Processing and Characterisation of Charcoal Briquettes Made from Waste Rice Straw as A Renewable Energy Alternative

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Abstract. In Malaysia, waste paddy plant after rice harvesting were abundant and have no commercial value and significant usage. This paddy waste is commonly burnt on the landfilled which cause open firing and leads to environmental problem. This study determines the potential of rice straw waste for charcoal briquette production and study the effect of using different binders (corn and tapioca starch) in making the briquettes. Raw rice straws were combusted at 260°C for 4 hours in oven to form char powder. Corn starch and tapioca starch used as binder and each of them was mixed with char powder before compacted into briquettes. Each briquette was characterized in terms of their bulk density, moisture content, ash content, compressive strength and flammable characteristics. It was found that corn starch-charcoal briquette showed higher ash content, higher bulk density and compressive strength up to 68 MPa. Increased of both binders has increased the bulk density and compressive strength of briquettes. Both type of charcoal briquettes showed similar ignition time and burning characteristic, approximately at 18 minutes and 0.08 gm/min respectively.

1 Introduction

Rice straw is a paddy leaves waste left in the field after the grain has been harvested. The paddy leaves are good biomass candidates that can be converted as renewable energy sources. Paddy leaves are considered a lignocellulosic biomass that contains 38% cellulose, 25% hemicellulose and 12% lignin. The average annual rice straw waste generated ranges from 2.6 to 2.7 million tons, and most rice straws are either burnt away or abandoned in the field after the rice is harvested by the farmers and leads to greenhouse effect [1]. This waste can be converted into useful product such as charcoal which can be used for the production of heat energy. The waste which converted to energy source or fuel materials become more

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values and has good potential to be commercialized [2]. Agricultural wastes can be converted into low-cost green energy with different designs and approaches. There are various processes in order to converting them as energy source such as pyrolysis, gasification, anaerobic, digestion, fermentation and esterification. These processes able to convert agricultural waste into more valuable product; however, different process produces different output and type of energy [3].

Densification involving compaction process to remove voids which in turn results in increased handling efficiency, transport qualities, density and strength [4]. The densification processes can be classified into baling, pelletizing, extrusion, and briquetting. Briquetting are the most common and viable processes used for solid fuel densification. The process of briquetting usually includes of crushing, screening, mixing with binder, and pressing [5]. Briquettes commonly takes the form of condemned wood chip bricks, sawdust or charcoal and coal dust used for lighting and combustion. More specifically, the briquette consists of flammable material used as fuel for fire creation and maintenance. Binders have several functions such as enhancing properties, providing mechanical strength of the charcoal briquette and increasing bulk and energy densities [6]. A binder may be a liquid or solid forming a bridge, film, matrix or triggering a chemical reaction to create a strong bond between particles. Several studies have been made to study the effect of different types of binder additions in the production and final properties of charcoal briquettes. They used different type of binder used such as molasses, wheat starch, cassava starch, gum Arabic [7-11].

Up to this point, there were lack of scientific study that basically utilize rice straw (the whole component of paddy plant waste) for the production of charcoal briquettes with corn starch and tapioca starch as the low-cost binder. Due to this reason, this study aims to evaluate the potential of converting rice straw waste into charcoal briquettes. These paddy leaves were combusted into charcoal powders and their properties were evaluated. In this study, two different types of binders were used for the preparations of charcoal briquettes; which is tapioca starch and corn starch. The final charcoal briquettes properties were compared and presented in this paper.

2 Methodology

There are two main types of raw materials used to develop the charcoal briquettes. Rice straw used in this study (MR297) was obtained from local supplier in Kedah, Malaysia as main materials. Meanwhile, commonly available corn starch and tapioca starch powder were used as the organic binder agent by adding with tap water. For consistency, both binders were only used within 3 hours after being prepared (mixing with water). Rice straw in bundle form was carefully sorted manually to remove impurities such as wood, sand and any other unwanted contaminant. Next, the paddy leaves were cut into 10 cm long and post dried in an oven for 24 hours at 80°C in order to reduce the moisture content. Then, the paddy leaves were reduced in size to 5 mm by manual cutting.

2.1 Materials preparation

At first, rice straw underwent combustion process with a temperature of 260 °C for 4 hours in a natural convection oven. Then, combusted rice straws were grounded and sieved to 60 mesh to obtain charcoal powder. Figure 1 shows rice straw before and after combustion process. Both type of binder (which is corn and tapioca starch) were used at three different concentrations; 4%, 8% and 12% in the charcoal composition as shown in Table 1. The binder in form of paste were produced through mixtures of starch and water. The water content of
the mixture is based on the ratio of starch to 30g of charcoal briquette. The paste was prepared by using magnetic stirrer at constant temperature of 80 °C until it coagulates. Then charcoal powder were weighted with digital balance and manually mixed thoroughly with the prepared binder. During this process, every single char powder must be coated with the binder.

![Fig. 1. (a) Cuts of rice straw (b) Combusted rice straw (c) charcoal powder.](image)

**Table 1.** The composition and amount used in preparing charcoal briquettes.

| Materials | Weight percentage of charcoal briquettes composition (wt.%) | Weight of materials (grams) |
|-----------|----------------------------------------------------------|----------------------------|
| Charcoal  | 50                                                      | 15                         |
| Starch    | 4                                                       | 1.2                        |
| Water     | 46                                                     | 13.8                       |
| Total     | 100                                                    | 30                         |

### 2.2 Briquettes preparation

The mixture of each composition was formed into briquettes by using hydraulic hand-press compacting machine. About 2 grams of each composition was filled into a cylindrical steel mould with dimension of 13 mm width and 13 mm height. Each specimen was compacted under 2 tonnes loading pressure for 5 min. The wet charcoal briquettes formed contains high moisture and water content. Because of this, these briquettes were dried in natural convection oven at 80 °C for 24 h and packed in well closed plastic container. Figure 2 shows example images of prepared charcoal briquettes with their labels. Physically, corn starch charcoal briquettes showed higher body compactness, stability and strength during handling.

![Fig. 2. Charcoal briquettes (a) from left; C4(Corn starch 4%), C8(Corn starch 8%) and C12(Corn starch 12%) (b) T4(Tapioca starch 4%), T8(Tapioca starch 8%) and T12(Tapioca starch 12%)](image)
2.3 Briquettes characterization

The characterization carried out in this study, including physical properties, mechanical properties, proximate analysis and combustion properties. Characterization of charcoal briquettes were carried out in the laboratory.

2.3.1 Moisture Content

The moisture content on the briquette will affect the process of combustion where the heat produced is used for evaporation. Moisture content is the proportion of water mass in a briquette sample, expressed in percentage and is calculated using Equation (1). The average value of moisture content, $MC$ was determined from each sample of briquettes.

\[
MC = \frac{(X_1 - X_2)}{X_2} \times 100\%
\]  

(1)

where; $X_1$ is weight of initial sample (g) and $X_2$ is weight of the sample after drying (g).

2.3.2 Ash Content

Ash content is the mass of incombustible material left after a given sample of charcoal briquette has been burnt. Percentage of ash content (PAC) was determined by heating 2 gm of charcoal sample in the furnace at temperature 550°C for 4 hours and weighed after cooling to obtain the weight of ash. The PAC was determined using Equation (2) and the average value were recorded.

\[
PAC = \frac{C}{A} \times 100\%
\]  

(2)

where; $C$ is weight of ash (g) and $A$ is weight of the oven-dried sample (g).

2.3.3 Bulk Density

Bulk density was done by weighing the charcoal briquette, then measuring the briquette height and diameter, then multiplying the results. Using Equation (3) the average value of bulk density, $p$ was determined from each sample of briquettes.

\[
p = \frac{m}{V}
\]  

(3)

where; $m$ is weight of charcoal briquette (g) and $V$ is volume of charcoal briquette (cm$^3$).

2.3.4 Compressive Strength

Compressive strength is the maximum crushing load that a briquette can withstand before it starts to break. This test conducted using Universal Testing Machine (INSTRON 3382) with a load capacity of 50 kN at constant speed of 0.305mm/min. The briquette was placed between the plates of the machine and was subjected to uniform loading until failure. The average value of compression modulus was determined from each sample of briquettes.

2.3.5 Ignition time and Burning Rate

Ignition time is the time taken for a known mass of sample to ignite. Meanwhile, burning rate is defined as the rate at which specific mass of sample is burnt in air. A briquette sample was placed on a wire mesh grid in between two fire-retardant bricks to allow free flow of air.
A Bunsen burner was placed directly underneath the platform and adjusted to a blue flame. The Bunsen burner was lighted until the briquette ignited. The burner was left in until the briquette was well ignited and entered into its steady state burn phase before the burner was closed and time was start recorded. Time taken stopped when the sample has stopped burning. The weight loss at a specific time, \( B_s \) was measured by using equation (4):

\[
B_s = \frac{W}{T}
\]

where; \( W \) = initial weight of sample (g) and \( T \) = Ignition time (min).

3 Result and Discussion

Figure 3 shows the analysis result of ash content and moisture content for both type of charcoal briquette specimens. It was found that, ash content is higher in corn starch briquettes compared to tapioca starch briquettes and also higher binder content affect in lower ash content. According to Sunardi et al. (2019) materials with higher density produces charcoal with highly-bonded carbon values and thus produced low ash content [12]. They also stated that lower ash content is valuable, while excess ash causes trouble during burning. This is because the ash is capable of blocking air from penetrating into the atmosphere, thereby retarding the burning rate of such briquette, unless it is often shaken to clear the ash during its use. Thus, by increased the amount of binder lower the amount of ash for charcoal briquettes. For moisture content, tapioca starch briquettes showed higher moisture level compared to similar binder percentage of corn starch briquettes. At the same time, higher binder content reduced moisture levels of briquettes. According to Chin & Siddiqui (2000) acceptable tolerance of moisture content for charcoal briquette is between 8% to 12%, and it shall depend on the nature of the agricultural waste [13].

![Graph showing ash content and moisture content](image)

Fig. 3. Ash content and moisture content measured for paddy leaves charcoal samples which is shown by bar graph and line graph respectively (TS = Tapioca: CS = Corn Starch).
Thus, it was found that corn starch briquettes and tapioca starch briquettes in this study were a slightly higher to that range. Besides that, Missagia et al. (2011) reported that a moisture content that is less than 5% will reduce the stability of briquettes, in fact make the briquettes too dry, hence making it burn out quickly [14]. According to Antwi-Boasiako & Acheampong (2016) high moisture content could have a positive effect on the compression strength of briquettes [15]. However, higher moisture content also will affect the briquettes combustion properties such as low heat output, low combustion temperature, and long fuel stay in the combustion chamber.

Figure 4 shows the bulk density and compressive strength of the prepared charcoal briquettes. In brief, higher binders increased both bulk density and compressive strength of these briquettes. Corn starch briquettes showed higher value of bulk density compared to similar binder percentage of tapioca starch briquettes. The highest bulk density attained for corn starch briquettes is 0.9168 g/cm$^3$ while 0.8855 g/cm$^3$ for tapioca starch briquettes. This is in par with the compressive strength trend of the briquettes. Bulk density directly reflects the compressive strength of these charcoal briquettes. From this result, the highest corn starch content increased the briquette strength to 68.01 MPa while 51.42 for tapioca starch. This indicate that, in order to prepare charcoal briquettes with higher density and strength, corn starch is preferable compared to tapioca starch. The higher compressive strength and bulk density of corn starch briquettes were mostly due to lower moisture content characteristic compared to tapioca starch briquettes. According to Okot et al. (2018) the lower bulk density of briquette may be due to decrease in briquette weight or an increase in briquette volume after drying and stabilising process [16]. Borowski & Hycnar (2013) has suggested that minimum value of compressive strength for charcoal briquette is 1.0 MPa. Compressive strength is one of the most important characteristics of a briquette that determines the stability and durability of the briquette [17]. Furthermore, compressive strength increases the lifespan of briquettes by reducing the absorbing ability of moisture [18].

![Figure 4. The compressive strength and bulk density of tapioca starch and corn starch charcoal briquettes.](image)
Figure 5 shows the analysis results of ignition time and burning rate for both type of charcoal briquettes. In general, burning rate of briquettes has decreased with increased in binder proportion. Davies & Davies, 2013 also obtained the same findings in the burning of sawdust briquettes with palm oil sludge as binder [19]. Furthermore, both types of briquettes showed an equal combustion characteristic, with the tapioca starch briquettes however, has slightly higher burning rate. The ignition time and burning rate of these charcoal briquettes were just slightly affected when using different type of binders. Interestingly, the ignition time for C12 briquette can last to 18.19 minutes. To be precise, the longer time it takes, the better charcoal briquettes characteristic. The difference in binder composition gives a different supply of oxygen which affects the combustion. Among factors that influence the burning of solid fuels includes particle size, velocity of air flow, type of fuel, and combustion air temperature [20]. So, it is important to understand the factors that affect burning rate and ignition time of charcoal briquettes for their more efficient utilization as fuel. The density of a briquette influences the burning rate and is characterized by low porosity and reduce the infiltration of oxidant and outflow of the combustion products during combustion [21]. According to Oladeji, 2010, density influences the flame propagation in briquettes as fewer free space for mass diffusion which is low in porosity will hinder drying, devolatization and burning [22]. Higher percentage of volatile matter of charcoal increased the combustion rate. Thus, reduces in moisture content caused these briquettes increasing their burning characteristics [23]. Both rice straw charcoal briquettes made with corn starch and tapioca starch binder in this study was found good enough in combustion characteristic and found adequate to the tolerant level.

4 Conclusion

The processing and characterization of charcoal briquettes made from paddy leaves waste as a renewable energy alternative has been successfully conducted. Different type of binder used along with different charcoal to binder ratios contributes to difference characteristics of paddy leaves charcoal briquettes. Meanwhile, bulk density and compressive strength were
much more affected by the addition of different binder, where these values were higher for corn starch charcoal briquettes. Thus, the amount of binder to charcoal briquettes needs to be optimized in order to obtain optimal charcoal briquettes properties. Therefore, rice straw waste is an excellent candidate for alternative source of renewable energy by converting into a simple and low-cost charcoal briquette. This approach is not only reducing environmental problem, but also potentially contribute to socio-economic benefits to local communities.

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