

Influence of organic binder and moisture content on the durability of rice husk and rice straw-based pellets

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ABSTRACT


Biomass can partly replace or reduce coal consumption in power generation, hence reducing the agricultural waste disposal issues and environmental pollution generated by fossil fuel emissions. Pelletization is among the techniques for utilizing biomass and has the advantage of being low cost and easy handling. In this research, broken rice was used as an organic binder at 5%, 10% and 15% and three different moistures (14%, 17% and 20%) were applied for rice husk and rice straw-based pellet, and the evaluation of pellet durability has been conducted. The results show that the addition of broken rice as a pellet binder significantly improves biomass pellet durability. The highest durability of rice husk-based pellet achieved was 99.4% with the binder addition of only 10%. For rice straw-based pellet, the binder percentage is directly proportional to pellet durability up to 15% of binder addition. The result shows a similar trend for the effect of moisture on pellet durability. For rice husk-based pellet, the optimal moisture addition is 17%, while for rice straw-based pellet, the durability increased as the moisture increased with the highest durability of 98.9% at 20% moisture addition. Rice straw requires more binder and moisture to enhance the pellet durability because raw rice straw contains less natural lignin and cellulose content than rice husk.

Keywords: Pelletization, Rice husk, Rice straw, Binder, Broken rice.

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1. INTRODUCTION

Biomass application and development have been in high demand for decades and will continue to be so in the near future due to its renewable, clean, and carbon-neutral properties (Carpenter et al., 2014). However, there are some drawbacks, including high cost for transportation, handling and storage cost due to low energy and mass density, high moisture content and irregular shape (Tumuluru et al., 2011a). Pellet, in particular, has been demonstrated as a viable feedstock for biomass applications in order to address the aforementioned issues. Pellets are typically formed by hammer-milling an untreated and dry biomass feedstock into fine pieces and then transforming them into cylindrical pellet under high temperature and pressure (Karkania et al., 2012).

The rice and paddy industry, which is Malaysia's second largest plantation industry, generates significant amount of waste specifically rice husk and rice straw. As of now,

approximately only 20% of rice straw and 23% of rice husk are used for practical purposes such as animal feed, fertilizers and papers while most is either burned, used as mulch for the following batch or incorporated in the soil (Hanafi et al., 2012; Shafie et al., 2012). Rice husk and rice straw also has significant potential for alternative energy application (Moraes et al., 2014). A rice mill can produce power of 700 to 1500 kW by consuming up to 240 t of rice husk per day, or approximately 86,400 per annum (Shafie et al., 2012). Many conversion techniques, including pyrolysis, gasification, and torrefaction, have been studied using rice husk and rice straw (Alvarez et al., 2014; Huang et al., 2020). However, most of the conversion techniques leads to a solid biofuel with low energy density and harder for transportation purposes. Pelletization is considered as the suitable process for dealing with the problem.

According to Kaliyan and Morey (2009a), the content of the binder has an impact on pellet quality. Binders with higher protein, starch, and lignin content may enhance pellet quality. Organic binders offer potential as a biological additive in the pelletization process since they are usually high in starch content, produce minimal ash, and emit less gas. During pelletization process, heat and shearing occurred resulting to gelatinization of starch, protein denaturation and softening of lignin. These processes will facilitate in the binding process and increasing the pellet durability. However, a higher content of fat oil reduces the pellet durability. Fat has hydrophobic properties and this can hinder the binding properties of water-soluble component in the feed.

The binder study for pelletization process of rice straw and rice husk is still limited, which means it is insufficient to draw firm conclusion (Liu et al., 2013; Ríos-Badrán et al., 2020). To further increase the pellet properties especially pellet durability, an addition of binder is encouraged. Abdul-Rahman et al. (2020) has done a study on rice husk pellet using PKS, POME and sawdust as the binder. They discovered that the addition of PKS and POME as a binder can increase the durability of the pellets. High lignin content in PKS and liquid state of POME aid in increasing the pellet durability. Meanwhile, Rahaman and Salam (2017) studied the application of sawdust as binder for rice straw pellet. The result indicated that addition of sawdust could increase the LHV value of the produced pellet due to its own higher LHV and higher lignin content compared to raw rice straw.

In addition, moisture content (MC) is also a crucial parameter in determining pellet durability (Samuelsson et al., 2009). The pellet durability may increase with increasing MC until an optimum is reached (Kaliyan & Vance Morey, 2009b). A study on similar big bluestem pellets recorded an increase in the pellet durability at increasing MC (9% d.b. to 11% d.b.) and the pellet durability decreases beyond 11% d.b. MC (Theerarattananoon et al., 2011). Similar trend was observed for Larix kaemferi C. and Liriodendron tulipifera L. sawdust (Ahn et al., 2014). Moisture can reduce the temperature for plasticises of lignin thus increasing the bond between particles (Stelte et

al., 2011). However, at higher MC, there may be an increase in steam pressure in the pellet thus reducing compression and weaken the durability (Filbakk et al., 2011).

Broken rice, which is readily available locally and is a by-product of rice processing, has the ability to be utilized as an organic binder, but it is often overlooked. To this date, there is no research specifically on the rice husk and rice straw pellets utilizing broken rice as the binder. Therefore, this paper aims at investigating the suitability of broken rice as a binder compound in improving mechanical durability of the pellets. The influence of binder percentage and moisture content on the produced pellets were investigated.

2. MATERIALS AND METHODS

2.1 Raw Material Preparation

Rice husk and rice straw as the main raw materials are supplied by Diyou Future Biomass Sdn. Bhd. The general properties such as lignocellulosic composition and high heating value (HHV) of the raw material is done using Fibertec 2010 fiber analysis system and Leco AC500 isoperibol bomb calorimeter respectively. They are both ground to a size of 1 mm using the pulverizer machine to increase the efficiency of pressure agglomeration process during pelletizing. Diyou Future Biomass Sdn. Bhd. also provides broken rice as a binder, which is ground to 1 mm size to ensure both main raw materials and binder are in uniform size. Fig. 1 shows the rice husk, rice straw and broken rice in raw and grinded condition. Each rice husk and rice straw are mixed with broken rice with a difference binder percentage of 5%, 10% and 15%. Then water is added to differentiate the moisture content at 14%, 17% and 20%. The moisture content is determined using moisture analyzer.



Fig. 1. A) Rice husk, B) rice straw, C) broken rice, D) rice husk (grinded), E) rice straw (grinded), F) broken rice (grinded)

2.2 Pelletizing Process

A pellet mill of flat die ring roller from TNBR is used to pelletize the mixed sample. The pellet mill is powered by 3 hp motor with a capacity of 30 kg/h. A batch of 1 kg per sample is fed into the pellet mill each time. The pellet formed is dried under sunlight for 1 h before packed to

ensure vaporization did not occur. The drying process may also reduce the temperature of the pellet. Then, the pellet is packed in a sealed container according to the binder percentage. European pellet's standard – EN 14961-2 has stated that standard pellets for domestics used are 6 to 8 mm in diameter and the industrial ones are 10 mm to 12 mm in diameter with length of 5 to 40 mm (Zabava et al., 2018). The produced pellet from this study is 7-10 mm in diameter and 20-25 mm in length.

2.3 Pellet Mechanical Durability

The durability of the pellet is tested using the tumbling machine illustrated in Fig. 2. The standard used for it is ISO 17831-1:2015. The pellet is sieved first to remove fine dust. Then, 500 g of pellet is weighted to be fed into the machine. This weight is set as m_1 . The machine's speed is set to 50 rpm and the time is set to 10 min. After 10 min of tumbling, the pellet is sieved using the 3.15 mm hand sieve again to remove fine dust. The sieved pellet is weighted again and the weight is set as m_2 . The durability of the pellet is determined using the following formula,

$$Du = \frac{m_2}{m_1} \times 100\%$$

where,

Du is durability of the pellet (%),

m_1 is mass of the sieved pellet before tumbling (g),

m_2 is mass of the sieved pellet after tumbling (g).

The experiments are repeated for several times in order to ensure the repeatability and accuracy of the data.



Fig. 2. Tumbling machine

3. RESULTS AND DISCUSSION

3.1 Composition of Raw Material and Binder

Table 1 recorded the lignocellulosic composition and high heating value (HHV) of the raw material. Broken rice has the highest cellulose as it has gone through a lot of processes thus decreasing the hemicellulose and lignin. Rice husk pellet is expected to have higher pellet durability than rice straw pellet due to higher lignin content in rice husk acts as glue during the pelletizing process (Kaliyan and Morey, 2009b). Broken rice has the highest HHV followed by rice straw and rice husk. Thus, using broken rice as a binder may help to enhance pellet quality by increasing the HHV of the binder-assisted pellets.

Table 1. Lignocellulosic composition and high heating value of raw material

Biomass	Lignocellulosic composition			High heating value (MJ/kg)
	Cellulose (%)	Hemicellulose (%)	Lignin (%)	
Rice husk	45.05	19.46	20.94	13.8
Rice straw	20.87	23.17	6.81	14.9
Broken rice	81.47	17.2	1.33	15.6

3.2 Effect of Binder Percentage on Pellet Durability

Fig. 3 shows that the durability of rice husk (RH)-based pellet, increases as broken rice (BR) is added as a binder and decrease as more than 10% BR is added. The raw RH pellet has a durability of 93.5% and highest durability of 99.3% is achieved as 10% BR is used. Increment in binder percentage may increase pellet durability due to high cellulose content of 81.47% in BR. Cellulose molecule has high hydrophilic properties due to the hydroxyl groups in the glucose unit and it helps in enhancing the pellet durability (Boulos et al., 2000). Cellulose could also contribute to the increment of electrostatic forces and interparticle bonding among the particle, thus increasing the pellet strength (Si et al., 2016).

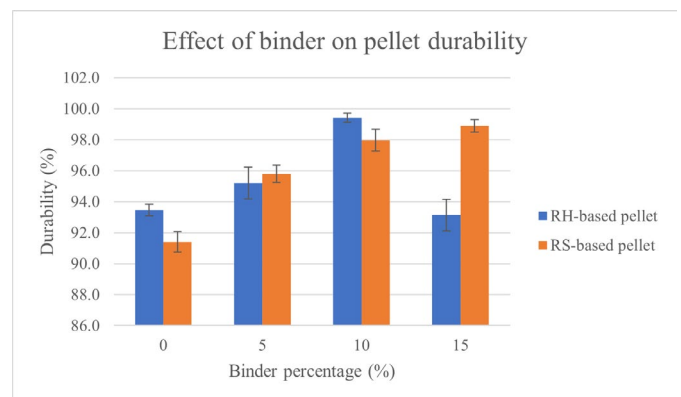


Fig. 3. Effect of binder percentage on rice husk-based and rice straw-based pellet durability

However, addition of 15% BR causing the durability of the pellet to drop significantly. This may be due to too much moisture in the pellet because raw RH itself has high water content due to high cellulose content that has high hydrophilic properties. If broken rice that has high cellulose is added, the overall moisture content might exceed the optimal value for moisture content, thus decreasing pellet durability (Carone et al., 2011).

The effect of binder percentage for rice straw (RS)-based pellet is also shown in Fig. 3. The trend shows an increment in durability as higher percentage of BR is being used. The highest pellet durability of 98.6% achieved when 15% of BR added. This is contradicting with RH-based pellet as durability of RH-based pellet decrease as 15% of BR is added. This may be due to lower cellulose content in raw RS (28.76%) compared to raw RH (45.05%). The optimal moisture content may not exceed for RS-based pellet as 15% BR is added.

According to European standard, the standard mechanical durability is 97.5% and higher (Tarasov et al., 2013). Based from the result, only 10% binder RH-based pellet comply the standard while for RS-based pellet, 10% and 15% binder RS-based pellet satisfy the standard.

By comparing the pellet durability of both RH-based pellet and RS-based pellet, it was discovered that RH-based pellet attained the highest pellet durability of 99.3% with just 10% broken rice addition. As for the RS-based pellet, the highest pellet durability is 98.6%, 0.7% lower than RH-based pellet, and obtained at higher broken rice addition of 17%. As indicated in Table 1, the cellulose content of raw rice husk is twice compared to raw rice straw. Cellulose is similar to starch while hemicellulose contributes to the quality of pellet by strengthening the cell wall alongside with cellulose and lignin in some walls (Salimi et al., 2019).

3.3 Effect of Moisture on Pellet Durability

In optimal condition, moisture can act as a binding agent, helps in particles self-bonding via Van der Waals forces and raises the contact area between particles (Graham et al., 2017; Sastry and Fuerstenau, 1973; Tumuluru et al., 2011b). As the moisture content exceed the optimal value, inter-particle forces decrease and eventually biphasic mixture will form leading to disintegration and swelling (Carone et al., 2011). In this study, three different moistures (14%, 17%, 20%) were used for both pellets at 10% binder percentage because 10% binder percentage produced the pellet with high durability for both RH-based and RS-based pellet.

Based on Fig. 4, the RH-based pellet durability increased from 93.5% to 96% as moisture content increased from 14% to 17%. The durability, however dropped to 93.1% when 20% moisture were used. Initially, the pellet durability increased because moisture or water acts as a lubricant and a binding agent, assisting in the generation of van der Waals forces by increasing the surface area of the particles. (Kaliyan and Morey, 2009b). However, as moisture exceeds its optimal value, a biphasic mixture forms, resulting in

lower inter-particle forces and lower durability (Ungureanu et al., 2018).

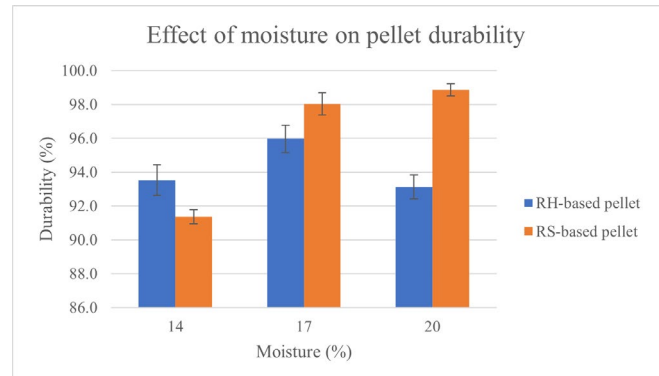


Fig. 4. Effect of moisture on RH-based and RS-based pellet durability

Results for RS-based pellet demonstrated the increment in the pellet durability as the moisture increased, with highest durability of 98.9% with 20% moisture addition. The result is in line with the study presented by Ungureanu et al. (2018). Typically, as the pellet durability reaches a certain value, it begins to deteriorate. However, the pellet durability does not degrade may be caused by the moisture percentage (20%) still does not exceed the optimum moisture value (Serrano et al., 2011).

Although adding moisture to the pellets may improve their durability, by combining both binder and moisture, the raw materials and binder composition may have an impact on the final product. Based on these two studies, it is obvious that 10% addition of binder in broken rice-rice husk (BR-RH)-based pellet can only achieve 96% with the addition of 17% moisture, as compared to 99.3% with no moisture addition. This demonstrates that adding moisture to the pellet may deteriorates pellet durability; thus for 10% binder addition BR-RH-based pellet, the optimum condition is reached without the addition of moisture. However, in the case of 10% binder addition for broken rice-rice straw (BR-RS)-based pellet, the addition of moisture significantly improved pellet durability by of 1.1% as compared to no moisture addition. Since the cellulose content of raw rice straw is half compared to raw rice husk, the moisture addition in RS-based pellet could substantially enhanced pellet quality.

4. CONCLUSION

The addition of broken rice as an organic binder considerably improves the pellet durability. Moisture control, on the other hand, has varying impact on pellet durability depending on the raw material and binder compositions. The highest pellet durability of 99.3% is achieved for RH-based pellet with the addition of 10% organic binder and the durability deteriorate after that. With the addition of more moisture, the durability continues to

deteriorate, with 10 percent BR-RH-based pellets having the highest durability of just 96% when 17% moisture is utilised. The finding suggests a different trend for RS-based pellet, indicating that both organic binder and moisture addition contribute in improving pellet durability. The highest pellet durability of 98.6% is attained at 15% binder addition, and the durability of 10% BR-RS-based pellet continues to improve to 99% at 20% moisture addition. In a conclusion broken rice is preferred to be used for RH-based pellet as it produced highest pellet durability of 99.3%. Extended study is suggested to be conducted to determine the optimal conditions for producing a pellet with the highest durability. The effect of another organic binder with higher hemi-cellulose can also be further investigated as there are limited study on this.

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