MISR JOURNAL OF AGRICULTURAL ENGINEERING
https://mjae.journals.ekb.eg/
ISSN-Print: 1687-384X
ISSN-Online: 2636-3062

Misr J. Ag. Eng., 40 (4): 393 – 418
DOI: 10.21608/mjae.2023.219214.1107

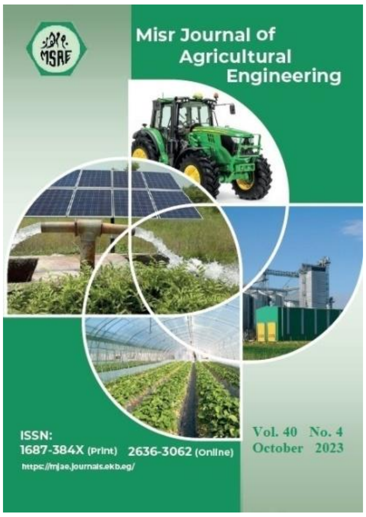
PRODUCTION THE BRIQUETTES FROM MIXTURE OF AGRICULTURAL RESIDUES AND EVALUATION ITS PHYSICAL, MECHANICAL AND COMBUSTION PROPERTIES

Said Fathy Elsisi[1*], Mohamed Nabih Omar[1], Abdellateif abdelwahab Samak[1], Ebrahim Mohamed Gomaa[2] and Ehab Abdelaziz Elsaeidy[1]

[1] Assoc. Prof. in Ag. and Biosystem Eng., Fac. of Ag., Menoufia U., Shebin Elkom, Menoufia, Egypt.

[2] Asist. Prof. in Ag. and Biosystem Eng., Fac. of Ag., Menoufia U., Shebin Elkom, Menoufia, Egypt.

* E-mail: said.elsese@agr.menofia.edu.eg



Keywords:
Briquettes; Density; Calorific value; Proximal analysis; Ignition time.

ABSTRACT

Nowadays, climate change is becoming an important issue mainly because of the energy consumption of human activities. The objective of this study is producing biomass energy using agricultural wastes for briquettes production with high physical, mechanical properties and high calorific value. The study is divided into two parts: Firstly, describing the manufacturing process of briquettes from a mixture of chopped residues in varying proportions including rice straw, sugar cane bagasse, banana peels, coconut shells, and cattle manure to produce eco-friendly briquettes. Secondly, estimate the properties of produced briquettes such as physical, mechanical, and combustion characteristics, including relaxed density, calorific value, proximal analysis, and ultimate analysis to determine quality of produced briquettes. The results showed that the moisture content ranged between 6.02 and 9.52% (w.b.), density of the produced briquettes was found in range of 1040.2 to 1538.8 kg/m^3, compressive strength ranged from 4.59 to 24.07 MPa, durability ranged from 86.43 to 99.75%, water resistance ranged from 77.28 to 92.48 %, calorific value ranged from 16.22 to 20.9 MJ/kg and burning rate ranged from 3.62 to 6.36 g/min with ignition time raged from 2.95 to 4.35 min. The volatile matter in the briquettes ranged from 68.5 to 75.8%. the high fixed carbon was 24.62%. The high-quality of produced briquettes were obtained from sugar cane bagasse sample that were, 24.07 MPa compressive strength, 18.71 MJ/kg calorific value, 6.36 g/min burning rate, 72.3 volatile matter, 99.8 % briquettes durability and 1538.8 kg/m^3 bulk density. While the high calorific value was 20.47 MJ/kg.

1. INTRODUCTION

Agricultural residues are biomass raw materials, most of these have potential appliance in the field of bioenergy **(Galembeck and Abreu Filho, 2017).** Due to the scarcity of fossil fuels and the effects of climate change, there is a growing demand for renewable energy today **(Wang *et al.*, 2019).** According to the **C.A.P.M.S (2023),** Egypt had a sugar cane cultivation area of around 342380 feddans, yielding about 15,959,336 Mg year^{-1} with an average yield of 48.47 Mg fed^{-1}. Egypt had a rice crop cultivation area of around 1104862 feddens. Every year, Egypt produces over a million tonnes of rice straw residues. Rice residues are either immediately burned for energy production in combustion systems or eliminated by burning in the field after harvest, just like in other parts of the world. Burning wastes in fields damages the ecosystem and habitat of rural areas. Egypt has a total of 73883 feddans of cultivated land, producing an average of 284000 Mg of banana fruits per feddan and about 1185148 tonnes of banana fruits overall. These peels are now not utilized for anything else and are instead primarily disposed of as expensive solid waste. Finding uses for these peels is thus important, if not absolutely necessary, given that they can actually worsen environmental issues **(Zhang *et al.*, 2005)**. Coconut shells must be used carefully because they are generated in enormous quantities throughout tropical nations. The primary way for turning biomass to charcoal is through thermochemical processes. The biomass's main downsides are the percentage of certain relative characteristics that include low density, low caloric value, high ash, SOX, NOX, moisture content, microstructure, and complex ingredients. On the carbonization of turning coconut shells into charcoal from local to global scales, however, no scientific investigations were done. As a result, there are few detailed and accurate data available on its manufacturing. Large amounts of manure from the cattle livestock are produced and used as solid fuel and manure. The mean calorific value of manures was 5333 kcal/kg, with a range of 2580 to 11,200 kcal/kg **(Pravin *et al.*, 2016).** The most potential agricultural source of biomass energy in the world is sugarcane. Local energy production is acceptable in the nations. Because of its high energy to volume ratio, sugarcane is regarded as one of nature's most efficient energy storage devices and the most economically significant energy crop **(Zafar, S., 2016).** Briquette fuel is more advantageous than raw materials in general because it is renewable, has a higher calorific value than other solid fuel sources, has less ash than coal (2-10% vs. 20-40%), and burns more effectively than coal **(Ifa *et al.*, 2020).** Briquettes are used in both rural and urban settings for domestic and commercial purposes, including cooking, steam production, oil grinding, and tile manufacturing **(Kpalo *et al.*, 2020).** The moisture and ash concentrations, flow properties, and particle size are the key determinants of raw material selection. Because high moisture content materials are difficult to grind and take more energy to dry, moisture content in the range of 10% to 15% is desirable **(Abdoli *et al*., 2018).** The physical, chemical, and energetic characteristics of biomass briquettes have been determined by several studies that have appeared in the literature on the conversion of biomass into briquettes in Egypt and throughout the world (**Bot *et al*., 2021, 2022 and Kapen *et al*., 2021).** In order to improve the qualities, other studies looked at the physico-chemical and mechanical characterization of mixed briquettes made from various agricultural biomass and sawdust. The factors determining briquette strength and durability have been examined in a several of research **(Adu-Poku *et al.*, 2022 and Akolgo *et al.*, 2021)**. The calorific value, and ultimate characteristics (C, H, O, S, and N) as well as density are the factors that allow the evaluation of a biomass for energy utilization **(Torquato *et al.*, 2017).** According to **De Conti *et al.* (2022),** adding cassava rhizomes to sugarcane bagasse and straw led to the production of binderless briquettes with improved mechanical resistance and durability. **Bill Vaneck *et al.*, (2022)** analyzes the energy usage and commercial viability of producing biomass briquettes from agricultural waste, the research focuses on converting banana peels, rattan trash, sugarcane bagasse, and coconut shells into briquets in a small-scale manufacturing facility. According to **De Conti *et al.*, (2022),** mixing cassava rhizomes to sugarcane bagasse and straw led to the production of binderless briquettes with improved mechanical resistance and durability. **Rabi *et al.*, (2022)** investigated the unique properties of the biomass derived from coconut shells, which is mostly used for thermochemical conversion to produce charcoal. The biomass has a high calorific value of 19.4 MJ/kg, a high density of 412 kg/m^3, a low amount of moisture of 5.6%, and a high quantity of fixed carbon of 21.8%, volatile matter of 70.8%, and carbon of 40.1%. According to **Bilgin *et al.*, (2019)** rice straw briquettes were quite strong in physical tests because of their high shatter index, tumbler index, compressive resistance, and water resistance. Briquettes were found to have an average density, shatter index, and tumbler index of 1221 kg/m^3, 99.46%, and 98.78%, respectively. Briquettes had a maximum compressive resistance of 8123 N. The briquetting machine had an average output capacity of 39 kg/h and a specific electrical energy usage of 0.133 kWh/kg. According to **Gamea, *et al*., (2012)** chopped cotton stalks and rice straw having moisture content (8, 10 and 12%) and (8, 10 and 12.8% w.b.) were densified into briquettes without binder and with binder (Urea-Formaldhyde) using a screw press machine. Quality properties for briquettes were durability, compression ratio hardness, bulk density, compression ratio, resiliency, water resistance and gases emission. The optimum quality properties found for briquettes at 8 % moisture content and without binder. Where the highest compression stress and durability were 8.95, 10.39 MPa and 97.06 %, 93.64 % for cotton stalks and rice straw briquettes, respectively. The CO and CO_2 emissions for cotton stalks and rice straw briquettes were less than these for loose residuals. The objective of this study is twofold: Firstly, describe the manufacturing process of briquettes from a mixture of chopped residues in varying proportions, including rice straw, sugar cane bagasse, banana peels, coconut shells, and cow manure to produce eco-friendly briquettes. Secondly, estimate the properties of briquettes such as physical, mechanical, and combustion characteristics, including density, calorific value, proximal analysis, and ultimate analysis to determine the high quality of briquettes.

2. MATERIALS AND METHODS

2.1. Residues collection and preparation

The current study was conducted beginning May 2023 in Agricultural and Biosystem Engineering lab, Faculty of Agriculture Menoufia University. The obtained briquettes from agricultural residues, including rice straw (RS), sugar cane bagasse (SCb), banana peels, coconut shell, cattle manure and starch as a binder. Rice straw was collected from local farms in Kafer Elsheikh governorate, Egypt, while the Sugar cane bagasse was obtained from the sugar industry, Egypt. Banana peels, coconut shell, cattle manure were obtained from local farmers in Beheira Governorate, Egypt as shown in figure 1. Initial moisture contents of rice straw (RS), sugar cane bagasse (SCb), banana peels, coconut shell and cattle manure as received were 15, 18, 35.4, 23.34 and 75.01% wet basis respectively. After that, the residues were dried by sun to reduce the moisture content below 12 % (w.b.). The moisture level of 10-12% (w.b.) was maintained throughout the briquette-making process in order to generate high density and high-quality briquettes **(Adap *et al*., 2009)**. All residues were later crushed into fine particles by a hammer mill machine (ELEKTRIM SLINIK MOTOR 013835) with screen opening size of 5 mm to manufacturing them in appropriate sizes for briquetting process. Nine different samples in various ratios were produced of rice straw (RS), sugar cane bagasse (SCb), banana peels, coconut shell, cattle manure and starch as a binder. All samples were mixed with each other by weight in different proportions (RS, SCb, Mix1, Mix2, Mix3, Mix4, Mix5, Mix6 and Mix7) as Table 1. Before densification, binder (10% by weight of mixed sample) was added to each of the mixtures. The crushed residues were mixed to stimulate the bonding process, which facilitates the production of briquettes. The physicochemical characteristics of the chopped residues as determined by previous studies are shown in Table 2. The moisture contents of chopped raw material were 10.53, 11.9, 11.65, 9.6 and 19.24% for rice straw (RS), sugar cane bagasse (SCb), banana peels, coconut shell, cattle manure, respectively.

Fig. (1): Agricultural residues production (Agricultural residues obtained after sorting, crushing and drying)

Table 1: Mixing material composition of rice straw (RS), sugar cane bagasse (SCb), banana peels, coconut shell and cattle manure briquettes.

S/No	Sample Name	Rice straw %	Sugar cane bagasse %	Banana peels %	Coconut shell %	Cattle manure %	Starch as a binder %
1	**RS**	90	0	0	0	0	10
2	**SCb**	0	90	0	0	0	10
3	**Mix_1**	50	25	5	5	5	10
4	**Mix_2**	25	50	5	5	5	10
5	**Mix_3**	50	0	15	10	15	10
6	**Mix_4**	0	50	15	10	15	10
7	**Mix_5**	15	0	20	30	25	10
8	**Mix_6**	0	15	20	30	25	10
9	**Mix_7**	0	0	30	30	30	10

2.2. Briquettes Production

Briquettes were produced using a lab-scale screw press briquette machine Shimada (Type SPMM-850 KS) under controlled pressure and temperature, the machine could produce 400 kg/h. An electric motor rated at 30 kW drives the press machine. It contains two integrated

"T" stirrers with 1.5 kW motors and two electrical ceramic heating bands, each of which requires 3 kW to operate. A typical 220/380 Volt, 50 Hz, three-phase electrical power supply is needed for the press as shown Fig.2a and b. The die was heated to about 140 °C before the briquetting procedure, and then the briquetting machine was started on. Briquettes were made in accordance with a set technique, which involved compacting 3 kg of residue for 1 minutes at 170 °C and 70 MPa of pressure then cooling it for 10 minutes.

Table 2: Physical and chemical properties of some raw biomass materials.

Analysis	Moisture content (wt %)	Bulk density kg/m^3	Volatile matter %	Ash %	Fixed carbo n %	HHV (MJ/kg , dry basis)	Lignin %	Hemic-elluloses %	Cellul-ose %	References
Rice straw	10.6	75.0	60.6	17	11.1	14.1	13.5	27.8	24.0	**(Rosado *et al.*, 2022)**
Sugarcane bagasse	11.9	153.6	82.6	3.9	8.3	16.8	23.5	28.6	43.8	**(Rabi *et al.*, 2022)**
Banana peels	11.6	360.0	88.0	9.3	2.7	16.2	8.9	41.4	9.9	**(Isa Kabenge1 *et al.*, 2018)**
Coconut shell	9.6	510-800	76.7	1.1	22.4	19.4	33.7	20.9	25.2	**(Rabi *et al.*, 2022)**
Cattle manure	19.2	120.0	83.9	5.8	16.1	20.1	8.0	12.8	23.5	**(Rabi et *al.*, 2022)**

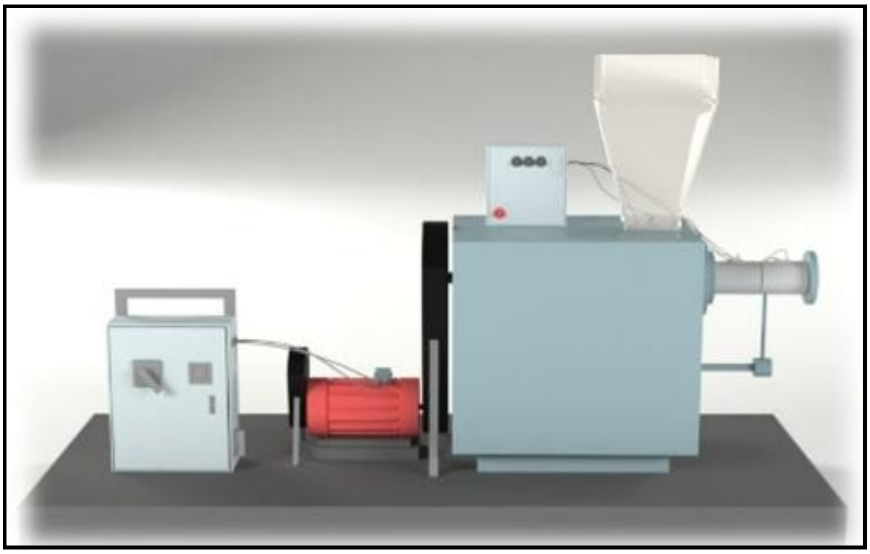


Fig. (2a): Schematic diagram of screw press machine.

Manually putting chopped residues as proportion mixing in Table 1 into the hopper of the briquetting machine was done and the loading process was periodically repeated during briquetting process. After the briquetting procedure, 50 mm diameter cylindrical briquettes with a 10 mm central hole and a slightly carbonised outer surface were produced due to heating system. The hole contributes to the briquette's increased porosity and oxygen availability, which enhances briquette combustion. The briquetting procedures as carried out in the production process are shown in Fig. 3. After drying the produced briquettes for 20 days in a secure space with enough ventilation, their fuel qualities were determined.

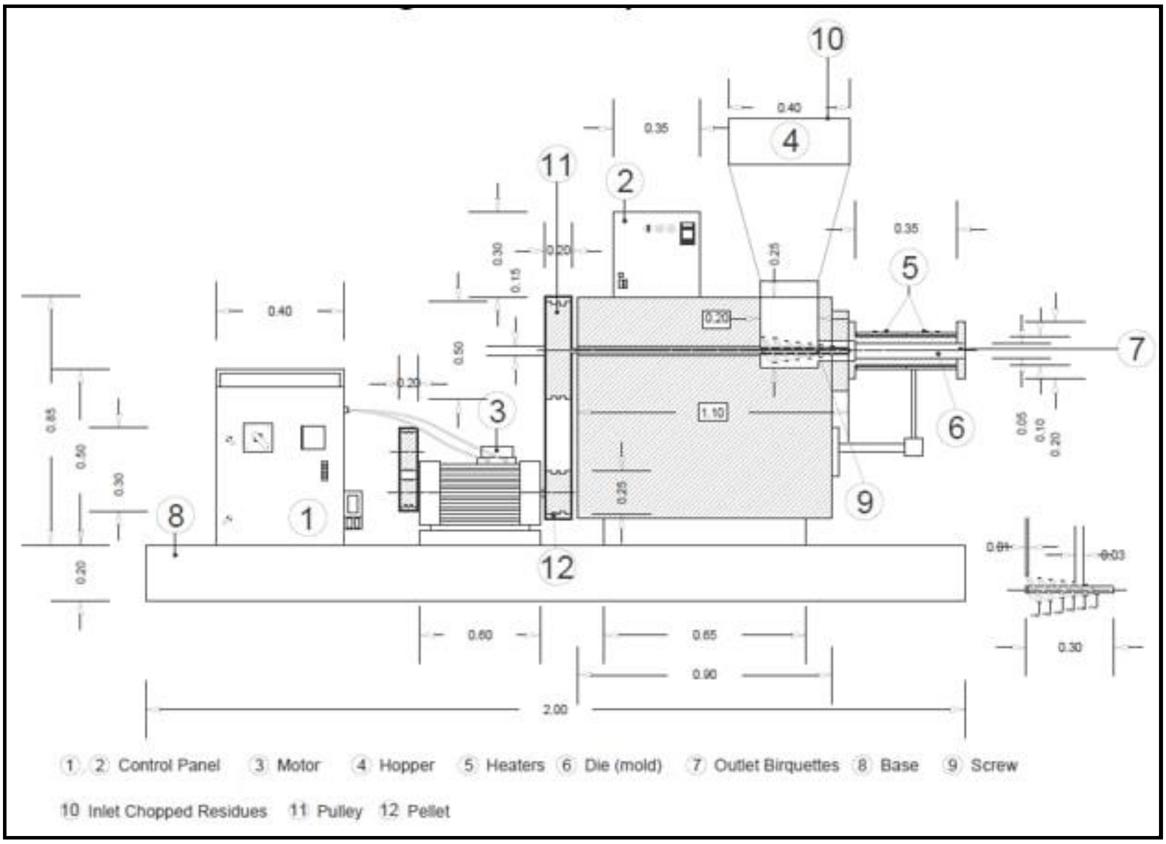


Fig. (2b): Conical screw type briquetting machine and parts.

Fig. (3): Briquettes producing process.

2.3. Characterization of Produced Agricultural residues briquette

1. Dimensional stability.

According to method of **Jiao *et al.*, (2020**) which might be used to expose whether the dimension of briquette changed during storage as a result of stress relaxation. The briquette's diameter and height were measured as soon as it was removed from the mold and daily until its measurements stopped fluctuating. Equation 1 was used to determine the briquette's dimensional stability.

$$DS = 100 - (\frac{v_t - v_0}{v_0} \times 100) \qquad (1)$$

where DS is dimensional stability (%), v_t is the volume of the briquette after releasing, cm^3 and v_0 is the volume of the briquette after production, cm^3.

2. Relaxed density.

The density of the briquette as determined after a specific amount of time is referred to as relaxed density. After allowing the briquettes to dry, the volumes were determined using the briquettes' height and diameter because they were cylindrical in shape. According to **Mandal *et al.*, (2019)**, the relaxed density of briquettes was determined using the mass and volume by Equation 2.

$$\rho = \frac{M}{\pi H(r_0^2 - r_i^2)} \qquad (2)$$

where ρ is relaxed density, kg/m^3, M is briquette mass, kg, π is mathematical constant, H is briquette height, m and r_o and r_i were outer and inner radius of briquette, m.

3. Water resistance.

Capacity of briquettes to absorb water is influenced by their porosity, The capacity of briquettes to absorb water depends on their porosity. According to **Kpalo *et al.*, (2020**), the porosity was determined by counting the amount of water that each sample absorbed. A pre-weighted briquette was immersed in water at room temperature for two minutes after drying. The weight was then measured once more, and the dispersion time and relative weight change were also recorded (**Samomssa *et al.*, 2021**). The water resistance was calculated using equation 3 as suggested by **Adu-Poku *et al.*, (2022)**.

$$WR = 100 - (\frac{(W_W - W_S)}{W_S} \times 100 \qquad (3)$$

where WR is water resistance, %, W_s is dry weight of briquette, g and W_w is wet weight of briquette after immersed in water, g.

4- Shatter resistance.

The durability of a briquette is demonstrated by its resistance to shatter. It was determined by the percentage of briquettes that did not break **(Kpalo *et al.*, 2020).** Briquette shatter resistance was determined by allowing it to fall freely from a fixed height. Five times from a height of 2 m, the dried briquette sample was dropped onto a concrete floor. Equation (4), proposed by **Adu- Poku *et al.*, (2022)**, was used to compute the shatter resistance after calculating the weight of the briquettes after they had broken.

$$SR = 100 - (\frac{w_1 - w_2}{w_1}) \times 100 \qquad (4)$$

Where SR is shattering resistance (%) and W_1 and W_2 are weight of briquette before and after shattering, respectively.

5. Determination of compressive strength

The greatest load that a briquette can support without breaking or cracking is used to determine the briquette's compressive strength. The weight that a briquette can support while being stored is estimated by this load. Compressive strength of briquettes was determined using a universal testing machine (H-500KN, Shimadzu) with a load cell capacity of 500 kN and a cross-head speed was 1mm/min. The briquette was put between the plates of machine and put under uniform loading until it failed or ruptured. It can be calculated from the following relation **(Navalta *et al.*, 2020).**

$$\sigma_C = \frac{F_C}{A} \qquad (5)$$

Where: $\boldsymbol{\sigma c}$ - Compressive strength, N/ mm^2, Fc - fracture force of the specimen, N, A - Cross section area ($\pi(r_0^2 - r_i^2)$of the briquette, mm^2.

2.4. Combustion properties of briquettes

1. Burning Rate

The burning rate is the rate at which a particular mass of fuel burns in air. It was determined as described by **(Onukak *et al.*, 2017)**. using insulated wire gauze of a weight that is known. The wire gauze was covered with approximately 100 g of briquettes, and the burner started burning it. Every 10 s, the weight of gauze was calculated until the briquette was completely consumed and a constant weight was retained. The weight loss at a specific time was computed using the equation 6:

$$B_s = \frac{Q_1 - Q_2}{T} \qquad (6)$$

where Bs = burning rate (g/min), Q_1 = initial weight of briquettes prior to burning (g), Q_2 = final weight of briquettes after burning, g, T = total burning time, min.

2. Ignition Time

The taken time for a known mass of fuel to ignite and that time was determined using a procedure followed by **(Onukak *et al.*, 2017).** Exactly 100 g of each different briquette was placed on a wire mesh grid (of known mass resting) on two fire-retardant bricks to allow free flow of air around it. A Bunsen burner was placed directly underneath this platform and adjusted to a blue flame. The burner was lighted until briquette was ignited. The ignition time was computed using the equation 7:

$$\text{Ignition time} = t_1 - t_0 \qquad (7)$$

where t_1 = time the briquette ignited, min, t_0 = time the burner was lighted, min.

3. Calorific Value

The briquettes calorific value was determined through correlation with the proximate analysis findings, as defined by **Ayse and Serdar (2017)**, the calculated as the equation 8 as following.

$$HHV=167.2-1.449\ VM-1.562\ FC-1.846\ Ash \qquad (8)$$

Where VM volatile matter, FC Fixed Carbon and Ash content, which calculated from equations 9, 10 and 11. The samples were milled after the tumbling test to perform the proximate analysis.

4. Emission test

The exhaust gas from the burning of each different briquette sample was analyzed for oxygen (O_2), carbon dioxide (CO_2), carbon monoxide (CO), nitrogen monoxide (NO), nitrogen oxide

(NO_2 and NOx), sulfur dioxide (SO_2) using a Stack gas analyzer (ECOM - D). A 2 m exhaust gas pipe was mounted on the top of the stove was installed.

2.5. Proximate analysis of briquettes

1. Volatile matter

According to **ASTM D-3175-18 (2018),** the volatile matter (VM) of different briquettes was estimated. 1 gram of the sample was weighed and placed in a crucible. The crucible was covered with a lid and heated in a Heraeus Hanau (HR170 E) oven for 7 minutes at 925±20 ^{0}C. Equation 9 was used to determine the amount of volatile matter in the sample as a percentage of the loss in weight due to volatile matter removal.

$$\text{volatile matter \%} = \frac{\text{Loss in weight due to volatile matter removal}}{\text{weight of sample}} \times 100 \qquad (9)$$

2. Ash content

According to the **ASTM D-3174-12 (2012)** standard, ash content (AC) was calculated. A closed, pre-weighed crucible containing 1 gram of each different briquette sample was slowly heated to 700±50 ^{0}C for 30 minutes. Before being weighed, the crucible was removed and cooled in a desiccator. The weight of the residue was reported as the ash content of the sample on percentage basis, and was calculated by equation 10.

$$\text{volatile matter \%} = \frac{\text{weight of ash left after heating}}{\text{weight of sample}} \times 100 \qquad (10)$$

3. Fixed carbon “FC”

After combining the ash content and volatile matter measurements, fixed carbon (FC) was computed by subtracting the total from 100. Equation (11) illustrates how this was also stated as a percentage.

$$\text{Fixed Carbon\%} = 100\% - \%\,(\text{Volatile Matter} + \text{Ash Content}) \qquad (11)$$

2.6. Ultimate analysis

The elemental composition of briquettes was determined on the basis of the results of experimentally verified proximate analysis, more precisely as a function of fixed carbon and volatile matter content as demonstrated by **Parikh *et al.* (2007). Ajimotokan *et al.* (2019)** followed this approach to calculate the main chemical elements such as carbon (C), hydrogen (H) and oxygen (O) from Eqs. (12-14), respectively.

$$C = 0.637 \text{ Fixed Carbon} + 0.455 \text{ Volatile Matter} \qquad (12)$$

$$H = 0.052 \text{ FC Fixed Carbon} + 0.062 \text{ Volatile Matter} \qquad (13)$$

$$O = 0.304 \text{ Fixed Carbon} + 0.476 \text{ Volatile Matter} \qquad (14)$$

3. RESULTS AND DISCUSSIONS

3.1. Characterization of the briquette produced.

The achieved briquettes (Figure 5) were laid out flat and allowed to air dry for 20 days in a sealed space with sufficient air ventilation before the properties were assessed, which included that density, water Resistance, durability, compressive strength, combustion properties, proximate analysis and ultimate analysis of briquettes.

3.1.1. Density

An essential physical characteristic of fuel briquettes is their density. The features of handling, transportation, energy content, ignition, and burning are all significantly influenced by density because a higher density implies a larger energy-to-volume ratio **(Adeleke *et al.*, 2022).** In terms of density, the Scb briquette had a density of 1538.8 kg/m^3, while the Mix7 briquette had the lowest density of 1040 kg/m^3 (Table 3 and Figure 6). An essential physical characteristic of fuel briquettes is their density. The features of handling, transportation, energy content, ignition, and burning are all significantly influenced by density because a higher density implies a larger energy-to-volume ratio **(Adeleke *et al.*, 2022).**

Fig. (5): Briquettes samples made from agricultural residues mixtures (rice straw (RS), sugar cane bagasse (SCb), banana peels, coconut shell, cattle manure) using a screw press.

In terms of density, the Scb briquette had a density of 1538.8 kg/m^3, while the Mix7 briquette had the lowest density of 1040 kg/m^3 (Table 3 and Figure 6). The increased lignin and cellulose content of the Scb materials can be used to explain the observed difference between the Mix7 and Scb briquettes. According to the results given in the first column of Table 4, the density values of the samples are between 1040- 1538.8 kg/m^3. A result of the briquettes increased volume as a result of their dimensions expanding after being removed from the briquetting machine. Compared to samples mixed with sugar cane bagasse, those with a significant percentage of cattle manure have lower densities. According to the literature **(Bot *et al.*, 2021**), the density of briquettes is a function of the density of the biomass employed. The result obtained is consistent with this finding. The briquettes made high proportion from Sugar cane bagasse had the highest density (sample Scb=1538.8 kg/m^3, Mix2=1372.2 kg/m^3 and Mix4=1369.9 kg/m^3), while the briquettes produced from the cattle manure, banana peels and rice straw had the lowest (sample Mix3=1118.6 kg/m^3, Mix5=1179.8 kg/m^3, and Mix7=1040 kg/m^3) relaxed briquette density. High-density briquettes have values that are comparable to those listed in **Falemara *et al.* (2018)**, which indicate that briquettes with high densities have a longer burning rate, such as Scb (1538.8 kg/m^3); Mix2 (1372.2 kg/m^3); Mix4 (1369.9 kg/m^3) than briquettes Mix3 (1118.6 kg/m^3), Mix5 (1179.8 kg/m^3) and Mix7 (1040 kg/m^3). The values obtained were greater than the minimal value of 600 kg/m^3 advised by **Mani *et al.* (2006)** for effective transportation and secure storage; Thus, briquettes of suitable in terms of density good enough can be produced by adding a high percentage of Scb. The conclusion that the higher density in briquettes, the higher the energy/volume ratio, is also in line with **Kers *et al*. (2010)** discovery. However, other combustion parameters of such briquettes may be adversely affected, resulting in a longer burning period. other than residues components the high-density values can be explained by the fact that the screw press is used.

Table 4: Characterization of produced mixed briquette

Sample ID	Density Kg/m^3	Water Resistance %	Dimensional stability %	Shater index %	Compressive Strength MPa
RS	1300.5	90.6	94.3	86.4	10.4
SCb	1538.8	92.5	95.8	99.8	24.1
Mix1	1220.4	90.5	94.4	92.3	15.1
Mix2	1372.2	90.1	95.7	98.2	17.5
Mix3	1118.6	85.9	93.7	97.8	8.4
Mix4	1369.9	87.4	95.6	98.0	17.3
Mix5	1179.8	89.5	93.0	98.9	6.7
Mix6	1214.1	85.3	93.7	99.8	11.3
Mix7	1040.2	77.3	28.2	99.7	4.6

3.2.3. Water Resistance

Briquettes are porous materials that can absorb moisture from their surroundings when handled, transported, and stored. Heat values of briquettes are influenced by their water resistance, which also affects how efficiently they burn. In order to prevent fungus from growing and decaying during storage, briquettes need to have a good resistance to water absorption, especially if the feedstock is agricultural waste.

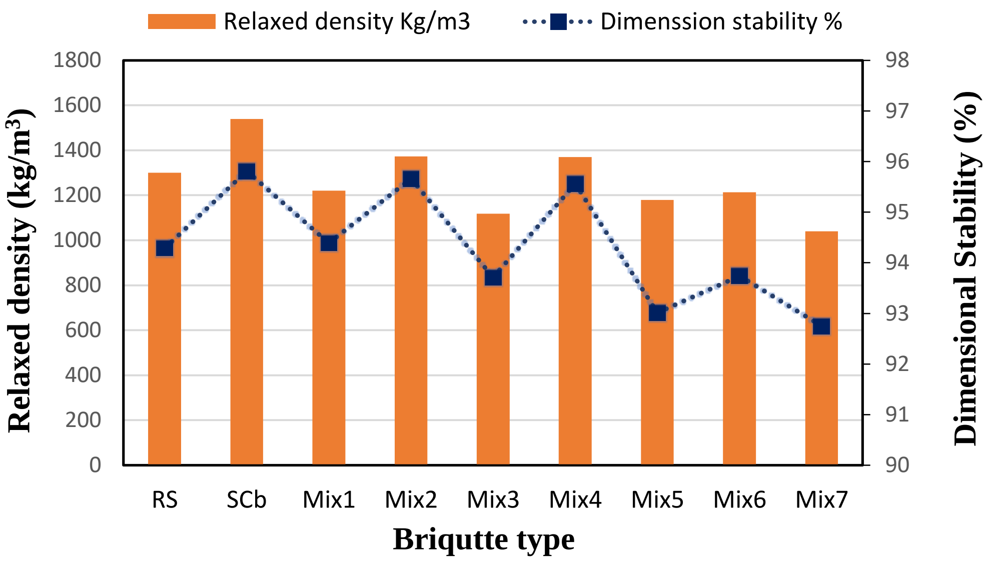


Fig. (6): Dimensional stability and relaxed density of briquettes.

The Scb briquette recorded the highest resistance to water penetration with a value of 9٢.5% followed by the RS briquette with a value of 90.63.6% (Table 4, Figure 7). The Mix7 briquette recorded the least water resistance (77.28%), most likely from due to the low density and porosity of cattle manure and banana peels particles. This is due to particle porosity from existence of a capillary network in mixed briquettes which containing cattle manure and banana peels gives rise to its tendency to absorb water. This result is agreement with **Pinto *et al.* (2012)**. On the other hand, higher rice straw and sugar cane bagasse content combined with sawdust material resulted in a decrease in the hygroscopic feature of ability briquettes to absorb water. According to **Yaman *et al.* (2001)**, sugar cane bagasse has a fibrous structure that has good effects on briquettes' improvement in water resistance.

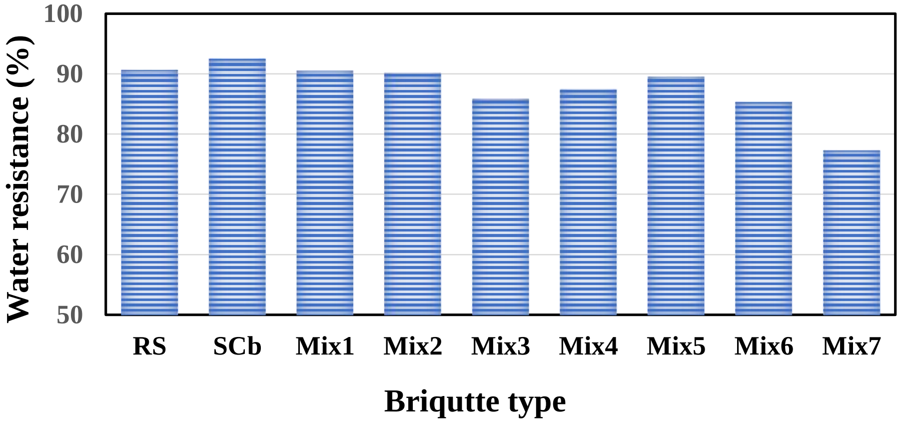


Fig. (7): Water resistance of briquettes.

3.2.4. Durability

Shatter resistance could be used to measure briquette durability **(Adeleke *et al.*, 2022)**. It was necessary to have a higher density or add a lot of binder or mix residues with different proportions of lignin, hemicelluloses, and celluloses as a binder because this increased shatter resistance in the fuel briquettes. According to **ASABE Standard S269.4 (2003) (Mohd-Faizal *et al.*, 2022)**, when shatter resistance was >90%, between 80% and 90%, and <80%, the briquette had good, medium, and poor durability, respectively. The shatter indices of the mixed briquettes in this study reveals that they can be good for transportation and storage. The results in Table 4 and Figure 8 show that the sugar cane (SCb) briquette recorded the greatest shatter index of 99.8 % which was closely followed by the Mix6 briquette with a value of 99.7 %.

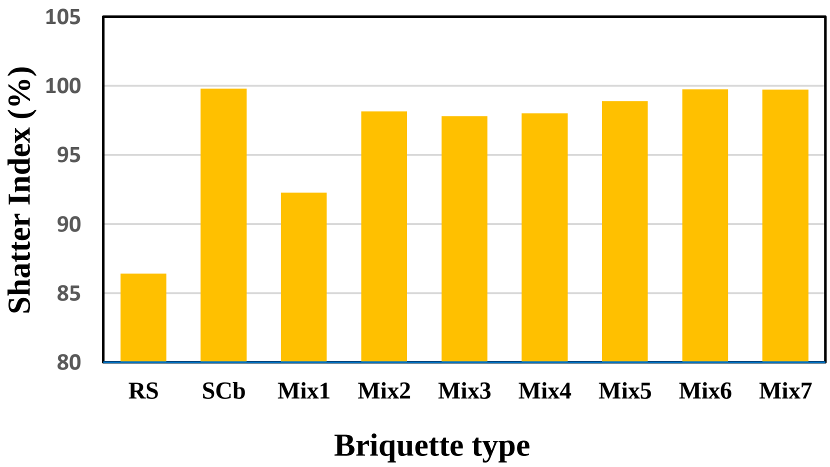


Fig. (8): Shatter resistance of briquettes.

While the briquettes showed a lower shatter index was 86.4 % for RS briquette. The difference of durability briquettes is caused the raw materials used to produce briquettes differ, the physical qualities of the briquettes will affect their durability. Also, the best results of shatter resistance of the briquettes were 99.8%, 99.75%, 99.73% and 98.9% at the samples Scb, Mix6, Mix7 and Mix5, respectively. This is due to it contains a significant amount of sugar cane bagasse and coconut shells, both of which are considered binder-rich sources to contain a high percentage cellulose and fiber. The higher the value of the shatter index, better the quality of briquette, the results agree with **Ujjinappa and Sreepathi (2018).**

3.2.5. Compressive strength

The compressive strength of a briquette is the maximum crushing force it can withstand before breaking or cracking as shown in Fig. 9. It is a different index from the shatter index that is used to evaluate how easily briquettes may be handled, packaged, and transported. According to the results given in the fifth column of Table 4, the compressive strength values of the samples are between 4.59 and 24.07 MPa. The compressive strength of briquettes produced with sugar cane (SCb) was 410.5% higher than that of the briquettes with Mix7 (4.57 MPa). The results concur with those of **Jamradloedluk and Wiriyaumpaiwong (2007),** who found that briquettes produced from higher density materials may be able to withstand more ultimate stress than those made from lower density materials. Compressive strength increases briquette lifespan by lowering the capacity for moisture absorption. A minimum value of 0.38 MPa was recommended as an acceptable compressive strength for briquettes test, which used as commercial fuel **(Kers *et al.*, 2010).** From Table 4 and Fig. 10 it was observed that the maximum and minimum compressive strength of briquettes ranged from 4.57 and 24.07 MPa. The highest compressive strength of 24.07 MPa was observed for briquette made of sugar cane bagasse (SCb) this is due to the uniform formulation and integration of particles of varying sizes, compacting while the lowest was observed for briquette made of Mix7. The compressive strength of sample (Mix1, Mix2 and Mix 4) were 15.07, 17.28 and 17.53 respectively. Due to excellent inter-particle bonding and almost no inter-particle gap of sugar cane bagasse and coconut a blend of different particle sizes will produce the best briquette quality. As a result, briquettes manufactured of sugar cane (SCb) will have less breakage or damage during storage and transit than briquettes derived from other Mixing. The results are also consistent with the observation by **Jamradloedluk and Wiriyaumpaiwong (2007)** resulted that briquettes made from denser materials may resist greater ultimate stress than those made from lower density materials.

Fig. (9): Compressive stress test until briquettes failure.

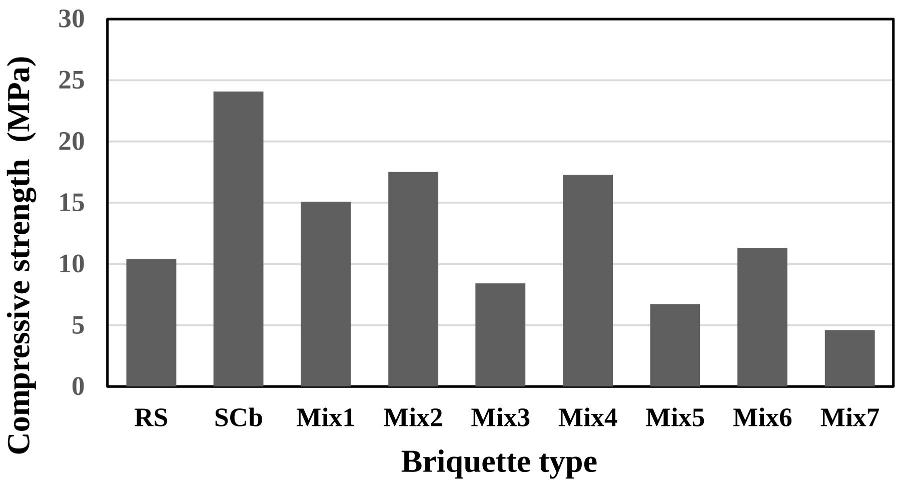


Fig. (10): Compressive strength of briquettes.

3.3. Combustion properties

3.3.1. Burning rate

Another factor used to describe how a fuel behaves during combustion, in addition to ignition time, is fuel burning rate. It gauges the rate of briquette combustion. Results show that sample Scb displayed the highest value (6.36 g/min) while sample A had the lowest (3.62 g/min) (Fig. 11). It has been demonstrated that when the sugar cane bagasse ratio rises, so does the fuel burning rate. As previously mentioned, the volatile matter level of the briquettes affected their burning rate; however, the burning rate decreased of sample Mix7, although having the most volatile matter, may have been caused by the lesser density briquettes. Briquette application is significantly impacted by burning rate. High burning rate of briquettes suggest that more briquettes will be needed during combustion because they burn off quickly. According to observations, briquettes having little or without sugar cane bagasse burn off more quickly than those that do. This result is agreed with **Imeh *et al.* (2017).**

3.3.2. Ignition Time

The igniting time is affected by functions of the particle size, porosity, Volatile matter and bonding strength of the briquettes **(Onukak *et al.*, 2017; Kebede *et al.*, 2022)**. The ignition time is the length of time needed for the briquette to ignite when using additional fuels like kerosene or gas in modest amounts. The highest ignition time from Fig. 11 was observed in sample Mix3 at 4.35 min. Sample Mix7, which is the sample at 2.95 min, has the shortest ignition time. According to **Onuegbu *et al.* (2011)**, the calorific content and burning rate of briquettes work together to determine how long it takes for an ignition to occur. According to the reported ignition duration and calorific values of the briquettes, the findings of this investigation support this study.

3.3.3. Calorific Value

Table 5 shows that Mix7, Mix6 and Mix5 briquettes have the highest calorific values of 20.47 MJ/kg, 20.27 MJ/kg and 20.20 MJ/kg. This is because cattle dung has a lower moisture content than those other residues. It is also observed that the calorific value of briquettes is high compared to the of Mix7, Mix6 and Mix5 because this characteristic is linked to fixed carbon; which confirm that when fixed carbon is higher calorific value is increased.

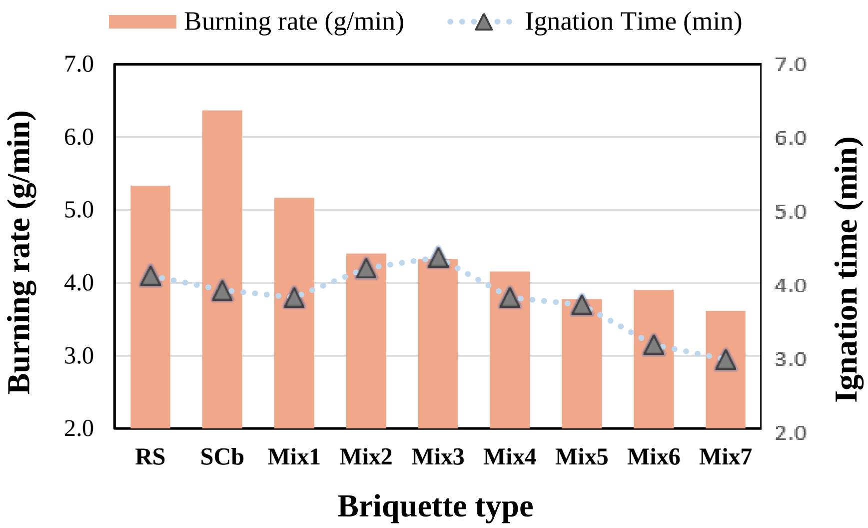


Fig. (11): Effect of different briquette types on burning rate and ignition time

The results in this study shows that Mix7 briquette had the highest calorific value of 20.47 MJ/kg while the lowest calorific value was 19.02 MJ/kg of the RS briquettes (Fig. 12). The biomass materials proximate and elemental analysis (Table 5) suggests they possessed sufficient thermal properties, which contributed to the relatively high and acceptable calorific values obtained. Mix7 Mix6 and Mix5 have a higher lignin content (33.7%) than its lignin content in other mixing. Higher lignin content in coconut could have also contributed to the higher calorific value of the Mix7 Mix6 and Mix5 briquette because lignin yields more energy when burned than cellulose. The mixed briquettes which include varying amounts of coconut, sawdust, and sugarcane bagasse have calorific values ranging from 18.71 MJ/kg to 20.47 MJ/kg, which indicates that they would emit very high heat. The structure and chemical makeup of these residues may have an impact on these results. Results show that calorific value of briquettes ranged from 17.56 to 20.47 MJ/kg (Fig. 12).

Table 5: Proximate and ultimate properties of mixed briquettes with a dry basis.

Sample ID	Proximate analysis			MC (%)	Ultimate analysis			Calorific Value MJ/kg
	FC (%)	VM (%)	Ash content (%)		Carbon (%)	Hydrogen (%)	Oxygen (%)	
RS	19.80	68.50	11.70	9.00	39.01	5.41	41.07	17.56
SCb	21.20	72.30	6.40	8.56	42.66	5.44	40.27	18.71
Mix1	20.00	70.60	9.30	7.05	40.24	5.55	40.86	18.00
Mix2	21.90	72.30	5.70	9.52	40.92	5.40	41.56	18.97
Mix3	22.00	73.10	5.10	8.97	40.80	5.49	40.72	19.12
Mix4	23.10	73.70	4.80	7.41	42.40	5.50	40.74	19.59
Mix5	23.80	74.50	2.40	7.29	43.44	5.48	39.89	20.20
Mix6	24.10	74.60	2.80	6.02	45.03	5.60	39.93	20.27
Mix7	24.60	75.80	2.90	6.28	45.29	5.61	39.80	20.47

The values also increased with the increase in ratio of banana peels and cattle manure which is similar to the observed trend in volatile matter and fixed carbon of produced briquettes.

According to a paper by **Suhartini *et al.* (2011)**, the removal of volatile matter directly affects the calorific value of fuel briquettes. This suggests that the higher the fixed carbon content and lower the volatile matter, the greater the calorific value. This is supported by **Sawadogo *et al.* (2018),** who found that the high volatile matter concentration in the mixing sample was the cause of lower calorific value of the briquettes (17.56 MJ/kg) compared to sample Mix7 (20.47 MJ/kg). The study found that the higher the carbon content, regardless of the raw materials, the higher the calorific value. The Mix7, Mix6 and Mix5 briquettes in this study have calorific values that are sufficient to support combustion and provide heat sufficient for cooking, potentially serving as an energy source. This result is in agreement with that of **Sawadogo *et al.* (2018)** who demonstrated that the Calorific value of the briquettes depends on their carbon content. Also, **Falemara *et al.* (2018)** mentioned that high-quality briquettes should have low moisture content, little ash, high fixed carbon content, and high heating value.

3.3.4. Emission

In this study, the emissions of CO, CO_2, NOx and NO_2 produced from burning the briquettes obtained from different wastes concerning the greenhouse gases due to global warming were determined as shown in Fig. 13. A comparison between the actual gas emissions from fuel briquettes and the maximum human exposure limit during a period of 8 hours is shown in Table 6. The table makes it clearly apparent that the gas emission generated by the fuel briquettes complies with occupational exposure limits set by the Occupational Safety and Health Agency (OSHA). In contrast to other toxic emissions shown in Table 6, high carbon dioxide concentrations imply complete combustion, which leads to the oxidation of carbon monoxide to less toxic carbon dioxide. The CO emissions are higher for the samples RS, Mix1 and Mix3 briquettes, due to its higher rice straw content as shown in Table 6. For SCb, Mix5, Mix6 and Mix7 briquettes, the CO and CO_2 concentrations were 61 ppm and 0.5%, 30 ppm and 0.26 %, 29 ppm and 0.5 %, 40 ppm and 0. 48 % respectively. While RS, Mix1 and Mix3 briquettes, the CO and CO_2 concentrations were 153 ppm and 0.63 %, 193 ppm and 0.3 %, 138 ppm and 0.4 % respectively.

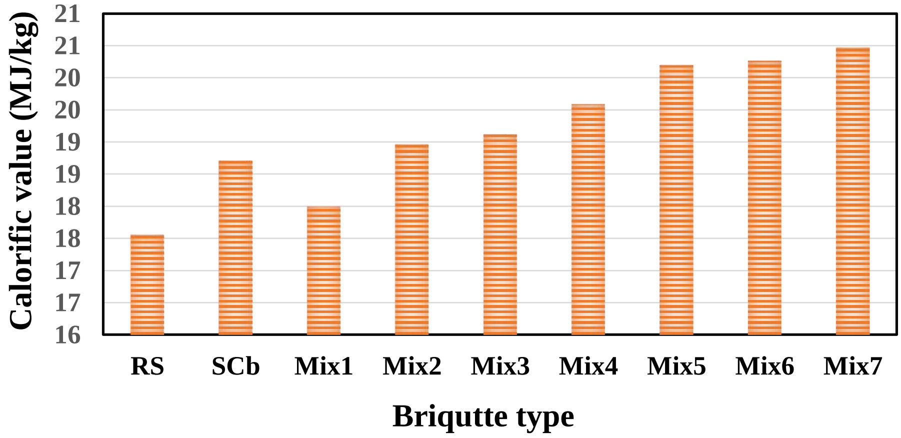


Fig. (12): Effect of briquette types on calorific value

The emission of unburned carbon-based pollutants such carbon monoxide results from incomplete combustion of briquettes, in accordance with **Obernberger *et al.* (2006).** The SCb, Mix5, Mix6 and Mix7 briquettes appear to burn more thoroughly than RS, Mix1 and

Mix3 briquettes, according to the lower CO and CO_2 concentrations they produce. NOx production is caused by the N concentration of the fuel (Table 6). The SCb, Mix5, Mix6, and Mix7 briquettes utilized in this investigation had reduced NO_2 emissions as well, showing combustion characteristics resembling those of more modern biomass solid fuels. **Nussbaumer (2003)** stated that the nitrogen fuel component is transformed into N_2 and NOx throughout the combustion process, with extremely little levels of NO_2 present in the combustion gases produced by modern biomass solid fuels.

Table 6: The actual gas emissions from fuel briquettes and maximum human exposure limit over 8 hours.

Sample ID	RS	SCb	Mix1	Mix2	Mix3	Mix4	Mix5	Mix6	Mix7	OSHA limit ppm
CO (ppm)	153	61	198	75	138	83	30	29	40	**5000**
CO_2 (%)	0.63	0.50	0.30	0.29	0.40	0.42	0.26	0.50	0.48	**50 -200**
NO (ppm)	16	14	15	10	16	11	5	8	3	**25**
NO_2 (ppm)	2	2	0	1	1	1	1	2	2	**5**
NOx (ppm)	16	8	18	9	12	17	6	7	5	**20**

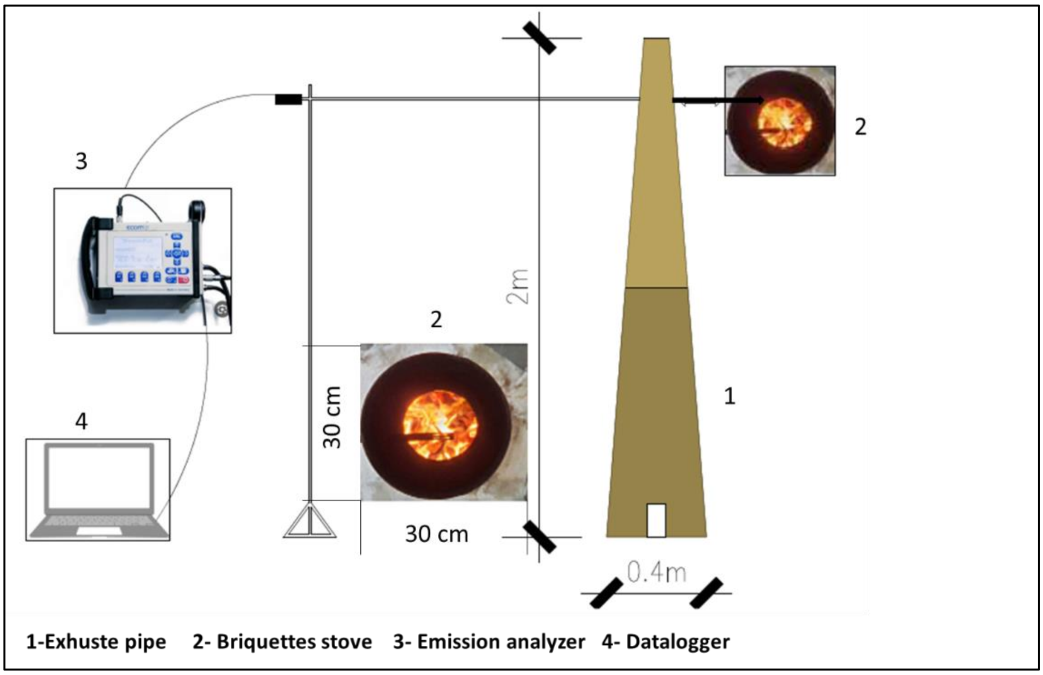


Fig. (13): The emission test.

3.4. Proximate analysis of produced briquettes

3.4.1. Volatile matter

Sample Mix7 had a largest percentage of volatile matter in the produced briquettes (75.8%), while sample RS had the lowest percentage (68.5%) as shown (Fig. 13 and table 5). The percentage of volatile matter in the briquettes was affected by the biomass mixing ratios. The results showed a gradual increase in volatile matter with residues mixing ratio of samples Mix7, Mix6 and Mix5. This is clear from the results of the mixed briquette samples since the raw material contains a lot of volatile substances, as was documented in an earlier study

(Kpalo *et al.*, 2020). The produced Mix7 (banana peels and cattle manure) briquettes contained VM ranging from 76.69 % to 88.02 % as raw residues, while VM was 60.55 % of rice straw as shown table 1. So, it's VM was greater than the Mix1, Mix2 briquette and RS briquettes. Fuel briquettes with a high volatile matter content are more likely to ignite readily when burned. Additionally, it means that it will require more energy to burn up the volatiles before the heat energy is released **(Onukak *et al.*, 2017)**. Additionally, as briquettes' volatile matter content rises, less gaseous emissions are released during combustion. **Chungcharoen and Srisang (2020),** who found that while the briquettes burnt due to the high volatile matter, the flame was smokey as a result of the combustion of volatile gases.

3.4.2. Ash content

The concentration of inorganic components in the biomass is measured by its ash content. It plays a significant role in deciding how much waste can be produced when solid biofuels are burned. According to Table 1, the ash level of briquettes varied from 2.9% to 11.7%, with sample RS being the highest as shown (Fig. 14 and Table 5). The presence of more rice straw in the mixed briquette led to a higher ash content in the briquettes. **Sawadogo *et al.* (2018)** noted that having high concentrations of ash is undesirable since it might lead to dust and hazardous compounds in the environment. They also, observed that the ash percentage of cashew industry waste briquettes ranged from 4% to 7%. Similar to how briquette ash content typically increases combustion residue, ash lessens the heating impact of briquettes **(Sotannde *et al.*, 2010).** Lower ash concentration is ideal for combustion efficiency since it prevents slagging and allows air to enter the stove, speeding up the burning process. In that study, mixing low-ash bovine dung, coconut shells, and sugar cane bagasse significantly reduced the amount of ash in the combined briquettes. The findings support the conclusion in an earlier study **(Kpalo *et al.*, 2020)** that the high ash concentration in briquettes may be resolved by mixing coconut shell in samples Mix7, Mix6, and Mix5. Based on its ash composition, it is predicted that the briquettes made from a mixture of sawdust, sugar cane bagasse, coconut shell, and cattle manure would perform well in a cooking application. Because of low ash level in that briquette, the briquettes may make excellent fuel for gasifiers and other thermal uses.

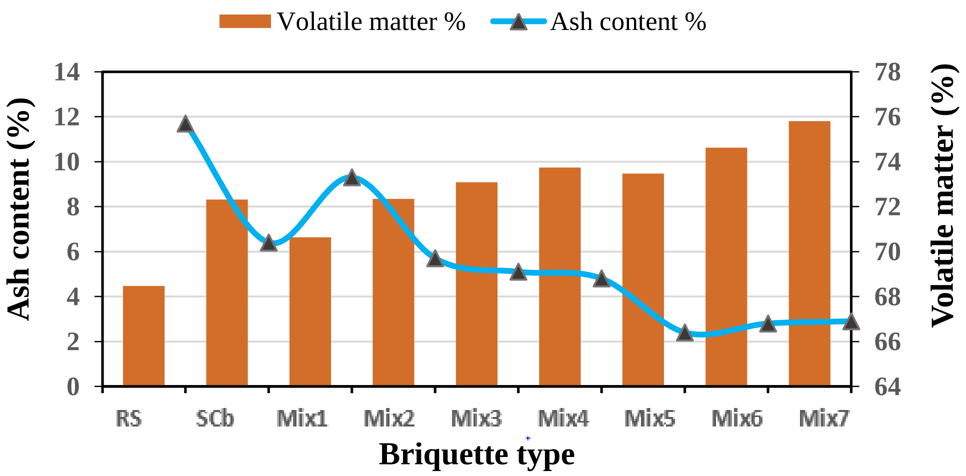


Fig. (14): The relationship between ash content and volatile matter for different types briquette

3.4.3. Fixed carbon

The amount of fixed carbon in a briquette that is required for char burning after all volatile materials have been removed from the biomass is a sign of high heating value of briquette. As shown in Fig. 15 and Table 5, sample Mix7 had the highest percentage of fixed carbon (24.6%), followed by sample Mix6 (24.1%). As volatile matter and ash concentration dropped, the data also demonstrate that the fixed carbon rose. It is difficult to determine appropriate percentage of fixed carbon by any standard. This is due to the fact that it is mostly reliant on the ash content and volatile matter levels. **According to Adeleke *et al.*, (2022),** the FC of coal and biomass briquettes made with an organic binder can range from 65.13% to 65.25% and yet be considered acceptable. The produced briquettes for this research had an FC content of 24.6%, which was much lower than the necessary amount. Fixed carbon acts as the primary source of heat during combustion, and the results of this study can effectively improve briquette combustion. The fixed carbon content ranges from 19.84 to 24.62% for the mixed briquette sample RS and the mixed briquettes Mix7, respectively.

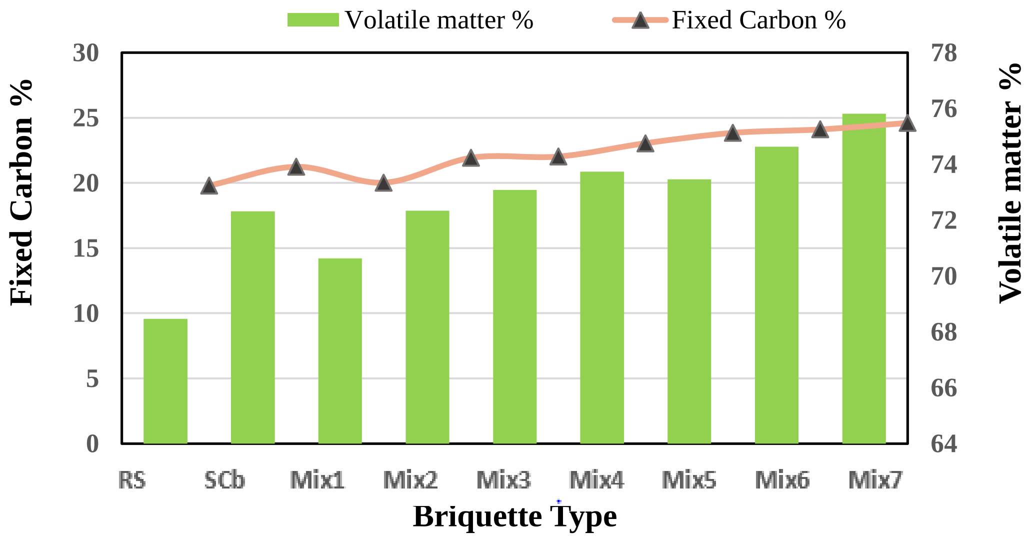


Fig. (15): The relationship between fixed carbon and Volatile matter for different types briquette

3.5. Ultimate analyses of briquettes

The elemental composition of the briquettes make up is revealed by the final examination of the briquettes. The percentage composition of these components in the briquettes produced is shown in Table 5. Important sources of heat emitted during burning are carbon and hydrogen. Higher concentrations of these two elements improve fuel quality; nevertheless, lesser carbon content is typically correlated with greater hydrogen in a fuel. According to **Mitchual *et al.*, (2019),** carbon approximates the heating value of biomass material, and it was further stated that materials with higher carbon contents would naturally have higher heating values. **Ujjinappa and Sreepathi (2018)** noted that briquettes with a high oxygen concentration exhibit a high level of inherent moisture. Its reaction with hydrogen produces water vapor, which reduces the amount of hydrogen available for combustion and lowers calorific value.

4. CONCLUSION

Nine different samples in various ratios were produced from rice straw (RS), sugar cane bagasse (SCb), banana peels, coconut shell, cattle manure and starch as a binder, all samples were mixed with each other by weight in different proportions (RS, SCb, Mix1, Mix2, Mix3, Mix4, Mix5, Mix6 and Mix7). The study examined the physical, mechanical and combustion properties of produced briquettes from agricultural residues. The results show that, it can be seen that the highest quality of briquettes were obtained from SCb sample was 24.07 MPa compressive strength, 18.71 MJ/kg calorific value, 21.2 % fixed carbon, 6.36 g/min burning rate, 72.3 Volatile matter, 99.8 % briquettes durability and 1538.8 kg/m^3 bulk density. While the high calorific value was 20.47 MJ/kg at Mix7 briquettes. Future research will also use experimental design, achieving briquette compositions that will allow for a complete understanding of the relationship between each component. The produced briquettes created were useful as eco-friendly alternative energy source since they have high calorific values, low ash content, and high compression strength.

5. REFERENCES

Abdoli, M.A., Golzary, A., Hosseini, A and Sadeghi, P. (2018). Biomass Densification. In: Wood Pellet Renew. Source Energy Prod. Consum., Cham: Springer International Publishing; ٤٠ (2): 33–46. Doi: 10.1007/ 978-3-319-74482-7_2.

Adap, P., Tabil, L and Schoenau, G. (2009). Compaction characteristics of barley, canola, oat and wheat straw. Biosyst. Eng. 104(3): 335–344.

Adeleke, A. A., Odusote, J. K., Ikubanni, P.P., Olabisi, A. S and Nzerem, P. (2022). Briquetting of subbituminous coal and torrefied biomass using bentonite as inorganic binder. Sci. Rep. 12 (1): 1–11. Doi.org/10.1038/s41598-022-12685-5.

Adu-Poku, K. A., Appiah, D., Asosega, K. A., Derkyi, N. A., Uba, F., Kumi, E.N., Akowuah, E., Akolgo, G. A and Gyamfi, D. (2022). Characterization of fuel and mechanical properties of charred agricultural wastes: Experimental and statistical studies. Energy Rep. 8 (3): 4319–4331. http://dx.doi.org/10.1016/j.egyr. 2022.03.015.

Ajimotokan, H. A., Ehindero, A. O., Ajao, K. S., Adeleke, A. A., Ikubanni, P. P and Shuaib- Babata, Y. L. (2019). Combustion characteristics of fuel briquettes made from charcoal particles and sawdust agglomerates. Sci. Afr. 6, e00202. http://dx. doi.org/10.1016/j.sciaf.2019.e00202.

Akolgo, G. A., Awafo, E., Essandoh, E.O., Owusu, P.A., Uba, F and Adu-poku, K. A. (2021). Assessment of the potential of charred briquettes of sawdust, rice and coconut husks: Using water boiling and user acceptability tests. Sci. Afr. e00789. http://dx.doi.org/10.1016/j.sciaf.2021.e00789.

ASAE Standards. S269.4: (2003). Cubes, pellets, and crumbles – definitions and methods for determining density, durability and moisture content. St. Joseph, MI: ASABE.

ASTM D3174-12, (2012). Standard Test Method for Ash in the Analysis Sample of Coal and Coke from Coal. ASTM International, West Conshohocken, PA. https://doi.org/10.1520/D3174-12.

ASTM D3175-18, (2018). Standard Test Method for Volatile Matter in the Analysis Sample of Coal and Coke. ASTM International, West Conshohocken, PA. https://doi.org/10.1520/D3175-18.

Ayse Özyuguran and Serdar Yaman (2017). Prediction of Calorific Value of Biomass from Proximate Analysis. 3rd International Conference on Energy and Environment Research, ICEER 2016, 7-11 September 2016, Barcelona, Spain. Energy Procedia 107 (2017) 130 – 136

Bilgin S., H. Y lmaz1., A. Koçer., M. Acar., M. Dok and S. Alparslan (2019). Briquetting of Rice Straw and Determination of Briquette Physical Properties, XXXVI CIOSTA & CIGR Section V Conference 26 – 28 May 2015 Saint Petersburg, the Russian Federation.

Bill Vaneck, B., Petros J. A., Olivier, T. S., Evangelos, I. S and Jean, G, T. (2022) Economic analysis of biomass briquettes made from coconut shells, rattan waste, banana peels and sugarcane bagasse in households cooking. International Journal of Energy and Environmental Engineering.

Bot, B.V., Sosso, O.T., Tamba, J.G., Lekane, E., Bikai, J and Ndame, M.K. (2021). Preparation and characterization of biomass briquettes made from banana peels, sugarcane bagasse, coconut shells and rattan waste. In: Biomass Conversion and Biorefinery. http://dx.doi.org/10.1007/s13399-021-01762-w.

Central Agency for Public Mobilization and statistics (2023). Annual Bulletin of statistical crop area and plant production.

Chungcharoen, T and Srisang, N. (2020). Preparation and characterization of fuel briquettes made from dual agricultural waste: cashew nut shells and areca nuts. J. Clean. Prod. 256, 120434 https://doi.org/10.1016/j.jclepro.2020.120434.

De Conti, A.C., Granado, M.P.P., Padilla, E.R.D., Nakashima, G.T., De Conti, C., Yamaji, F.M. (2022). Binderless briquetting of mixed cassava rhizome, sugarcane bagasse, and sugarcane straw for producing solid biofuel with high durability. Bio Energy Research. 15 (2): 507–516. https://doi.org/10.1007/s12155-021-10300-5.

Falemara, B.C., Joshua, V.I., Aina, O.O and Nuhu, R. D. (2018). Performance evaluation of the physical and combustion properties of briquettes produced from agro-wastes and wood residues. Recycling 3, 3. http://dx.doi.org/10.3390/ recycling3030037.

Galembeck, F and Abreu Filho, P. P. (2017). Perspectives for biomass production and use in Brazil. Rev. Virt. Quím. 9(3): 274–293. https://doi.org/10.21577/1984-6835.20170018.

Gamea G. R., E. A. El Saeidy and S. F. El Sisi (2012). Quality properties for cotton stalks and rice straw briquettes, The 19 th. Annual Conference of the Misr Soc. of Ag. Eng., 14-15 November, 2012

Ifa, L., Yani, S., Nurjannah, N., Darnengsih, D., Rusnaenah, A and Mel, M. (2020) Techno-economic analysis of bio-briquette from cashew nut shell waste. Heliyon 2020, 6 (9): e05009. https://doi.org/10.1016/j.heliyon.2020.e05009.

Imeh, E. O., Ibrahim, A., Mohammed-Dabo, A. O., Ameh S., I.R. Okoduwa and Opeoluwa, O. F. (2017). Production and Characterization of Biomass Briquettes from Tannery Solid Waste Recycling 2017, 2 (17): doi:10.3390/recycling 2040017

Isa, K., Godfrey, O., Noble, B., Jeffrey, S., Ahamada, Z and Nicholas K. (2018). Characterization of Banana Peels Wastes as Potential Slow Pyrolysis Feedstock. Journal of Sustainable Development. 11(2): 2018 ISSN 1913-9063 E-ISSN 1913-9071

Jamradloedluk, J and Wiriyaumpaiwong, S. (2007) Production and Characterization of Rice Husk Based Charcoal Briquettes. KKU Eng. J. **2007**, 34, 391–398.

Jiao, W., Tabil, L. G., Xin, M., Song, Y., Chi, B., Wu, L., Chen, T., Meng, J and Bai, X. (2020). Optimization of process variables for briquetting of biochar from corn stover. Bioresources 15 (3): 6811–6825. In: https://ojs.cnr.ncsu.edu/index.php/BioRes/art.

Kebede, T., Dargie, T. B and Yohannes, Z. (2022) Combustion Characteristics of Briquette Fuel Produced from Biomass Residues and Binding Materials. Journal of Energy Volume 2022, Article ID 4222205, 10. https://doi.org/10.1155/2022/4222205

Kers, J., Kulu, P., Aruniit, A., Laurmaa, V., Krizan, P., Soos, L and Kask, Ü. (2010). Determination of physical, mechanical and burning characteristics of polymeric waste material briquettes. Est. J. Eng. **2010**, 16, 307–316. [CrossRef]

Kpalo, S.Y., Zainuddin, M.F., Manaf, L. A and Roslan, A. M. (2020). A review of technical and economic aspects of biomass briquetting. Sustain 2020;12(11):4609. https://doi. org/10.3390/su12114609.

Kpalo, S.Y., Zainuddin, M.F., Manaf, L.A and Roslan, A.M. (2020). Production and characterization of hybrid briquettes from corncobs and oil palm trunk bark under a low pressure densification technique. Sustainability 12 (6): 1e16. https:// doi.org/10.3390/su12062468.

Mandal, S., Kumar, G.P., Bhattacharya, T.K., Tanna, H.R and Jena, P.C. (2019). Briquetting of pine needles (Pinus roxburgii) and their physical, handling and combustion properties. Waste Biomass Valorization 10 (8): 2415–2424. https://doi.org/10.1007/s12649-018-0239-4.

Mani, S., Tabil, L.G and Sokhansanj, S. (2006). Specific energy requirement for compacting corn stover. Bioresour. Technol. 97, 1420–1426

Mitchual, S.J., Katamani, P and Afrifa, K.A. (2019). In: Fuel Characteristics of Binder Free Briquettes Made at Room Temperature from Blends of Oil Palm Mesocarp Fibre and Ceiba Pentandra. Biomass Conversion and Biorefinery, pp. 541e551. https://doi.org/10.1007/s13399-019-00410-8.

Mohd, F. S., Jaffar, N and Mohd, A.S., (2022). Integrate the adoption and readiness of digital technologies amongst accounting professionals towards the fourth industrial revolution. Cogent Bus. Manag. 9 (1): 2122160. https://doi.org/10.1080/23311975.2022.2122160.

Mohd-Faizal, A.N., Mohd-Shaid, M.S.H and Ahmad-Zaini, M.A. (2022). Solid fuel briquette from biomass: recent trends. O.U.A.C. 33 (2): 150–155. https://doi.org/10.2478/ auoc 2022-0022.

Navalta, C. J. L. G., K. G. C. Banaag., V. A. O. Raboy., A. W. Go., L. K. Cabatingan and Y. H. Ju (2020). Solid fuel from Co-briquetting of sugarcane bagasse and rice bran. Renewable Energy, 147, 1941−1958.

Nussbaumer T. (2003) Combustion and co-combustion of biomass: fundamentals, technologies, and primary measures for emission reduction. Energy. Fuels. 2003; 17:1510-1521

Obernberger, I., Brunner, T and Bärnthaler, G. (2006) Chemical properties of solid biofuels—significance and impact. Biomass. Bioenergy. 2006; 30: 973-982.

Onuegbu, T.U., Ekpunobi, U.E., Ogbu, I.M., Ekeoma, M.O and Obumselu, F.O. (2011). Comparative studies of ignition time and water boiling test of coal and biomass briquettes blend. Int. J. Res. Rev. Appl. Sci. 7 (2): 153e159.

Onukak, I. E., Mohammed-Dabo, I. A., Ameh, A. O., Okoduwa, S.I and Fasanya, O.O. (2017). Production and characterization of biomass briquettes from tannery solid waste. Recycling 2 (4): 17–33. https://doi.org/10.3390/recycling2040017.

Parikh, J., Channiwala, S.A and Ghosal, G.K. (2007). A correlation for calculating elemental composition from proximate analysis of biomass materials. Fuel 86 (12–13): 1710–1719. http://dx.doi.org/10.1016/j.fuel.2006.12.029.

Pinto, J., Cruz, D., Paiva, A., Pereira, S., Tavares, P., Fernandes, L and Varum, H. (2012) Characterization of corn cob as a possible raw building material. Constr. Build. Mater. **2012**, 34: 28–33.

Pravin, K. S., Suryakant, C., Satendra, D., Khageshwar, S. P. (2016) Combustion Characteristics of Animal Manures. Journal of Environmental Protection, 2016, 7: 951-960 http://dx.doi.org/10.4236/jep.2016.76084

Rabi, K. A., Shaharin, A. Sulaiman., Suzana, Y., Sharul, S. Dol., Muddasser, I and Hadiza, A. U. (2022) Exploring the potential of coconut shell biomass for charcoal production Ain Shams Engineering Journal 13: 101499.

Rosado, M.J., Marques, G., Rencoret, J., Gutiérrez, A and del Río, J. C. (2022) Chemical Composition of Lipophilic Compounds from Rice (Oryza sativa) Straw: An Attractive Feedstock for Obtaining Valuable Front. Plant Sci. 13:868319. doi: 10.3389/fpls.2022.868319 Phytochemicals

Samomssa, I., Nono., Y.J., Carac, G., Gurau, G., Dinica, M.R and Kamga, R. (2021). Optimization of fuel briquette production from cassava peels, plantain peels and corncobs. J. Mater. Cycles Waste Manag. 1–13. https://doi.org/10.1007/s10163- 021-01260-1.

Sawadogo, M., Kpai, N., Tankoano, I., Tanoh, S.T and Sidib, S. (2018). Cleaner production in Burkina Faso: case study of fuel briquettes made from cashew industry waste. J. Clean. Prod. 195, 1047-1056. https://doi.org/10.1016/ j.jclepro.2018.05.261.

Sotannde, O.A., Oluyege, A.O and Abah, G.B. (2010). Physical and combustion properties of briquettes from sawdust of Azadirachta indica. J. For. Res. 21 (1): 63e67. https://doi.org/10.1007/s11676-010-0010-6.

Suhartini, S., Hidayat, N and Wijaya, S. (2011). Physical properties characterization of fuel briquette made from spent bleaching earth. Biomass Bioenergy 35 (10): 4209-4214. https://doi.org/10.1016/j.biombioe.2011.07.002.

Torquato, L. D. M., Crnkovic, P.M., Ribeiro, C.A and Crespi, M.S. (2017). New approach for proximate analysis by thermogravimetry using CO2 atmosphere: Validation and application to different biomasses. J. Therm. Anal. Calorim. 128 (1): 1–14. http://dx.doi.org/10.1007/s10973-016-5882-z.

Ujjinappa, S and Sreepathi, L. K., (2018). Production and quality testing of fuel briquettes made from pongamia and tamarind shell. Sadhana 43 (58): 1e7. https://doi.org/ 10.1007/s12046-018-0836-8S.

Wang, T., Li, Y., Zhi, D., Lin, Y., He, K., Liu, B and Mao, H. (2019). Assessment of combustion and emission behavior of corn straw biochar briquette fuels under different temperatures. J. Environ. Manag. 250, 109399. https://doi.org/10.1016/j. jenvman.2019.109399.

Yaman, S., Sahan, M., Haykiri-Açma, H., ¸Sesen, K and Küçükbayrak, S. (2001) Fuel briquettes from biomass-lignite blends. Fuel Process Technol. **2001**, 72: 1–8.

Zafar, S. (2016). Biomass resources from sugar industry, http://www.bioenergyconsult. com/tag.

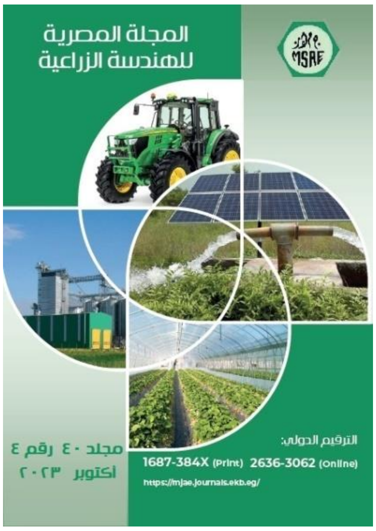
Zhang, P., Whistler, R.L., BeMiller, J. N and Hamaker, B. R. (2005). Banana starch: Production, physicochemical properties and digestibility– a review. Carbohydrate Polymers. 2005; 59(4): 443-458.

انتاج قوالب من خليط للمخلفات الزراعية وتقييم خواصها الفيزيائية والميكانيكية وخواص الحرق

د/سعيد فتحى السيسى[١] ، د/محمد بيومى عمر[١] ، د/عبداللطيف عبدالوهاب سمك[١] ،
د/ابراهيم محمد جمعه[٢] و د/ايهاب عبدالعزيز الصعيدى[١]

[١] استاذ مساعد الهندسة الزراعية والنظم الحيوية – كلية الزراعة – جامعة المنوفية- شبين الكوم – مصر.

[٢] مدرس الهندسة الزراعية والنظم الحيوية – كلية الزراعة – جامعة المنوفية- شبين الكوم – مصر.



الكلمات المفتاحية:
القوالب؛ الكثافة؛ القيمة الحرارية؛ التحليل التقريبى؛ زمن الاشتعال.

الملخص العربى

في الوقت الراهن ، أصبحت قضية تغير المناخ الناتج عن التلوث البيئى نتيجة سوء استخدام المخلفات الزراعية امر يشغل معظم دول العالم ، لذلك كان الهدف من الدراسة تعظيم الاستفادة من المخلفات الزراعية من خلال انتاج وقود حيوى صديق للبيئة ذو قيمة حرارية عالية ، وتنقسم الدراسة إلى مرحلتين: أولاً ، تصنيع القوالب من خليط من المخلفات الزراعية المفرومة بنسب متفاوتة والتى تشمل كلاً من قش الأرز وتفل قصب السكر وقشور الموز وقشور جوز الهند وروث الماشية لإنتاج قوالب صديقة للبيئة. ثانيًا ، تقدير الخواص الفيزيائية والميكانيكية للقوالب وخصائص الحرق ، وهى الكثافة وقوة الضغط والقيمة الحرارية والتحليل النهائي لتحديد أفضل جودة للقوالب. تم إجراء التجارب لانتاج ٩ عينات من القوالب التى تم تحضيرها بخلط المخلفات المفرومة بنسب مختلفة مع ١٠% من النشا كمادة رابطة ثم كبسها بمكبس ميكانيكى (Screw press). أوضحت النتائج أن أفضل جودة للقوالب كانت من خلط ٩٠% من تفل قصب السكر مع ١٠% من النشا ، حيث كانت قوة ضغط لها ٢٤,٠٧ ميجا باسكال ، وكانت القيمة الحرارية ١٨,٧١ ميجا جول / كجم ، ونسبة الكربون الثابت كانت ٢١,٢٪ ، وكان معدل الاحتراق ٦,٣٦ جرام / دقيقة ، ونسبة المادة المتطايرة كانت ٧٢,٣% ، وكانت المتانة ٩٩,٨٪ وكانت الكثافة ١٥٣٨,٨ كجم/م^{٣}. تعتبر القوالب التي تم انتاجها مصدر طاقة بديل وصديق للبيئة نظرًا لأنها تحتوي على قيم عالية من القيمة الحرارية ونسبة قليلة من الانبعاثات.