# The Characterization of Rice Straw Briquette as an Alternative Fuel in Indonesia

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Abstract: Rice straw is largely generated and can be used to produce energy and reduce greenhouse gas emissions. In Indonesia, rice straw is mostly only used as animal feed and fertiliser; however it is highly promoted to be made into briquettes or pellets. The goal of this study is to discover the optimum condition for producing rice straw briquettes. The influence of the briquette formulation (temperature, pressure and particle size) was studied. The briquettes were prepared by utilising a hydraulic-press briquette machine and analysed by performing density and compression tests. The results show the characteristics of the briquettes as increasing in pressure and finer particle size as the temperature increases.

## 1 INTRODUCTION

Indonesia is one of the fastest growing and developing countries in Asia with an average economic growth of 5.05% year and a population of more than 262 million in 2017 (Anonymous, 2018; BPS Indonesia, 2013). As a consequence, it is struggling with energy sustainability for its citizens and battling environment issues at the same time, such as climate change and greenhouse gas emissions (Balat, 2005; Demirbas et al., 2009; Evans et al., 2010; Omer, 2009). In recent years, the conversion of biomass to produce fuel and chemicals is seen as one of the most promising technologies to reduce dependence on fossil fuels for energy production. It is estimated that Indonesia produces 146.7 million tons of biomass annually, which is equal to 470 GJ (Dani and Wibawa, 2018; Prastowo, 2011). There are many kinds of biomass that do not compete with food supplies and originates from agriculture, forestry and agroindustry residues. These residues can be transformed into renewable energy sources.

Biomass residue that is abundant in Indonesia are rice straw and rice husks. Prastowo estimated the potential technical energy of rice straw and rice husk is 143.3 GJ per year (Prastowo, 2011). Rice straw and rice husks are highly promoted as electrical energy in the form of briquettes or pellets through densification technology. The advantages of densification include the reduction of handling, transportation and storage (Clarke et al., 2011; Jamradloedluk and Wiriyaumpaiwong, 2007; Tumuluru et al., 2011; Ulker et al., 2012). A number of studies have been carried out on the densification of rice straw. Several authors have studied the characteristics of the rice straw briquette using binders (Chou et al., 2009; Ndiema et al., 2002; Rahaman and Salam, 2017; Wang et al., 2018). It was stated that operating conditions such as temperature, pressure, size of material, characteristics of binders and the type of densification machine have an influence on rice straw briquette quality (Chou et al., 2009; Nguyen et al., 2015; Rahaman and Salam, 2017; Tumuluru et al., 2011). Therefore, the quality of rice straw briquette has been evaluated with an international standard for briquettes such as EN ISO 17225-7.

## 2 MATERIALS AND METHOD

Rice straw was collected in June 2018 from East Java. It was dried in natural air for 24 hours. The rice straw was ground in a hammer mill using different apertures. The properties of the materials



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along with its corresponding international standard are provided on Table 1.

Table 1: Standard used to determine properties of the rice straw before briquetting

| Properties | Standard |
|---|---|
| Moisture content (%) | EN 14774:2009 (European Committee for Standardization-CEN, 2009) |
| Bulk density (kg.m$^{-3}$) | EN 15103:2009 (European Committee for Standardization, 2009) |
| Proximate analysis (%) | ASTM 1762-84 (American Society for Testing and Materials, 2007) |

The production of briquettes was made using variable operating conditions with a box behnken for 3 factors and 3 levels (Table 2).

Table 2: Standard use to determine the properties of rice straw before briquetting

| Properties | -1 | 0 | +1 |
|---|---|---|---|
| Temperature (°C) | 25 | 100 | 175 |
| Pressure (MPa) | 10 | 25 | 40 |
| Particle size (mm) | 1 | 3 | 5 |

The briquettes were produced in a manual hydraulic press briquetting machine (Figure 1). Each briquette was 50 mm in length and width and had variable height, with a mass of 20 grams of raw material.

Figure 1: Hot densification system hydraulic press.

The bulk density of the rice straw briquettes was measured by geometric measurement and weighing. This can be calculated by using the ratio between the mass briquette and the volume briquette. Furthermore, the compressive test of briquette or mechanical resistance is the maximum crushing load a briquette can withstand before cracking or breaking, (Kaliyan and Vance Morey, 2009). The procedure of the test consists of placing a single briquette between two flat, parallel plates which have flat areas greater than the projected area of the briquette. An increasing load is applied at a constant rate until the test specimen fails by cracking or breaking (Figure 2). The displacement of the briquette compressive test is 10 mm per minute (Figure 3).

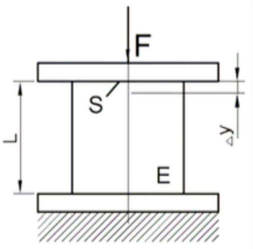


Figure 2: Testing of the rice straw briquette in axial pressure conditions.

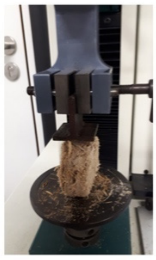

Figure 3: Position of the rice straw briquette in the compressive test.

# 3 RESULTS AND DISCUSSION

## 3.1 Characteristics of rice straw

The characteristics of the rice straw sample are provided in Table 3. Rice straw has a 26.63% moisture content which is above the suitable range for briquette preparation. The desired parameter for briquettes is between 8% and 12% (Kaliyan and Vance Morey, 2009; Rahaman and Salam, 2017). The moisture content also has an effect on energy consumption during the chopping stage (Mani et al., 2006). Due to this reason, the rice straw requires drying before the chopping and compressing process. The moisture content of rice straw depends on the condition and equipment used for storage and wiping. Other studies reported that moisture content of the rice straw is influenced by the variety, climate and cultivation conditions (Zhang et al., 2012).

Rice straw has a low bulk density; densification may improve it through size reduction as it increases the contact surface area between particles. The average bulk density of rice straw is 166.29 kg.m$^{-3}$ for long grain rice straw and 162.03 kg.m$^{-3}$ for short grain rice straw (Zhang et al., 2012). Kadam et al. reported the bulk density of rice straw after harvesting was over 227 kg.m$^{-3}$ and increased by 20% after densification (Kadam et al., 2000). The rice straw occupies more space and has a lower calorific value than the briquette. The calorific value of rice straw is 15.60 MJ.kg$^{-1}$, depending on the ash content. Rice straw contains the least amount of ash and fixed carbon. Its calorific value shows that rice straw has potential for bio-energy. Paula et al. studied the calorific value, volatiles content, fixed carbon content, and ash content of rice straw, which was respectively 15.09 MJ.kg$^{-1}$, 65.47%, 15.86% and 18.67% (Paula et al., 2011). Kargbo et al. explained that the bulk density and calorific value of rice straw are low and is not significant to the performance of the energy combustion and emissions from chlorinated organic compounds and NOx (Kargbo et al., 2010).

Table 3: Properties of rice straw

| Properties | Rice straw | Literature (Brand et al., 2017) |
|---|---|---|
| Moisture content (%) | 26.63 | 23.03 |
| Bulk density (kg.m$^{-3}$) | 112.87 | 106.89 |
| Volatile content (%) | 75.76 | 79.71 |
| Fixed carbon content (%) | 11.01 | 11.23 |
| Ash content (%) | 13.32 | 9.07 |
| Calorific value (MJ.kg$^{-1}$) | 15.60 | 17.65 |

## 3.2 Characteristics of rice straw briquettes

The characteristics of the rice straw briquettes are provided in Table 4. The densities of briquettes are provided in Figure 3. The highest densities were observed in the briquettes with the highest proportion in temperature, pressure and particle size at respectively 100°C, 40 MPa and 3 mm. The stabile densities of the rice straw briquette increased proportionally as temperature and pressure increased. Mani explained that the bulk density of pellet or briquette depend on the material properties such as moisture, particle size, temperature, and pressure. The higher moisture content along with large particle size reduces the bulk density (Mani et al., 2006, 2003; Tumuluru, 2014).

Table 4: Properties of rice straw

| Exp | T (°C) | P (MPa) | Particle size (mm) | Density (kg.m$^{-3}$) | Comp. Test (MPa) |
|---|---|---|---|---|---|
| 1 | 100 | 10 | 1 | 791 | 0.750 |
| 2 | 100 | 10 | 5 | 756 | 0.897 |
| 3 | 100 | 40 | 1 | 912 | 1.890 |
| 4 | 100 | 40 | 5 | 854 | 1.245 |
| 5 | 25 | 25 | 1 | 618 | 0.356 |
| 6 | 25 | 25 | 5 | 660 | 0.115 |
| 7 | 175 | 25 | 1 | 917 | 1.985 |
| 8 | 175 | 25 | 5 | 884 | 1.952 |
| 9 | 25 | 10 | 3 | 538 | 0.112 |
| 10 | 25 | 40 | 3 | 695 | 0.456 |
| 11 | 175 | 10 | 3 | 888 | 2.450 |
| 12 | 175 | 40 | 3 | 1178 | 2.050 |
| 13 | 100 | 25 | 3 | 897 | 0.975 |
| 14 | 100 | 25 | 3 | 907 | 1.140 |
| 15 | 100 | 25 | 3 | 902 | 0.856 |

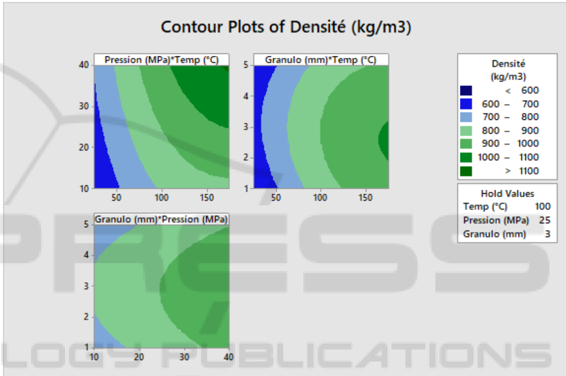


Figure 4: Effects of temperature, pressure and particle size (y) on the density of rice straw briquette (x).

Increasing densification temperature with a lower moisture content of rice straw and the maximum pressure might have allowed the water in the material to exit quickly. Less moisture content results in maximum bulk density. The optimum temperature of the experiment to obtain the highest density and compression strength is around >125°C (Figures 4 and 5). Increasing the temperature will strengthen the bond and adhesion of particles, which will indirectly increase the contact with lignin. Lignin plays an important role in the compacting process that will improve solid bridges among particles, and fewer cavities for the uptake of moisture available. Therefore the water absorption of the briquette could be reduced.

Increasing the densification temperature will increase the compression strength of the briquette, where the highest value of compression strength could be achieved to some extent. Kers et al. explained that once the temperature is lower than the optimum value, the briquette has lower compressive strength. By increasing the temperature of densification, the volatile compounds can burn out from the pressed material (Kers et al., 2010).

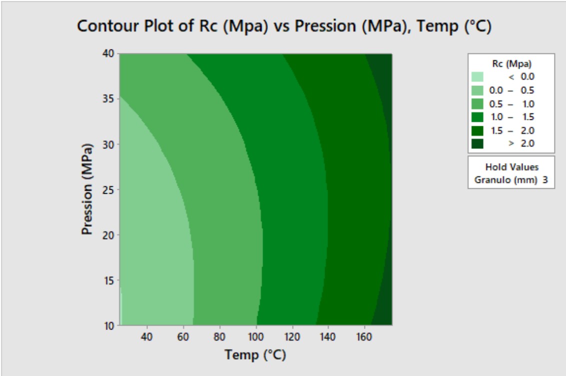


Figure 5: Effect of pressure (y) on temperature of experiment (x).

The bulk density of the rice straw briquette increased proportionally as pressure increased from 25 MPa to 40 MPa (Figure 4). Literature has found a significant relation between the pressure and bulk density of briquettes (Chin and Siddiqui, 2000; Oladeji and Enweremadu, 2012; Saikia and Baruah, 2013; Thabuot et al., 2015). Table 4 shows that increasing the pressure of densification also led to increased compressive resistance of the briquette. This is one of the important factors that influence the compressive strength of briquettes. The briquette strength will increase with the applied pressure until a limit value of the compacting material is reached. Kaliyan and Morey explained that increasing pressure from 15 to 100 MPa increased the tensile strength of pellets from 0.5 to 2.0 MPa. Furthermore, by increasing the pressure above 100 MPa and up to 165 MPa, the tensile strength of the pellet started to decrease and levelled off at 1.5-2.0 MPa (Kaliyan and Vance Morey, 2009). Muazu and Steemann found that the higher compaction pressure of densification had a positive effect on the density and compressive strength of the briquette (Muazu and Stegemann, 2015).

Mani explained that the particle size of a material influences on the density of briquette. (Mani et al., 2003). They found that grinding the rice straw into a smaller particle size resulted in a higher bulk density and lower moisture content. The coarser rice straw creates natural fissures, which is susceptible to breakage. Furthermore, the moisture content will increase and reduce the bulk density of the briquette and also reduce durability. Increasing pressure of densification increased the tensile strength of briquette. The effect of particle size did not significantly improve the compressive strength (Figure 5). Mitchual et al. indicated that finer particle size had a significant effect on the bulk density and compression strength of briquettes (Mitchual et al., 2012). The briquette's strength is very important for briquette transportation, manipulation and storage.

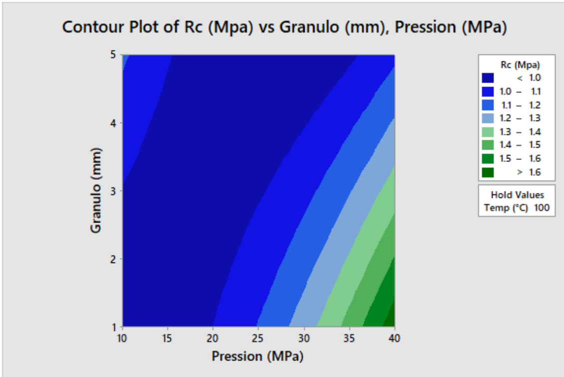


Figure 6: Effect of particle size (y) on the compressive strength of rice straw briquettes (x).

## 4 CONCLUSION

In this study, the characteristics of rice straw briquette were investigated and is concluded as follows:

1. The characteristics of the rice straw assessed in the study showed that rice straw had a high calorific value (15.60 $MJ.kg^{-1}$) and low ash content (13.32%). There is also is an indication that rice straw is a potential source of bioenergy.
2. There was a positive correlation between the temperature and pressure with the density and compression test of the briquette. However, the relationship between particle size and compression test were unpredictable.
3. The optimum conditions of densification in proportion to temperature, pressure and particle size were 100°C, 40 MPa and 3 mm, respectively.

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