is consistent with the suggested moisture level range of 5 to 10%, which produced briquettes that were denser, more stable, and more lasting than those made from biomass with higher moisture content (15%) (Mani et al., 2006). According to the findings, okra stalk residue-based briquettes had a lower moisture content than residues made from other materials. Briquettes' moisture contents are 5.51, 5.2, 5, and 4.6% for sawdust, 4.39, 4, 3.91, and 3.64% for okra stalks, and 6.4, 5.1, 5, and 4.4% for cob corn under 150, 200, 250, and 300 0C, respectively. Moisture contents of the Briquettes decreased by increasing pressing temperatures and adding 15% PP plastic waste.

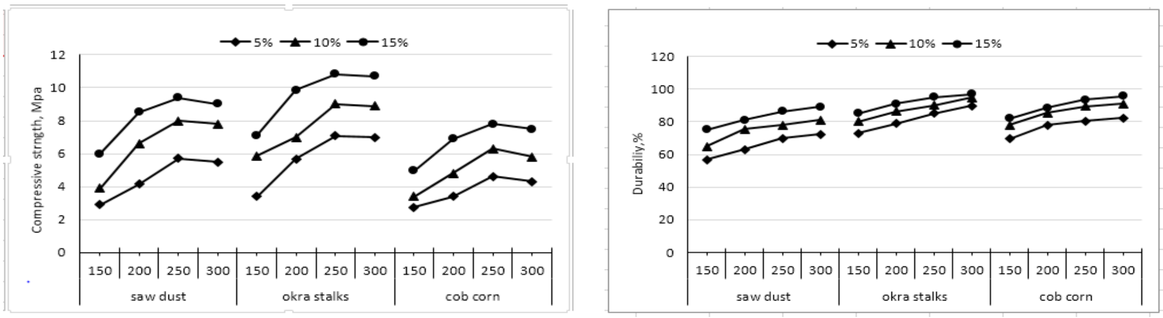


Fig. 9. Effect of different pressing temperatures and concentrations of thermoplastic ratios on compressive strength and durability percentage of the charred biomass briquette

The bulk density of the charred biomass briquette

The bulk density of the charred biomass briquettes is a vital indicator to its physical properties, which affects the cost of transportation and storage requirements. The results indicated that the increase of pressing temperatures and increasing concentrations of thermoplastic ratio increase the bulk density of the briquette. This is because the increase of this ratio, more particulate adhesion was obtained, thereby decreasing the volume and at the same time increasing the mass. From Fig (10), the bulk density of the briquettes increased from 360 to 420, from 370 to 433, from 400 to 455 and from 412 to 460 kg/m^3 when increasing concentrations of thermoplastic ratio from 5 to 15 % for saw dust under pressing temperatures of 150, 200, 250 and 300 ^{0}C, respectively. Increase in values changed from 385 to 460, from 400 to 470, from 435 to 510 and from 455 to 500 kg/m^3 for okra and from 370 to 450, from 390 to 459, from 412 to 490 and from 434 to 498 kg/m^3 for cob corn under the same previous pressing temperatures. Briquette made with okra stalks residues had the highest bulk density (500 kg/m^3) under 15% concentrations of thermoplastic ratio and 300 ^{0}C pressing temperature. This increase in bulk density is likely due to filling some of the void spaces inside and between particles of okra stalks with plastics during the extrusion and briquetting, while briquettes produced from saw dust had the lowest bulk density of 360 kg/m^3 under 5% concentration of thermoplastic ratios and 150 ^{0}C pressing temperature.

CONCLUSION

The study looked at the briquettes made from three distinct agricultural leftovers in terms of their combustion, mechanical, and physical characteristics. In turn, the briquettes will offer more effective and ecologically friendly substitutes for other energy sources and aid in the management of agricultural and wood waste.

From the results of the current study, it can be seen that the highest quality of briquettes could be produced using okra stalks, 15% thermoplastic ratios, and a pressing temperature of 250 °C. Under these conditions, the maximum fixed carbon is

(86.9%), the lowest moisture content is (3.64%), highest bulk density is (510 kg/m3), highest calorific value is (38.9 MJ/kg), highest burning time is (23 min), highest compressive strength is (10.8 MPa), and highest durability percentage is (94.9%).

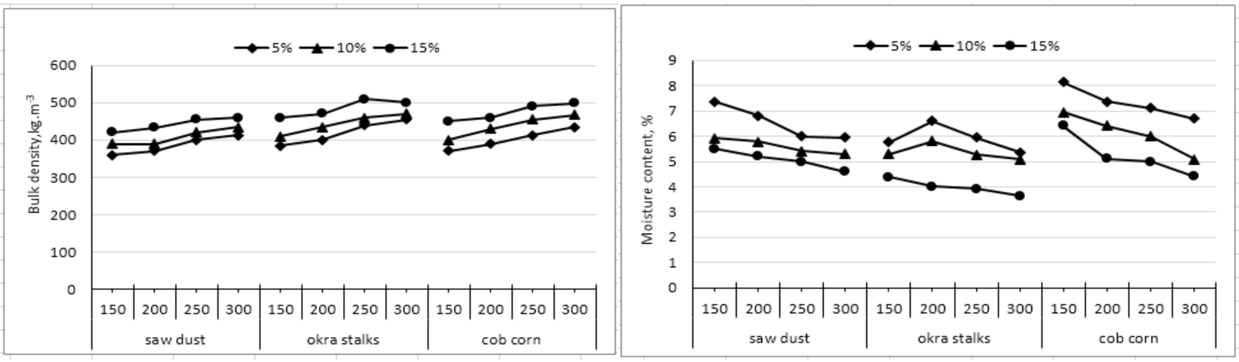


Fig. 10. Effect of different pressing temperatures and concentrations of thermoplastic ratios on moisture content and bulk density of the charred biomass briquettes

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استخدام اللدائن الحرارية كمادة رابطة في إنتاج قوالب فحم عالية الجودة من المخلفات الزراعية

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الملخص

في محاولة للتغلب علي مشكلة زيادة المخلفات الزراعيه وإنخفاض القيمة الحرارية للفحم المنتج من المخلفات الزراعية كان الهدف من هذه الدراسه استخدام اللدائن الحرارية كماده رابطة مع نواتج حرق المخلفات الزراعية لانتاج فحم عالي الجودة لاستخدامه فى الاغراض المختلفه. تم اجراء هذه التجارب باستخدام اربع درجات حراره للكبس (150، 200، 250 و 300 م^0) واضافه ثلاث تركيزات من الماده البلاستيكيه (البروبلين) كماده رابطه (5، 10 و 15%) لثلاث انواع مختلفه من المخلفات الزراعيه (نشاره خشب، سيقان الباميه و قوالح الذره). تم اختبار جودة القوالب المنتجه من خلال خواص الاحتراق والخواص الميكانيكيه والفيزيائيه. وأوضحت النتائج أنه يمكن الحصول على قوالب فحم عاليه الجوده من سيقان الباميه وتركيز 15% من البلاستيك تحت درجه حراره الكبس 250 م^{0}للحصول على قوالب فحم تحتوى على 86.9% كربون ،وقيمه حراريه 38.9 ميجا جول /كجم، فتره الاحتراق 23 دقيقه ، مقاومه انضغاط 10.8 ميجا باسكال ، نسبه المتانه 94.9% و كثافه ظاهريه 510 كجم/م^3