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Characterization of Fuel Briquettes Produced from Pet Plastics and Sawdust

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Abstract

This study is focused on proffering a sustainable option for managing plastic wastes and wood wastes by converting them into fuel briquettes. The plastic wastes (Polyethylene Terephthalate, PET, bottles) were pulverized without the labels and covers using a shredding machine while the wood wastes (sawdust) were collected from wood workshops in Benin City. The wood wastes were sorted using a 2mm mesh sieve to attain uniform grain distribution. The wastes were mixed in varying proportions of plastic to sawdust in ratios 50:50, 60:40, 40:60 respectively which were then binded with an aqueous starch. The mixture was compacted into polyvinyl chloride (PVC) pipes that served as moulds to form briquettes. These briquettes were left to sun-dry to produce Sample A, Sample B, and Sample C respectively. The samples were analysed to ascertain their combustion and physicochemical properties. The results obtained show that Sample C had the highest calorific value of 13.95MJ/Kg, Sample A had 13.17MJ/Kg while Sample B had 6.04MJ/Kg. The results show that the quantity of sawdust in each sample probably contributed greatly to the calorific value of each sample. With such reasonably high calorific value, it can be concluded that can serve as fuel for energy generation and by extension contribute to the sustainable management with plastic wastes and wood wastes

1. Introduction

Nigeria, The health and environmental challenges posed by municipal solid waste (product packaging, bottles, paper, wood, and so on) is a global problem that is not unique to Nigeria. Globally, solid waste generation has increased dramatically in recent decades, causing waste management facilities to become overburdened and ineffective [1]. Authorities in charge of waste management must deal with the massive amount of solid garbage generated.
Environmental planning and management are becoming increasingly popular around the world. Nigeria, regrettably, has not created and implemented environmental protection policies in a timely manner. Lagos, which is one of Nigeria's largest and most industrialized cities, remains one of its dirtiest, with trash carpeting the landscape. Municipal Solid Waste (MSW) generation in Nigeria

has increased dramatically over the years, owing primarily to the country's fast population growth as well as its economic and industrial development [2].

In 2010, 4.4 million tonnes of solid waste were projected to have been "mismanaged" in Africa due to poor infrastructure and inefficient waste management agencies, who are unable to evacuate wastes regularly and promptly, thereby leading to various adverse consequences such as plastic waste pollution [3].

Plastic is an ever-present threat to waste management facilities and our modern society. Today, about four hundred tonnes of plastic waste is being produced globally every year [3]. It is common practice to see many used plastic products not collected in waste bins for further processing: re-use, recycling, and recovery, rather, they are indiscriminately disposed of into the environment where they become a menace to public health and the environment. The common practice includes plastic bottles and containers being thrown on the ground, thrust out of vehicles, hipped around narrow passages, or blown away by the wind littering the surroundings and subsequently polluting the immediate ecosystem. This poor management of used plastic products has become a serious global environmental challenge and threat to the ecosystem hence, the need to come up with solutions that would reduce the effects of waste pollution on the environment. Figure 1 shows the menace of PET bottles in cities across Nigeria.

Figure 1: Menace of plastic wastes in cities across Nigeria: (a) Lagos state, (b) Kaduna state, (c) Ogun state, (d) Benin city, Edo state (image by authors)

Another threat to waste management facilities is wood waste. Management of wood waste has its own challenge, especially considering that most wood processing industries are mainly concerned with how much profit they earn, and have little or no consideration for proper waste management practices [5]. Approximately 50-55% of the logs supplied to the sawmill are left as scrap, this equates to over five million tonnes of wood waste generated yearly across Nigeria, with the southern states accounting for a significant percentage of this waste [6].

Figure 2: Wood processing activities and wood wastes in a sawmill in Benin City, Edo State [6]

Various developed countries over the years have adopted the method of converting waste to briquettes as a waste management option to put an end to landfills which contribute to numerous environmental issues [8]. According to the America Standards for Testing and Materials (ASTM) [9], RDF is a densified fuel derived from municipal solid wastes when non-combustible components have been removed.

Maninder *et al.* [10] described briquetting as a process of compacting residues into a product of higher density than the original material, while Kaur *et al.* [11] and Olurunnisola [12] defined briquetting as a densification process. Briquettes have advantages over firewood in terms of higher energy content, safer and more convenient to use, and less space requirement for storage [13]. Briquetting compacts low density and loose combustible organic materials into high-density solid fuel of various shapes. It improves the physicochemical and combustion properties of the raw materials, improves materials handling, increases the net calorific value, reduces transportation costs and makes them useful for a variety of applications [14]. The shape and size of briquettes depend on the mould, while the appearance and calorific values depend on the type of feedstock and the level of compactness [15. 16].

Briquetting technologies are generally categorised into three viz: high, medium and low compaction technologies and briquettes can either be formed with or without binders [10, 12]. Olaoye and Kudabo [14] reported that agricultural residues such as straws, tree leaves, maize husks, grass, rice, groundnut shells, banana leaves, sawdust and castor stover can be used for briquette production and that though some materials have better calorific value than others, the selection of feedstock is usually dependent on what is readily available. Several types of briquetting machines are available for densification of biomass, and their mode of operation vary from one principle to another [11, 17]. These types of briquetting machines include screw press, manual piston press, hydraulic piston press and pellet press.

Adoption of briquette technology will not only create a safe and hygienic way of disposing wastes but turn them into an economic venture by converting waste into solid fuels and also contributing towards a safer environment. The utilization of sawdust and PET bottles as materials for the production of fuel briquettes will help to prevent open dumping of refuse, burying, indiscriminate burning, etc. thus preserving the environment and guiding against health hazards. Due to the availability of sawdust and PET bottles in large quantities, their utilization will serve as an alternative energy source in the country.

This study, therefore, aims at attaining a solution for proper waste management practice by disposing of waste in an economic and ecological manner. The objectives of this study include (i) the production of SWDF samples, and (ii) the characterization of the SWDF samples to determine their combustion and physicochemical properties.

2. Materials and Method

2.1 Materials

The materials and equipment used for the production and analysis of the briquettes are sawdust, PET bottles, starch, water, wooden spatula, digital weighing scale, bowls, gas cylinder, pot, sieve of 2mm mesh size, ½ inch pipes, rod and plastic shredding machine.

2.2 Preparation of Raw Materials

The sawdust collected from wood workshops was sieved to achieve uniform grain distribution using a 2mm mesh sieve (Figure 3). This is important as it aims to improve the intermolecular bond between the samples. The PET bottles were gathered by picking improperly discarded PET bottles from drainages, pavements, etc. The covers and labels were disposed of, in an attempt to get a homogenous sample.

Figure 1: Sample of filtered Sawdust

The PET bottles were pulverized using a plastic shredding machine to also achieve uniform grain distribution. The plastic shredding machine consists of an angle grinder, a cutting wheel, and a cylindrical body frame made of steel. The angle grinder was mounted at the bottom of the cylindrical body frame and the cutting wheel (disc) was coupled on top of the angle grinder. The angle grinder was set to a speed of about 1900rpm to effectively cut the plastic bottles. The detailed procedure for the RDF pellet production process is shown in Figure 4.

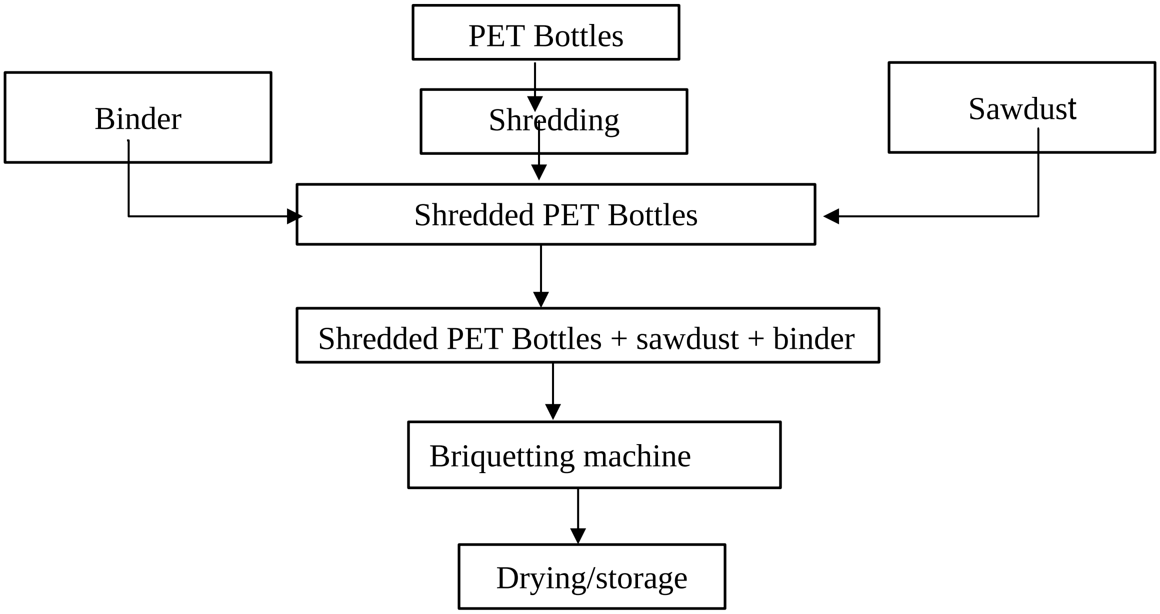

Figure 4: detail procedure for the SWDF pellet production process

Due to the lightweight and softness of the PET bottles, the machine cannot be used to directly shred the bottles. Hence, the PET bottles were first heated in a mild steel plate at regulated heat between 260℃-300℃ to melt the PET bottles. The melted plastic was left to cool for about 1-2 minutes before placing it in the plastic shredding machine. The machine crushed the melted plastic into powdery form (Figure 5) to achieve uniform grain distribution.

Figure 5: Sample of pulverized plastic bottles

The binder used in this study was cassava starch gel. The gel was prepared by dissolving 30g cassava starch in 50 ml cold water and mixing thoroughly to form a paste. Thereafter, 120ml of boiled water was added to the paste and mixed properly with a stirrer to form a starch gel (Figure 6). The starch gel was left to cool before application.

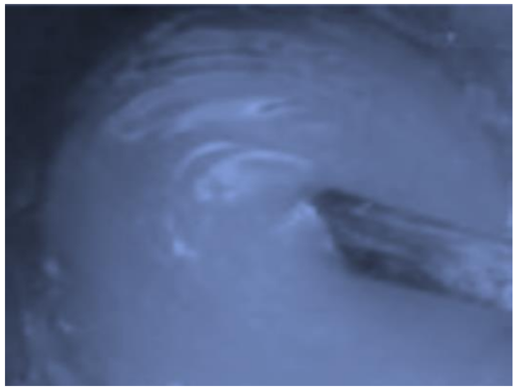

Figure 6: Cassava starch gel

2.3 Production Process of the Briquettes

The powdered plastic and sawdust were mixed in proportions of 50:50%, 60:40% and 40:60% respectively, and binded with the starch gel to create three blends; sample A, sample B, and sample C respectively. The three different blends were placed into ½-inch cylindrical pipes which were covered at one end using PET bottle covers (Figure 7). The pipes were used as mould to give the mixture a well-compacted shape. The blends were compressed manually using a rod. This was done to improve combustion by densifying the molecules of the mixture. After densification, the blends were left to sun-dry to remove moisture content and improve combustion (Figure 8).

Figure 7: Briquette samples inside pipes (molds)

Figure 8: Briquette Samples of SWDF

2.4 Proximate Analysis of Briquettes

Proximate analysis was carried out to measure the moisture content, volatile matter, fixed carbon, and ash content of the produced briquettes in terms of percentage by weight. Ascertaining these parameters helps to predict fuel quality, and energy content, where low moisture content and high volatile matter indicate high-quality fuel.

To determine the moisture content, one gram of the briquette samples was taken in an evaporating dish and placed in an air-dry oven for 1 hour at 105°C in the absence of air, until a constant mass was achieved. The samples were then cooled and re-weighed to estimate the moisture content. To ascertain the volatile matter content, one gram of briquette samples was taken in a covered crucible and the crucible was placed in an air-dry oven maintained at 900°C for 7 minutes. For determination of ash content, 1g of the pulverized sample was weighed in different crucibles and subjected to a temperature of 850°C in a muffle furnace for about 4 hours until a constant weight was attained. The fixed carbon (FC) percentage was obtained by subtracting the sum of mass percentages of moisture content (MC), volatile matter (V.M), and ash content from 100 (Equation 1).

$$\% FC = 100 - (MC + Ash + V.M) \quad (1)$$

2.5 Ultimate Analysis of Briquettes

Ultimate analysis was conducted using a LECO CHNS 932 to evaluate the chemical constituents of the briquette samples (Figure 9). This includes determining the fuel's carbon, hydrogen, nitrogen, oxygen, and sulphur weight percentages. The results of the ultimate analysis can be used to predict the fuel's heating value (also called calorific value), which is a measure of the fuel's energy content. One gram of briquette is placed into the autoloader of the analyser and is automatically dropped into the high-temperature combustion furnace, allowing the sample to combust. The combustion converts carbon to CO_2, hydrogen to H_2O, nitrogen to N_2, and sulfur to SO_2. The combustion gases are swept from the furnace, through scrubbing reagents, and onto the detection systems as they are being released. Independent infrared detectors are used for the simultaneous detection of carbon, hydrogen, and sulfur. Nitrogen is measured using a thermal conductivity detection system. Percentage of oxygen was obtained by subtracting the sum of the percentages of carbon, hydrogen, nitrogen, and sulphur from 100.

Figure 9: Briquette sample for analyses

2.6 Calorific Value

The calorific value, as measured by an oxygen bomb calorimeter, is determined by a substitution method that compares the heat obtained from the sample with the heat obtained from burning the same amount of benzoic acid of a known calorific value.

1.0g of briquette sample was inserted inside the bomb, which was with oxygen at a pressure of 30 atmospheres. The bomb was then placed inside a vessel containing a given quantity of water. The ignition circuit was connected, and the water temperature was noted. After ignition, the temperature rise was noted after every 30 seconds interval. After the analysis, the pressure was released, and the length of the unburned fuse wire was measured. The calorific values of the briquette samples were calculated using Equation 2

$$CV = \frac{M_W \times C_W \times (b-a)}{M_s} \quad (2)$$

2.7 Combustion Test

The combustion test was done by determining the combustion rate of each briquette sample. A traditional tripod stove was used to set the briquette samples on fire. 12g of each sample were placed on the stove and ignited using an ignition source. The time taken for the briquette to start burning (ignition time) and to completely stop burning was recorded using a stopwatch [18]. The final mass of the fuel briquettes samples after burning out was measured and recorded. Combustion rates of the briquette samples were calculated using Equation (3) and Equation (4).

$$\text{Combustion rate} = {mass\ (g)\ of\ burnt\ briquette} \Big/ {burning\ time\ (mins)} \quad (3)$$

mass of burnt briquette = mass before igniting – mass after burning out (4)

3. Results and Discussion

3.1 Characterization of Briquettes

3.1.1 Proximate Analysis

Obtained results from the proximate analysis are presented in Table 1. The results showed a high volatile matter content for all three briquette samples. Previous studies show that plastics demonstrate very high volatile matter content but very little ash and fixed carbon percentage [19]. The moisture content of the briquette samples ranges from 4.59% to 5.94%. Studies show that a moisture content of less than 20% is the required standard for the briquettes [20]. The proximate analysis results reveal that the produced briquettes in this study are within the feasible limits for combustion without auxiliary fuel, as their ash content is <10%, moisture content <20%, and volatile matter >50% [21].

Table 1: Proximate Analysis for Briquette Samples

PROPERTY	SAMPLE A	SAMPLE B	SAMPLE C
Ash Content (%)	3.8095	2.9702	5.4545
Moisture Content (%)	5.9406	4.5872	4.6296
Volatile Matter (%)	89.1479	91.3416	88.8149
Fixed Carbon (%)	1.102	1.101	1.101

3.1.2 Ultimate Analysis

The results of the ultimate analysis of the produced briquettes are shown in Table 2.

Table 2: Ultimate analysis results for Briquette samples

PROPERTY (%)	SAMPLE A	SAMPLE B	SAMPLE C
Carbon	29.804	29.557	29.902
Hydrogen	6.6475	5.1331	5.1805
Oxygen	52.7584	40.7389	41.1155
Nitrogen	1.2172	16.5637	12.8371
Sulphur	5.6342	5.0371	5.5104

The carbon content is approximately the same in all three samples, and they are all significantly low when compared to previous studies [20 - 22]. The carbon content falling within the ranges of 20.8% to 29.9% could be due to the nature of the wood waste selected for this study. The oxygen and nitrogen contents in this study are quite high which may lead to higher NOx emissions. This could be attributed to the impurities associated with the PET bottle wastes being collected as there was no pre-treatment done on either waste product [22].

3.1.3 Calorific Value

Table 3 shows the results of the calorific value for all three briquette samples. From the results, it can be observed that Sample C with the plastic-sawdust ratio of 40:60% had the highest calorific value of 13.954KJ/Kg and Sample B with the plastic-sawdust ratio of 60:40% had the lowest calorific value of 6.04KJ/Kg. Hence, the amount of sawdust in each sample probably contributed to the energy content of each briquette sample.

Table 3: Calorific value results for briquette samples

PROPERTY	SAMPLE A	SAMPLE B	SAMPLE C
Calorific Value (J/Kg)	13,172,016	6,042,608	13,954,512

3.2 Combustion Test

Table 4 shows the findings of the thermal test carried out on the briquette samples.

S/N	SAMPLE TYPE	COMPOSITION	INITIAL MASS OF SAMPLE	BURNING TIME	MASS AFTER BURNING	COMBUSTION RATE
1	Sample A	50% sawdust 50% plastic	12g	8mins 2secs	2.5g	1.183g/min
2	Sample B	60% plastic 40% sawdust	12g	5mins 47secs	3g	1.556g/min
3	Sample C	40% plastic 60% sawdust	12g	7mins 54secs	1.5g	1.329g/min

During the combustion process of sample C, no smoke was observed. However, white smoke was produced after the flames went out. The smell during combustion was dominated by the burning sawdust. The combustion of sample A produced a whitish smoke, which has a smell like burning wood. There were however small traces of burning plastic odour. The combustion of sample B produced predominantly black smoke, which has a pungent odour of burning plastic. The melting plastic could be seen forming a layer on the burning briquettes' surface.

4. Conclusion

In this study, briquettes were successfully produced from blends of plastic wastes and sawdust using cassava starch as binding material. Three different briquette samples consisting of various proportions of plastic-sawdust compositions were produced and characterised. The results obtained show that Sample C had the highest calorific value of 13.95MJ/Kg, Sample A had 13.17MJ/Kg while Sample B had 6.04MJ/Kg. These results indicate that the quantity of sawdust in each sample probably contributed greatly to the calorific value of each sample. With such reasonably high calorific value, it can be concluded that these briquettes, especially samples A and C, can serve as fuel for energy generation and by extension contribute to the sustainable management of plastic wastes and wood wastes, especially in Nigeria.

Conflict of Interest

The authors declare that there are no conflicts of interest with this work.

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