The proximate analysis and mechanical properties of rice husk charcoal briquette

S. Mohamad Jani¹

¹Agrobiodiversity and Environment Research Centre, MARDI Headquarters, Persiaran MARDI-UPM, 43400 Serdang, Selangor Malaysia

Abstract

The research was carried out to study the briquetting of rice husk (RH) charcoal combined with tapioca flour. Tapioca flour was chosen because it is cheap, bonds well and easily available. RH charcoal was prepared by carbonisation process using a furnace at a temperature ranging from 400 – 500 °C. Charcoal contents at 40, 50, 60, 70% (w/w) and starch paste of 5, 7 and 9% (w/w) were mixed prior to undergoing cold pressing process. The RH charcoal briquette was analysed for its proximate properties i.e. moisture content, volatile matter, ash content, fixed carbon, density, and calorific value. Its mechanical property, the compression strength was also evaluated and its mean value was 4650.38 KPa. Charcoal content of 50% and starch of 7% produced briquette with the highest compression strength. The best compression strength will reduce defect of briquette during transportation or handling process.

Keywords: proximate, mechanical, rice husk, charcoal briquette

Introduction

Rice is a grass and belongs to the genus Oryza (meaning oriental). Rice (Oryza sativa) is grown in a wide range of environments from the equatorial tropics to sub-tropical mid-latitudes, from lowland paddy fields to high altitude terraces, and from swamps to upland rice fields. By-products of rice industry are straw and husk. Rice straw is removed from the field, burned, incorporated into the soil, or used as mulch for the following crop (Lim et al. 2012).

Rice husk (RH) as an agricultural waste biomass could be used as an alternative source of lignocellulosic to substitute forest for reducing greenhouse gas emission as well as to avoid local pollution problems from open burning. Malaysia produces more than 2.0 million tonnes of rice. The RH production is about 45 – 50% of the total of rice cultivation (MADA 2010). RH as lignocellulosic materials can be used by many industries and converted into many products such as charcoal and charcoal briquette (Kong 1995). These agricultural wastes have been actively promoted to be used in various heating systems since the past decades. When compared to fossil fuel, agricultural wastes have higher moisture content and lower density, thus making them technically unsuitable for direct use due to combustion and handling problems. Converting of biomass wastes to briquettes is a solution for such problems. It improves biomass handling characteristics, increases the volumetric calorific values, and reduces transportation, collection, and storage costs (Grover and Mishra 1996).
Briquetting is a technology that uses either a dry or a wet process to compress rice husks charcoal into different shapes. The dry briquetting process requires high pressure and does not need a binder. This process is expensive and recommended only for high production levels. On the other hand, wet process allows the use of low-pressure equipment, but a binder must be used. In this process the wetted binder will wet the charcoal and made pressing easy in the pressing machine. In addition, the selected binders are available in the market, not expensive and provide a good bond (Estela 2002). In this study tapioca is used as a binder for wet production of RH charcoal briquette. Briquetting of biomass can be considered for its economics, reliability and ease of operation. Hence, briquetting of rice husk for solid fuel is used for domestic heating in cooking stove, fireplace and furnace. They also have the advantage of cleanliness, ease of handling and igniting, produce a small amount of smoke and its ash content is rich in potash and phosphate (Yahaya et al. 2012). Charcoal briquettes are mostly used for cooking, heating, barbecuing and camping in countries such as USA, EU, Australia, Japan, Korea and Taiwan. In the developing countries, charcoal briquettes are mainly for household usage. For commercial purpose, it can be used as fuel for producing steam, heating district and generating electricity (Nasrin et al. 2008). In Malaysia, the briquette industry started with wood wastes, mainly in the form of sawdust (Kong 1995). Most of the local sawdust briquettes or charcoal briquettes are for overseas markets (Kong 1995). The products can be used to replace cheap fuels such as wood and kerosene which are widely used in the rural areas and restaurants (Kong 1995). This industry has grown impressively for the past few years and has indicated that there is good return for investment (Kong 1995). Several biomasses are being studied for the production of briquettes. Kaliyan and Morey (2010) studied the densification characteristics of corn cob. Oladeji (2010) evaluated the fuel characterisation of briquettes produced from corn cob and rice husk residues. The preparation and characterisation of solid biomass fuel made from rice straw and rice bran were studied by Chou et al. (2009). Yumak et al. (2010) reported briquettes from soda weed (Salsola tragus) were used as a rural fuel source. The production of bio-briquettes from carbonised brown seaweed was evaluated by Acma et al. (2013) and the effects of briquetting pressure on banana-peel briquettes and on banana waste in northern Thailand by Wilaipon (2009). Among the advantages of using briquettes are reduction of deforestation, due to the substitution of the wood generally used; production of cheaper energy; reduction of the environmental impact caused by the large amount of wastes and its destination; and reuse of leftover materials (Noeli et al. 2013).

Proximate analysis is a standardised procedure that gives an idea of the bulk components in the fuel (Chaney 2010). It was done to determine the percentage content of volatile matter, ash, moisture and fixed carbon of RH briquettes (Akowuah et al. 2012). Proximate analysis also showed the thermal properties of briquette (Sengar et al. 2012). Compression strength determined the robustness of briquette during handling and transportation. The best mixture ratio between charcoal material and starch binder give the best compression strength of the briquette.
Therefore, this study aimed to analyse the proximate properties of RH charcoal briquette i.e. moisture content, density, volatile matter, ash content, fixed carbon, and calorific value. The effect of the charcoal content and tapioca flour loading on the compressive strength of the RH charcoal briquette were also been investigated.

Materials and methods

Rice husk and starch
Rice husk was obtained from Malaysian Agriculture Research and Development Institute (MARDI) Seberang Perai, Penang. Moisture contents were 10 – 12%. Starch used was made from tapioca starch which was purchased from a local grocery store.

Carbonisation
A furnace used to carbonise the RH was heated to a temperature ranging between 400 and 500 °C. The diameter of the furnace is 40 cm. It took about 4 h to complete the carbonisation process and to produce RH charcoal.

Briquetting process
The size of charcoal powder used was 20 mesh – 40 mesh (0.84 mm – 0.42 mm). Table 1 shows the composition of charcoal, starch and water that is used for briquette processing. Starch paste was prepared by heating the starch flour and water at about 80 °C. The RH charcoal powder was then mixed properly with the starch paste in the mixer (model HT/HT 20). An amount of 50 g of the mixed charcoal were put into a mould (32 mm width and 26 mm heights). It is then pressed at a pressure range of 50 – 90 bar using the cold press machine model IMEC 1000C to produce RH charcoal briquette. These wet charcoal briquettes were dried in an oven at a temperature of 90 °C.

Table 1. Composition of charcoal content, starch and water in the RH charcoal briquette (Weight in %, g)

<table>
<thead>
<tr>
<th>Charcoal</th>
<th>Starch</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>5</td>
<td>55</td>
</tr>
<tr>
<td>40</td>
<td>7</td>
<td>53</td>
</tr>
<tr>
<td>40</td>
<td>9</td>
<td>51</td>
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<tr>
<td>50</td>
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<td>45</td>
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<tr>
<td>50</td>
<td>7</td>
<td>43</td>
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<tr>
<td>50</td>
<td>9</td>
<td>41</td>
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<tr>
<td>60</td>
<td>5</td>
<td>35</td>
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<tr>
<td>60</td>
<td>7</td>
<td>33</td>
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<tr>
<td>60</td>
<td>9</td>
<td>31</td>
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<tr>
<td>70</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>70</td>
<td>7</td>
<td>23</td>
</tr>
<tr>
<td>70</td>
<td>9</td>
<td>21</td>
</tr>
</tbody>
</table>

Proximate analysis
Proximate analysis that were carried out were MC, VM, AC, and FC following BS EN 1016-104 (BS 1998). Meanwhile the density and calorific value of RH charcoal briquette were analysed according to ASTM D2854 (ASTM 2009) and ASTM D2015 (ASTM 2000) respectively. The summarised methodology of proximate analyses was reported below.

Determination of moisture content
The moisture content (MC) of rice husk was determined by calculating the loss in weight of material using oven drying method at 105 °C to 110 °C for 1 h until it reached a constant weight loss (BS 1998).

\[
\text{Moisture content (\%) } = \frac{w_2 - w_3}{w_2 - w_1} \times 100\%
\]

Where,
\( w_1 \) = weight of crucible (g)
\( w_2 \) = weight of crucible + sample (g)
\( w_3 \) = weight of crucible + sample after heating (g)
Briquetting of rice husk charcoal

Determination of density
The density of RH charcoal briquette was determined using the Densitometer model AND by following the ASTM standard.

Determination of volatile matter
The dried sample left in the crucible was covered with a lid and placed in an electric furnace (muffle furnace) and maintained at the temperature of 900 ± 15 °C for 7 min. The crucible was then first cooled in air, then inside a desiccator and weighed again. Loss in weight was reported as volatile matter on the percentage basis (BS 1998).

\[
\text{Volatile matter (\%) = } \frac{w_5 - w_6}{w_5 - w_4} \times 100
\]

where,
- \( w_4 \) = weight of the empty crucible (g)
- \( w_5 \) = weight of empty crucible + sample (g)
- \( w_6 \) = weight of the crucible + sample after heating (g)

Determination of ash content
The residual sample in the crucible was heated without lid in a muffle furnace at the temperature of 815 ± 15 °C for 3 h. The crucible was then taken out, cooled first in air, then in desiccators and weighed. The residue was reported as ash on percentage basis (BS 1998).

\[
\text{Ash content (\%) = } \frac{w_9 - w_7}{w_8 - w_7} \times 100
\]

where,
- \( w_7 \) = weight of the empty crucible (g)
- \( w_8 \) = weight of empty crucible + sample (g)
- \( w_9 \) = weight of the crucible + ash (g)

Fixed carbon determination
The fixed carbon (FC) percentage was calculated using the following relationship. Percentage of fixed carbon = 100 – % of (moisture content + volatile matter + ash content) (BS 1998).

Calorific value
The calorific value (CV) of briquetted fuel was determined by using bomb calorimeter model A500. The calorific value of briquetted fuel was determined by using following formula (ASTM 2000).

\[
\text{Calorific value (MJ/kg) = } \frac{(W + w) \times (T_1 - T_2)}{X}
\]

where,
- \( W \) = weight of water in calorimeter (kg)
- \( w \) = water equivalent of apparatus
- \( T_1 \) = initial temperature of water (°C)
- \( T_2 \) = final temperature of water (°C)
- \( X \) = weight of fuel sample taken (kg)

Compression strength
The compression strength test was carried out using Instron Universal Testing Machine model 5567. A load with 1 kN capacity was pressed at 5 mm/0.1 min constant rate on the RH charcoal briquette until it cracked. A total of four samples of RH charcoal briquette from each formulation were tested and the data of compression strength were compiled for evaluation.

Experimental design and statistical analysis
A completely randomised design (CRD) in factorial arrangements was used for the experiments. All the data were analysed using Statistical Analysis Software (SAS 9.3). This is to study the effect of RH charcoal content and starch flour loading on compressive strength of the RH charcoal briquettes. The differences among the means were analysed according to Duncan Multiple Range Test at \( p < 0.05 \) level.

Results and discussion
Proximate analysis
The MC of charcoal briquette is the quantity of water in the briquette, expressed as percentage of the material's weight (Raju et al. 2014). MC is a very important property
which can greatly affect the burning characteristics of biomass (Yang et al. 2005).

Table 2 shows a mean value MC of RH charcoal briquette which is 6.79% at a density of 782 kg/m³. The value obtained was within the maximum limits of 15% MC recommended by Wilaipon (2008) and Grover and Mishra (1996). Kong (1995), Jamradoedluk and Wiriyauampaiwong (2007) reported in their study that they produced RH charcoal briquette with MC below 12%. Moisture content has an effect on the strength of briquette (Husain et al. 2001). According to Aina et al. 2009, MC is one of the main parameters that determine briquette quality and MC of charcoal briquette at 5% performed durable briquette. Moisture content of 5.7% of charcoal briquette is acceptable for storability and combustibility (Akowuah et al. 2012).

VM represents the components of carbon, hydrogen and oxygen presents in the biomass that when heated turn into vapour, and usually mixture of short and long hydrocarbons (Chaney 2010). Mean value of VM of RH charcoal briquette was determined at 20.11% (Table 2). The VM value of RH charcoal briquette was lower compared to saw dust briquette which is 71% (Akowuah et al. 2012) and coal at 38.3% (Chaiklangmuang et al. 2008). VM parameters might be influence the calorific value of the solid fuel (Kathiravale et al. 2003). VM refers to the part of the charcoal that is released when the charcoal is heated at 400 – 500 °C (Raju et al. 2014). During this heating process, it decomposes into volatile gases and char.

AC is a level of sand, mineral, lignite or non-barbeque substances. Ash has a significant influence on the heat transfer to the surface of a fuel as well as the diffusion of oxygen to the fuel surface during char combustion. As ash is an impurity that will not burn, fuels with low ash content are better suited for thermal utilisation than fuels with high ash content. Mean value AC of RH charcoal briquette was found to be 22.98% in Table 2. Yahaya et al. (2012) reported the ash content of RH charcoal briquette was 20 – 22.4%. Meanwhile the ash content of saw dust charcoal briquette reported by Akowuah et al. (2012) was 2.6% and for coal as reported by Chaiklangmuang et al. (2008) was 21.9%. Higher ash content in a fuel usually leads to higher dust emissions and affect the combustion volume and efficiency.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content (%)</td>
<td>6.79</td>
</tr>
<tr>
<td>Volatile matter (%)</td>
<td>20.11</td>
</tr>
<tr>
<td>Fixed carbon (%)</td>
<td>50.13</td>
</tr>
<tr>
<td>Ash content (%)</td>
<td>22.98</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>782.00</td>
</tr>
<tr>
<td>Calorific value (MJ/kg)</td>
<td>21.78</td>
</tr>
</tbody>
</table>

The fixed carbon (FC) of the RH charcoal briquette which is the percentage of carbon available for char combustion after volatile matter (VM) is distilled off was determined to be 50.13% (Table 2). FC of RH charcoal briquette obtained in this study has higher value than other based briquette such as saw dust charcoal briquette at 20.7% (Akowuah et al. 2012) and coal at 27.6% (Chaiklangmuang et al. 2008). Fixed carbon gives an indication of the proportion of char that remains after the devolatilisation phase. The high amount of FC content produced better charcoal because the corresponding calorific energy is usually high (Raju et al. 2014). The low FC making it tends to prolong cooking time by its low heat release. It also reduced the calorific energy of the briquettes by causing fuel-saving effect (Onchieku et al. 2012). The calorific value (CV) is an energy value that can produce enough heat required. It is the property of biomass fuel that depends on its chemical composition and moisture content. The CV or heat value was the most important fuel property (Aina et al. 2009). The CV’s mean
value of the RH charcoal briquettes found to be 21.78 MJ/kg. It was better as compared to the results of the calorific value of saw dust briquette of 17.06 MJ/kg and coal at 16.02 MJ/kg which were reported by Chaiklangmuang et al. (2008) and most biomass briquettes including almond shell briquette at 19 MJ/kg (Grover et al. 1994), corn cob briquette of 20 MJ/kg (Oladeji 2010), cowpea with 14 MJ/kg and soybeans at 13 MJ/kg (Enweremadu et al. 2004). The calorific value at 20.18 MJ/kg can produce enough heat required for household cooking and small-scale industrial cottage applications (Akowuah et al. 2012).

**Compression strength**

Compressive strength results of the RH charcoal briquette are demonstrated in Table 3. The good compression strength of briquette will avoid any unwanted broken during handling or transportation processes. The compression strength is a criterion of briquette durability (Richard 1990). Results showed that briquette compressive strength increased significantly from briquette with 40% charcoal content (2363.30 KPa) to 50% charcoal content (6891.20 KPa) but the strength was decreased gradually at 60% (5673.70 KPa) and 70% (3673.40 KPa) charcoal contents. Charcoal content at 50% displayed the highest compression strength of the briquettes. The increasing of compressive strength as RH charcoal content increase may due to the presence of silicate in RH charcoal. It is generally accepted that silica is a chemical component of RH and it can be converted into silicate, a high strength compound, through the oxidation reaction. Silicate is a material with high strength and causes high compressive of the briquette (Jamradoedluk and Wiriyampaiwong 2007). In the case of the starch loading from 5% to 7%, it contributed significantly to improve briquette compressive strength from 3874.10 KPa to 5175.10 Kpa, respectively. The compressive strength observed decreased significantly of 9% (4902.00 KPa) starch loading. A starch loading at 7% was determined the best percentage to produce highest compressive strength of the briquette. Kong (1995) had used 5% starch in his manufacturing of wood charcoal briquette. Oladeji (2010) had also been used 5% starch in development of charcoal briquette using corn cob and rice husk.

Table 3. Effect of charcoal content and starch loading on compression strength of RH charcoal briquette

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Compression strength (KPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charcoal Content (CC) (%)</td>
<td>** 2363.30d</td>
</tr>
<tr>
<td>40</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>6891.20a</td>
</tr>
<tr>
<td>60</td>
<td>5673.70b</td>
</tr>
<tr>
<td>70</td>
<td>3673.40c</td>
</tr>
<tr>
<td>Starch binder (SB) (%)</td>
<td>* 3874.10b</td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>5175.10a</td>
</tr>
<tr>
<td>9</td>
<td>4902.00a</td>
</tr>
<tr>
<td>CC × SB</td>
<td>*</td>
</tr>
<tr>
<td>CV</td>
<td>17.17</td>
</tr>
<tr>
<td>Mean</td>
<td>4650.38</td>
</tr>
</tbody>
</table>

Means with the same letter within the same column are not significantly different at 5% level of significance.

**Conclusion**

The proximate analysis of RH charcoal briquette produced has been determined. The proximate analysis of the briquette assessed in this study showed that briquette manufactured from RH had MC of 6.79%, VM of 20.11%, CV of 21.78 MJ/kg, AC of 22.98% and FC of 50.13%. Value of CV of RH charcoal briquette had enough heat for household cooking and small scale industrial applications. The content of charcoal and starch loadings significantly influenced the compression strength of the RH charcoal briquette. The charcoal briquette manufactured with the charcoal contents of 50% and 7% starch was the best composition.
to obtain the best compressive strength and good for handling during transportation process.

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Abstrak
Kajian ini adalah untuk mengkaji proses pembriketing arang sekam padi bersama kanji. Sekam padi telah menjalani proses karbonisasi di dalam kebuk bakar pada julat suhu 400 – 500 °C selama 4 jam. Di dalam kajian ini kandungan arang yang digunakan adalah 40%, 50%, 60% dan 70% (w/w), manakala kandungan kanji ialah 5%, 7% dan 9% (w/w) dan dicampurkan bersama sebelum pembuatan arang briket dilakukan. Arang briket dihasilkan melalui proses penekanan sejuk. Arang briket sekam padi dilakukan analisis proksimat seperti; kandungan lembapan (MC), bahan meruap (VM), kandungan abu (AC), karbon tetap (FC), ketumpatan (D) dan nilai kalorifik (CV). Kekuatan mampatan ke atas arang briket turut dijalankan. Nilai purata keputusan analisis proksimat arang briket sekam meliputi MC, VM, AC, FC, D dan CV masing-masing ialah 6.79%, 2011%, 22.98%, 50.13%, 782 kg/m³ dan 21.78 MJ/kg. Nilai purata ujian mampatan arang briket sekam ialah 4650.38 KPa. Hasil ujian mampatan memperlihatkan adanya pengaruh kandungan arang dan kandungan kanji ke atas arang briket. Kandungan arang pada 50% dan kandungan kanji pada 7% menghasilkan kekuatan mampatan paling tinggi. Briket dengan kekuatan mampatan yang baik akan mengurangkan kesan rosak semasa proses transportasi dan pembungkusan.