Increasing product quality of torrefied palm kernel shell batch model with internal surface area modification

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Abstract. As the largest palm oil-producing country in the world, Indonesia has abundant biomass potential from the production of crude palm oil (CPO). Palm oil production in 2018 in Indonesia is 34.94 million tons, where have by-products are empty bunches (23%), mesocarp fiber (12%), and palm kernel shell (5%). Palm kernel shells are a potential biomass that can upgrade the quality as a solid fuel through thermochemical processes. Torrefaction is one of the thermochemical processes where currently being used to increase the quality of biomass. The usual method used for the torrefaction process in the laboratory is the batch method. However, this method has a disadvantage when the capacity is improved make decreases the quality of the fuel produced. In this study, the quality of torrefied palm kernel shell from batch and batch torrefaction with internal surface area modification were compared. The torrefaction process was carried out at 275°C, with a residence time of 30 minutes. The results showed that the torrefaction of the modified batch method had a better heating value, and was proximate as a fuel.

1. Introduction

Biomass is one of the renewable energy that is potent and currently replaces fossil fuels in industries such as steam power plants [1]. Biomass is defined as biological material originating from life or living organisms with a carbon structure and a chemical mixture of organic matter containing hydrogen, nitrogen, oxygen, and a small number of atoms & other elements. However, in terms of utilization as energy, biomass is defined as all organic materials from plants, animals, products, or wastes from aquaculture industries such as agriculture, plantation, forestry, animal husbandry, and fisheries [2]. Biomass as an energy source is very important to maintaining the availability of energy can also help reduce the environmental impact of plantation or forestry waste [3,5]. As the most significant crude palm oil (CPO) production globally, Indonesia has a large amount of biomass as a by-product of this production. Indonesia is also committed to increasing palm oil products, which can be seen from the increased production of fresh fruit bunches (FFB) every year. In 2016, it amounted to 31.73 million tons to 45.86 million tons in 2019 [6]. By-products generated from each ton of FFB is 23 % empty bunches, 12% mesocarp fiber, and 5% palm kernel shells [7,8]. Compared to other solid waste from CPO production, the highest potential to be used as fuel by going through a thermochemical process to increase its quality is palm kernel shell.

Torrefaction is a thermochemical process to improve the quality of biomass as a fuel such as increasing heat value and carbon content [9,11]. There are various kinds of torrefaction methods, one...
of which is the most widely used batch method. The method's weakness is that the reaction time is directly proportional to the amount of biomass that is processed. This method causes the energy requirements of the torrefaction to be higher. Therefore, in this research, a modification of the biomass receptacle for increasing the surface area/heat contact of the biomass to streamline the torrefaction time.

2. Materials and methods

2.1. Torrefaction process

The Torrefaction process is shown in figure 1 [4] by modifying the torrefaction bait container into 2 (two) different models (model I and model II). Torrefaction model I had one container like the conventional batch method, while in model II, the container was modified into a rack to increase heat contact on the biomass surface. In figure 1, nitrogen gas was supplied at a rate of 2 Liters/minute for 10 minutes until the reactor in inert conditions. The torrefaction process was carried out at 275°C, with a residence time of 30 minutes [12].

![Figure 1. Torrefaction process [4].](image)

Torrefaction process by the batch method used two container models intending to modify the surface area of biomass that was in contact with heat. The model I biomass container that was currently commonly used only consisted of one container. Model II was modified into a rack so that the heat contact to the biomass would be more efficient. The model, I and II containers, can be seen in figure 2.

![Figure 2. (A) Model I and (b) Model II](image)

2.2. Calorific value analysis

Calorific value or higher heating value (HHV) was determined by following the ASTM D240 or EN 14918 procedure using a bomb calorimeter [4,13]. The samples measured were samples before treatment (control), after torrefaction model I dan II.
2.3. Proximate analysis

The proximate analysis to determine humidity, volatility, and ash content, in this study was tested following standard procedures of ASTM D3171, D3175, and D3174. The sample of this analysis controls was torrefaction model I and II [5, 13, 14].

3. Results and discussion

3.1. The visual products of torrefaction

The Torrefaction process in this study referred to Dirgantara et al. 2020, where the optimal conditions of the torrefaction process at 275 °C with a residence time of 30 minutes [12]. Visually, the results of the model I torrefaction looked less optimal where physically, it did not look much different from the control. Black color on the torrefied palm kernel shell was an indication that the carbonization process was successful during the torrefaction [4,15,16]. The torrefaction results with model II looked better than model I. The black color of the palm kernel shell was distributed evenly. The following results of torrefaction in models I and II were compared with controls (figure 3).

![Figure 3](image-url)

**Figure 3.** (A) Control, (b) Model and (C) Model II.

3.2. Calorific value

Calorific value is the main parameter that indicates the quality of biomass as a solid fuel[17,19]. More heat can be released by every gram of biomass when an increase in the calorific value [12]. The results of the analysis of the heating value are shown in figure 4. The heating value increased significantly after the torrefaction process, where the control of 4469.35 Cal/gram increased to 5072.48 Cal/gram (model I) and 5440.67 Cal/gram (model II). An increase in the carbon content to the palm shells during the torrefaction process caused an increase in HHV. This caused the elimination of volatile substances during the torrefaction process, such as water, acetic acid, and phenols in the palm shells [3]. During the process of torrefaction, thermal degradation of hemicellulose and lignin occurred in volatile substances. The formation of volatile substances, causing the ratio of O/C and H/C, would continue to decrease, thereby increasing the palm shell's carbon content [20]. This had led to an increase in the calorific value of the palm kernel shell resulting from torrefaction. Making the biomass container into a shelf (model II) in the torrefaction process, as shown in figure 2, made the heat more evenly distributed so that the thermochemical process on the palm kernel shell was better. With the even distribution of heat distributed causes more volatile compounds to be lost, so that the bound carbon value increases and had an impact on increasing the heating value.

3.3. Proximate analysis

Analysis Proximate used to determine the characteristics of the and quality of solid fuels concerning the use of solid fuels, namely to determine the relative amounts of water moist (moisture content), volatile substance (volatile matter), ash (ash content), and carbon moored (fixed carbon) [19,21]. The results of the proximate analysis are shown in figure 5. Moisture content in biomass affected the
calorific value. The higher the water content of solid fuels, the more significant the heating value needed in the combustion process, so that it required extra energy. Also, the high-water content would increase the risk of fire hazards when storing biomass for a long time. High humidity could potentially cause fermentation so that the temperature of the material increased, which could cause a fire if there was friction or was close to a heat source.

Figure 4. Calorific value of palm kernel shell control, model I and model II.

Moisture content in biomass affected the calorific value. The higher the water content of solid fuels, the more significant the heating value needed in the combustion process, so that it required extra energy [4,22]. Also, the high-water content would increase the risk of fire hazards when storing biomass for a long time. High humidity could potentially cause fermentation so that the temperature of the material increased, which could cause a fire if there was friction or was close to a heat source. The water content in model II was smaller than the model I; this condition indicated that model II was more efficient in reducing water content.

The high ash content in solid fuels resulted in lower total heat [21,23]. Low ash content was significant in the thermal conversion of biomass, increasing efficiency, mainly when the biomass contained potassium or halides such as chlorine. The ash content of the palm shell torrefaction product in Model I and II increased. The mass reduction that occurred during the process of torrefaction is not accompanied by degradation of the ash-forming inorganic component into the cause of this increase.

Figure 5. Proximate analysis torrefied palm kernel shell (control, model I and model II).

Volatile matter (VM) is the amount of substance lost when biomass is heated at a specific temperature and time. One of the factors influencing the rate of release of volatile compounds is the surface area of the biomass. The more surface area (torrefaction model II), the faster the rate of release of volatile compounds. The main chemical components that lost during the torrefaction process in
biomass are hydrogen and oxygen [24]. Phenols and carbonyl are produced in the temperature range of 200 - 300 °C from volatile compounds, especially oxygen. The reduction of hydrogen and oxygen content leads to an increase in the ratio of carbon to hydrogen and oxygen, which affects to increase in the calorific value products [25,26].

Fixed Carbon (FC) states the amount of carbon contained in material or biomass [4,12]. The Torrefaction process caused much volatile matter to be lost so that fixed carbon would continue to increase after torrefaction. Levels of fixed carbon were associated with volatile levels. The lower levels of volatiles in biomass caused higher levels of fixed carbon so that the heating value was also higher. Torrefaction products with model II had higher fixed carbon values than the model I torrefaction products. The large surface area of biomass in model II caused more volatile compounds that were lost affect ed the higher carbon content bound to the model II torrefaction product.

4. Conclusion
Modification of the biomass container in the torrefaction reactor (model II) batch method produced more optimal products than without modification (model I). This product quality can be seen from the higher heating value and lower volatile matter in model II. Thus, increasing the surface area/heat contact area of the biomass could streamline the batch method torrefaction process and produce better fuel quality.

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