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Upgrading Characteristics of Empty Fruit Bunch Biopellet with Addition of Bintaro Fruit as Co-firing

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ABSTRACT

The low density of mass and energy are the main reason for the underutilization of great potential of Empty Fruit Bunch (EFB) as a raw material of alternative and renewable fuels. The using of bintaro fruit as co-firing and treatment of torrefaction – densification processes were believed to increase the density of mass and energy of the EFB biopellet. This study aims to determine the effect of residence time, compaction pressure, and addition of bintaro fruit to the characteristics of EFB biopellet according to ISO 17225-6 standards. Biopellet manufacture was carried out two processes sequence, namely the torrefaction process and the densification process. The torrefaction process was carried out at 275°C with residence time variations 30, 45, and 60 minutes. The densification process was carried out without binder with compaction pressure variations 30, 40, and 50 bar. The addition of bintaro fruit was intended as co-firing of EFB at a ratio 70:30. The best characteristics of biopellet were obtained under conditions of 60 minutes residence time and 50 bar compaction pressures with 3.00% of moisture content, 7.90% of ash content, 8.70% of volatile content, 80.40% of fixed carbon content, 4719.59 cal/gr of heating value, and 1.28 gr/cm3 of density. Characteristics of moisture content and volatile content decreased while ash content, fixed carbon content, and heating value increased with increasing residence time. Characteristics of density increased with increasing compaction pressure. Characteristics of proximate and heating value increased while density properties of biopellet decreased with the addition of bintaro fruit as co-firing.

1. INTRODUCTION

The increase in energy consumption is faced with the problem of the exploitation of fossil fuels that are non-renewable and produce side wastes from their use. Coal is one example of fossil fuels which in their activities produce SO_2 and NOx emissions which cause acid rain. Besides gas emissions, coal combustion also produces solid waste in the form of fly ash and bottom ash causing environmental pollution.

Remember the side effects of the use of sustainable fossil fuels, it is necessary to develop alternative fuels that are environmentally friendly and renewable. A renewable energy source that is environmentally friendly and abundant in nature is biomass. Biomass is a renewable energy source based on carbon and its availability is abundant in nature (Stelt et al, 2011).

Biopellet is an alternative fuel from biomass conversion. Biomass which has great potential to be converted into biopellet is Empty Fruit Bunch (EFB). EFB is a solid waste from palm oil processing activities. Each Palm Oil Processing Plant which has a processing capacity of 30 tons/hour will produce as much as 120 tons/day EFB. EFB that are so abundant generally doesn't have economic value so they are relatively underutilized and tend to potentially pollute the environment.

Indonesia's Crude Palm Oil (CPO) production of 6 million tons/year simultaneously produces EFB waste of 2.5 million tons/year. According to data from the Directorate General of Plantations, the Indonesian Ministry of Agriculture, Indonesia's CPO production in 2018 has reached 43.9 million tons. The increase in CPO production will certainly be directly proportional to the availability of EFB as a raw material that can be converted into alternative fuels in the form of biopellet in a sustainably.

Based on data from the International Energy Agency (IEA) Bioenergy Task 40 Global Wood Pellet Industry Market and Trade Study in 2011 the total production and global biopellet need reaching nearly 20 million tons. The number of world biopellet consumptions is estimated to increase to 80 million tons in 2020. Observe the high world biopellet needs, Indonesia has a huge opportunity to participate in meeting those needs. This is also supported by the big source of biomass in Indonesia, such as from agricultural and industrial waste including the potential for EFB.

The purpose of this study is to determine the effect of the torrefaction process to improve the proximate characteristics and the heating value of biopellet. Determine the effect of the densification process to improve the density of biopellet. Determine the effect of adding bintaro fruit to improve biopellet characteristics. Comparing biopellet characteristics with ISO 17225-6 standards.

2. METHODOLOGY

Material and Equipment

The materials used in this study include the main raw materials for EFB and bintaro fruit as co-firing raw materials. The equipment used in this study includes a series of torrefaction equipment, a series of densification equipment, analytical mass, oven, furnace, desiccator, crucible, stopwatch, blender, and bomb calorimeter.

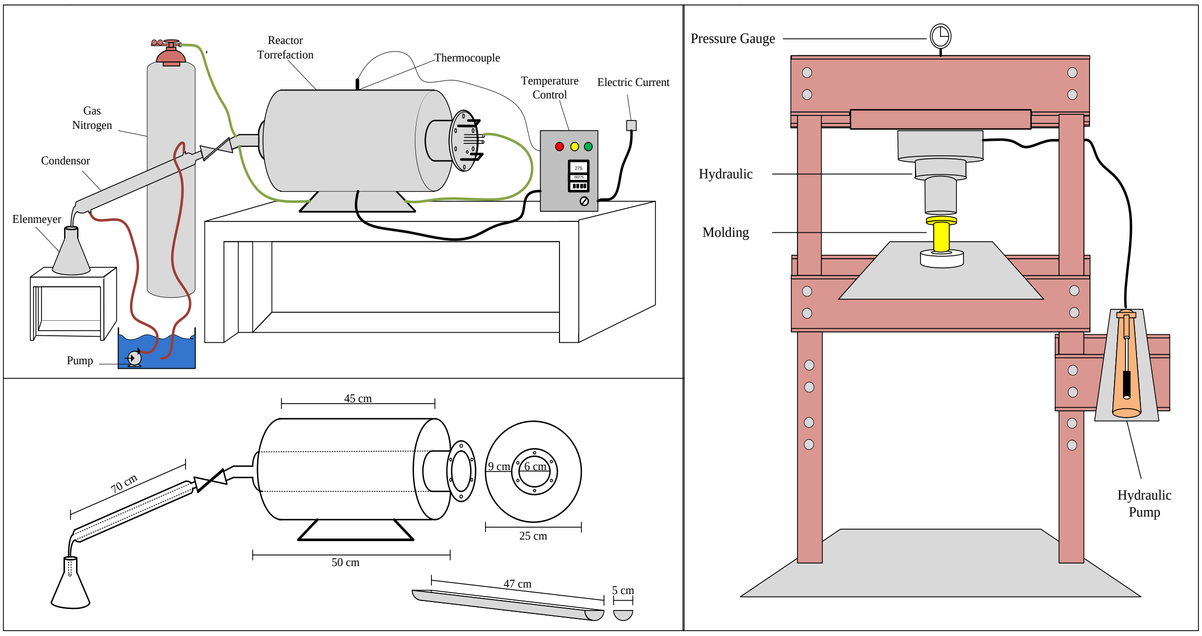

Figure 1. Torrefaction and Densification Equipment

Raw Material Preparation

Stages preparation of raw materials include reducing the size and drying of raw materials. The raw material is cut to a size of 15 mm to facilitate drying and optimize the torrefaction process (Mitchual et al, 2013). Drying is carried out for 2 days conventionally by utilizing sunlight to obtain a moisture content of 6-8%.

Torrefaction Process

Torrefaction process begins by weighing the weight of raw materials that feeding the reactor. Torrefaction was carried out at 275ºC with residence time of 30 minutes, 45 minutes and 60 minutes. Nitrogen is released during the torrefaction process with a flow rate of 50 mL/min. The raw material is fed into the reactor and the residence time of the reaction is calculated after the temperature of the reaction is reached. After the torrefaction process is complete, the torrefaction product is cooled and put in a desiccator for further analysis of the yield mass of raw materials.

Pelletization Process

Biomass torrefied and then carried out by crusher, grinding, and sieving to mixed with 14 gr EFB and 6 gr bintaro fruits. After that, the biomass torrefied is put into a disinfection device to pelletization by hydraulic press. Compaction is carried out with variations in pressing of 30, 40, and 50 bar. After each desired compression pressure has been reached the pressure is held for 5-10 seconds to ensure the homogeneity of the pressure. Furthermore, the compressed biopellet was analyzed proximate, heating value, and density.

Result Analysis

The characteristics analyzed in this study include the characteristics of proximate, heating value, and density of biopellet. The characteristic obtained will be compared with biopellet standards ISO 17225-6. The analytical method used is proximate based on ASTM D-3172-13 to ASTM D-3175-13. The heating value was analyzed based on ASTM D-5865-13. Density is analyzed based on mass per volume dimension of the biopellet.

3. RESULTS AND DISCUSSION

Raw Material Characteristics

EFB and bintaro fruits which became the raw material in this study were first analyzed before being converted to biopellet. Analysis of raw materials includes proximate and heating value. Table 2 is the result of raw materials analysis.

Table 1. Standards characteristics of biopellet

No.	Characteristics	ISO 17225-6
1	Moisture content (%)	≤12
2	Ash content (%)	≤5
3	Volatile content (%)	≤15
4	Fixed carbon content (%)	≥77
5	Heating value (cal/gr)	≥4000
6	Density (kg/m^3)	≥600

Table 2. Raw material characteristics

No.	Parameter	EFB	Bintaro Fruits
1	Moisture content (%)	8.02	7.75
2	Ash content (%)	11.05	2.04
3	Volatile content (%)	14.04	12.50
4	Fixed carbon content (%)	66.90	77.72
5	Heating value (cal/gr)	3832.28	4189.63

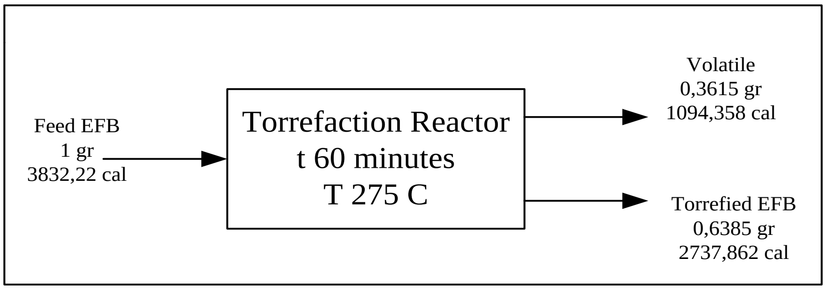

Figure 2. Mass and energy balance torrefaction of EFB

Moisture Content

Moisture content is one of the parameters that affect the combustion process of solid fuels. The high moisture content of a fuel solid causes reduced combustion heat. The reduced heat of combustion is due to by the heat used to evaporate water from solid fuels. Figure 3 is the result of biopelet moisture content analysis.

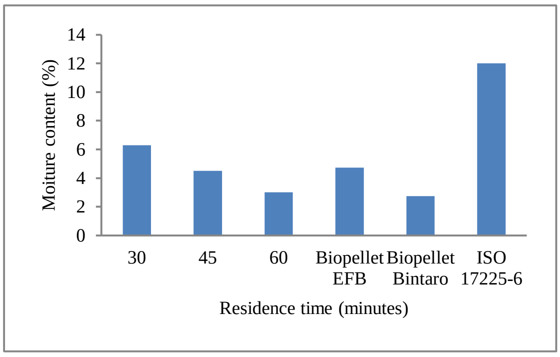

Figure 3. Effect residence time to moisture content of biopellet

The moisture content of biopellet is presented in Figure 3, which is observed to decrease with increasing residence time. This is due to the torrefaction process occur drying process. The evaporation of water molecules or dehydration occurs on the material due to thermal conditions in the reactor (Tumuluru et al, 2010). Similar results were also obtained by Chen et al (2014) that moisture content inversely to residence time. Likewise with the results by Rasid et al (2019) about characteristics of torrefaction products from food waste. The result shows that the lowest moisture content is obtained under conditions of residence time 60 minutes in the range of 15 - 60 minutes.

Overall, the moisture content of biopellet from three conditions of residence time has complied with the ISO 17225-6 standard of 12%. EFB biopellet has a higher moisture content due to the initial moisture content of the raw material. EFB biomass has an initial moisture content of 8.02% and bintaro fruit of 7.75%. According to Strandberg et al (2015), the initial moisture content of the raw materials affects the moisture content of the carbonized product. The addition of bintaro fruit as co-firing can improve the characteristics of moisture content of the EFB biopellet.

Ash Content

Ash content is one component of the proximate analysis. Ash content is also a parameter that affects the combustion process of solid fuels. Ash content consists of inorganic compounds which are generally mineral compounds that can't be oxidized such as SiO_2, Al_2O_3, Fe_2O_3, CaO, and K_2O (Stelt et al, 2011). As a compound can't be oxidized, ash is a component doesn't produce heat in the combustion process. So that high ash content causes a decrease in combustion heat. Figure 4 is the result of biopellet ash content analysis.

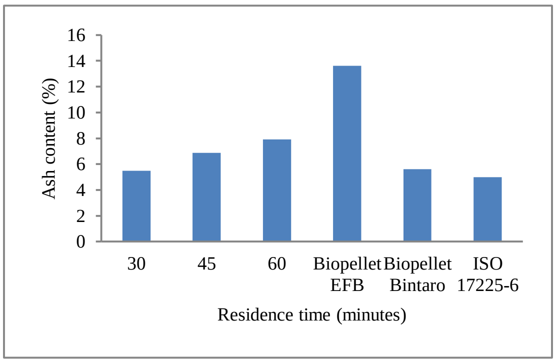

Figure 4. Effect residence time to ash content of biopellet

The ash content of biopellet is presented in Figure 4, which is observed to increase with increasing residence time. Generally, the process of torrefaction doesn't produce ash but is due to ash content from biomass raw material (Syamsiro et al, 2019). Ash content in the raw materials will increase when moisture content and volatile content of the raw materials was decreased during the torrefaction process. Ash content is also due to impurities external such as clay and sand. Similar results were also obtained by Rasid et al (2019) that the longer residence time would produce higher ash content.

Overall, the ash content of biopellet uncomply the minimum ISO 17225-6 standard of 5%. It's due to the initial ash content of raw material exceeds from the standard. EFB has an initial ash content of 11.05% and bintaro fruit of 2.04%. So that the addition of torrefied bintaro fruit provides interactions that can improve the quality ash content of biopellet although it does not meet the ISO 17225-6 standard.

Volatile Content

Volatile content is the amount of substance lost when the sample is heated at a predetermined temperature and time. The volatile content of solid fuel directly proportional to the combustion rate, so that it will be easier for ignition. However, it will reduce the heating value of combustion due to the decreation of the fixed carbon content and more combustion fumes. Volatile content generally consists of flammable gases such as hydrogen, carbon monoxide, methane, and condensate compounds. Figure 5 is the result of biopellet volatile content analysis.

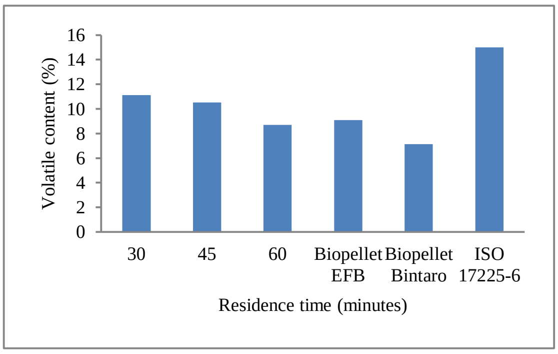

Figure 5. Effect residence time to volatile content of biopellet

The volatile content of biopellet is presented in Figure 5, which is observed to decrease with increasing residence time. This is due to the torrefaction process the devolatilization process occurs. In the devolatilization process, the termination of chemical bonds between C-C and C-O occurs which are converted to condensate. So that the longer residence time causes the maximum devolatilization process (Tumuluru et al, 2010). Similar results were also obtained by Strandberg et al (2015) and Rasid et al (2019) that the longer residence time causes reduced volatile content.

Volatile content obtained in this study generally has complied with the ISO 17225-6 standard that is a maximum of 15%. It's due to the initial volatile content of the two raw materials which are already below 15%. Bintaro fruit has lower volatile content due to has lower cellulose component when compared to the cellulose component in EFB. According to Bhavsar et al (2018) volatile content due to high cellulose content in biomass. The high cellulose content in biomass will produce lots of light hydrocarbon volatile substances and condensation products such as levoglucosan, furfural methyl hydroxyl, hydro acetaldehyde, acetone, and formaldehyde (Uzun et al, 2007 and Shumeiko et al, 2017). Moreover according to Ching et al (2014) depolymerization of cellulose occurs very quickly up to 80% of volatile compounds with the majority being organic compounds that can be condensed.

Fixed Carbon Content

Fixed carbon is the remaining decomposition of organic components in the thermal decomposition process. In coal, fixed carbon content used as an index rank coal and parameter for classifying. High classified coal has a high fixed carbon content. Figure 6 is the result of biopellet fixed carbon content analysis.

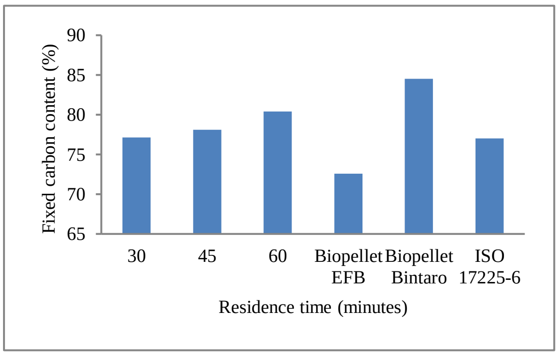

Figure 6. Effect residence time to fixed carbon content of biopellet

The fixed carbon content of biopellet is presented in Figure 6, which is observed to increase with increasing residence time. It's due to during the torrefaction process a dehydration and devolatilization reaction occurs. Longer residence times cause increased dehydration and devolatilization reactions. The reduction of moisture content and volatile content during the reaction will automatically increase the fixed carbon content in biomass (Tumuluru et al, 2010). Similar results were also obtained by Rasid et al (2019) and Thaim and Rasid (2016) that the fixed carbon content is linear to the residence time.

High fixed carbon will increase the heating value of biomass, but reduce the reactive nature of biomass (Chen et al, 2014). The fixed carbon content of biopellet as a whole has complied with the ISO 17225-6 standard that is a minimum of 77%. The fixed carbon content of bintaro fruit higher than EFB due to bintaro fruit has contains higher hemicellulose. Bintaro fruits and EFB have hemicellulose content of around 37.5% (Rosalina et al, 2018) and 35.8% (Ching and Ng, 2014). According to Tumuluru et al (2010) hemicellulose is the lignocellulose component of maximum decomposed so that it will have a major effect on fixed carbon content. So the addition of bintaro fruits as co-firing will improve the characteristics fixed carbon of biopellet.

Heating Value

The heating value is an important indicator for evaluating the quality of solid fuels. The heating value is the amount of energy released when a fuel is combusted completely in a flow process steady state. The heating value was analyzed using an equipment bomb calorimeter. Figure 7 is the result of biopellet heating value analysis.

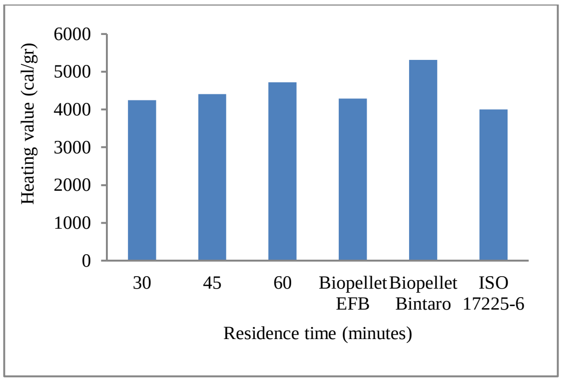

Figure 7. Effect residence time to heating value of biopellet

The heating value of biopellet is presented in Figure 7, which is observed to increase with increasing residence time. The highest heating value in this study obtained in the condition of the residence time of 60 minutes ie 4719.59 cal/gr. Theoretically, the increased heating value is due to by high of fixed carbon content in solid fuel (Sulaiman et al, 2016). The increase of fixed carbon content in a solid fuel is due to a decrease in moisture content and volatile content during the torrefaction process (Tumuluru et al, 2010). Similar results were also obtained by Syamsiro et al (2019) and Rasid et al (2019) that the highest heating value in the torrefaction process was obtained at a residence time of 60 minutes.

The results of the analysis showed that the overall heating value of the biopellet produced has complied with the ISO 17225-6 standard, which was a minimum of 4000 cal/gr. This indicates that the process treatment given can increase the energy density of raw material. The heating value of bintaro fruit is higher than the heating value of EFB. The higher heating value of bintaro fruit is very influenced by proximate characteristics. The proximate characteristics of bintaro fruit show lower moisture content, ash content, and volatile content as well as higher fixed carbon content than EFB.

Density

Density is a measurement of mass per volume of the object. Solid fuels that have high density will easier storage but reduce the rate of combustion due to the reduced pores. The good combustion rate is a result of a compromise between density and porosity. Figure 8 is the result of biopelet density analysis.

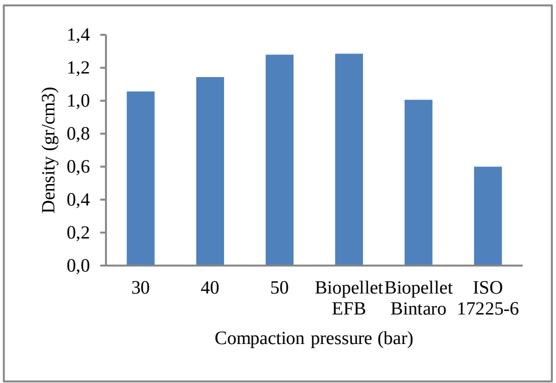

Figure 8. Effect compaction pressure to density of biopellet

The density of biopellet is presented in Figure 8, which is observed to increase with increasing compaction pressure. The density of biopellet obtained successively 1.06, 1.14, and 1.28 gr/cm3. According to Cavallo and Pampuro (2017), compaction pressure causes particles to be forced to fill empty pores so that porosity decreases and density increases. A similar result was obtained by Krizan et al (2014) that density is directly proportional to compaction pressure.

The results of the analysis showed that the density of biopellet obtained has complied with the ISO 17225-6 standard, a minimum of 0.6 gr/cm3. EFB biopellet has a higher density than bintaro fruit biopellet. According to Mitchual et al (2013), the density of solid fuel is influenced by the particle size and particle density of fuel solid. In another study, Nasrin et al (2011) made an effort to increase the density of EFB biopellet by adding palm shells. Palm shell has a higher density so that it can increase the density of the EFB biopellet. Cork-shaped constituent particle structure causes the bintaro fruit to have a light density (Rosalina et al, 2018).

4. CONCLUSION

1. Effect residence time simultaneous to proximate characteristics and heating value of biopellet.
2. Effect compaction pressure simultaneous to increase density properties of biopellet.
3. Effect addition of bintaro fruit torrified as co-firing can improve characteristics of biopellet, except density characteristic.
4. The characteristics of biopellet obtained have complied with ISO 17225-6 standards, except ash content characteristics.

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