Effect of Temperature and Residence Time Torrefaction Palm Kernel Shell On The Calorific Value and Energy Yield

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Abstract. Torrefaction was thermochemical processes to make biomass a fuel that had better properties, such as increased carbon content and calorific value. It was a temperature-sensitive process that was effective between 200 °C and 300 °C in an inert environment with a residence time of 20-60 minutes. Palm kernel shell was one of the biomass that has the potential to be used as fuel, where its availability was abundant and has good physical properties. In this study of palm kernel shell torrefaction was carried out from 0.5 cm sieve with three variations in temperature and residence time follows 250 °C - 300 °C and 20 -40 minutes. The results obtained were the increase in temperature and holding time causes an increase in the calorific value but relatively on energy yield because of a large mass loss at a temperature of 300 °C. The optimum process for torrefaction of palm kernel shell according to calorific value and energy yield was 275 °C with residence time 20 minutes.

1. Introduction

The thermochemical process of torrefaction is actually an incomplete pyrolysis process also known as mild pyrolysis, which is another widely applied and studied technology to increase the properties of biomass as a fuel [1–3]. Torrefaction is a heating process between 200-325°C with minimal oxygen conditions. This process is being widely used to improve the properties of biomass as fuel and reduce the weaknesses of biomass, such as low heating and energy density, high inertia, low combustion efficiency, and high milling energy [4,5]. The heating value of biomass is an important parameter for the planning and the control of power plants using this type of fuel. Optimizing torrefaction parameters leads to an improvement in both the quantity and quality of the torrefied biomass. With that in mind, it means that maximizing biomass higher heating value whilst minimizing biomass weight loss from its raw state results in optimized torrefaction parameters [6,7]. Thus, the focus is on finding the optimized torrefaction parameters which have an energy yield of more than 100%.

Lignocellulosic biomass is one of the most important renewable energy resources; however, in energetic applications, the raw material has several disadvantages, such as the high oxygen content, low calorific value, low energy density, hydrophilic nature and high moisture content [8, 9]. One of the large biomass potentials in Indonesia is a by-product of the oil palm industry such as palm kernel shells and empty fruit bunches. Production of palm oil every year in Indonesia has always increased, in 2012 itself is 26 million tons up to 40.5 million tons in 2018 [10]. From this production, the biomass produces from the palm oil industry includes empty fruit bunches (23%), mesocarp fibers (12%) and
palm kernel shells (5%) from every ton of fresh fruit bunches [4,11]. The potential for that large biomass is a big loss if it is not utilized properly, so far many palm kernel shells have been exported to developed countries such as Japan to be used as fuel.

The focus in the torrefaction process is to get a high HHV value and low mass loss due to this process [12–14]. In this study of palm kernel shell torrefaction is carried out from 0.5 cm sieve with three variations in temperature and residence time follows 250 °C - 300 °C and 20-40 minutes then analyze the high heating value (HHV). The value of HHV, initial and torrefied palm kernel shell then use to determine energy yield of this process.

2. Methodology
2.1. Raw material preparation and torrefaction
The raw material for palm kernel shells was obtained from palm oil production of PT. Mulia Agro Permai Mill, Kotawaringin Timur Regency, Central Kalimantan, the samples were dried under the sun for 3 hot days until the moisture less than 9 % and left in an airtight bag for 2 more weeks then sieved with a size of 0.5 cm [4,13].

The torrefaction process was then carried out at the Banjarbaru Baristand Process Laboratory in South Kalimantan using a 500-grams batch system torrefaction tool with inert conditions. the torrefaction temperature was varied from 250 °C, 275 °C, 300°C [13], with residence time varied 20, 30 and 40 minutes [6,7]

2.2. Measurement of HHV and process efficiency parameter
Calorific value measurement was performed to determine Higher Heating Value (HHV) and the Lowest Heating Value (LHV). This measurement followed the procedure of ASTM D240 or EN 14918 [6,15] using the bomb calorimeter Samples measured were samples before and after torrefaction.

Three critical parameters that were used to determine the success of the torrefaction process were weight loss, mass yield, and energy yield. The focus in the torrefaction process was to get a high HHV value and low mass loss due to this process [12–14].

Weight loss calculated using the equation

\[
Weight\ loss\ (WL) = \left(\frac{M_r - M_t}{M_r}\right) \times 100\%
\]

Where \( M_r \) is mass of raw biomass and \( M_t \) is mass of torrefied biomass.

Mass yield computed as

\[
Mass\ yield\ (MY) = \frac{M_t}{M_r} \times 100\%
\]

Energy yield was computed as

\[
Energy\ yield = MY \times \frac{CV_t}{CV_p}
\]

Where \( CV_t \) and \( CV_p \) is the calorific value of the briquettes after and before torrefaction.

3. Results and Discussions
3.1. Effect temperature on torrefaction
The effect of the temperature of the torrefaction on the palm kernel shell was carried out with variations in temperature of 0 °C (control), 250 °C, 275 °C and 300 °C with a residence time of 40 minutes. The effect of temperature on HHV values is shown in Figure 1 and the effect of temperature on the process efficiency parameter are shown in Figure 3. The heating value was one of the main parameters that determine the quality of solid fuels [16]. The higher the heating value, the more heat can be released by every gram or kilogram of solid fuel. Figure 1 shows the higher the temperature of
the torrefaction, the higher the heating value. The heating value significantly increased where control 4018.78 cal/gram increased to 6633.79 cal/gram at a temperature of 300 °C. This can occur due to an increase in the amount of carbon content in the palm shell that has undergone torrefaction and the removal of some chemical compounds in the palm shell that have the potential to cause smoke, especially volatile substances loss during the torrefaction process such as water, acetic acid, and phenols. During the process of torrefaction, thermal decomposition of hemicellulose becomes volatile [17]. With the formation of volatile substances, the O/C and H/C levels will continue to decrease thereby increasing the carbon content of the palm shell.

![Figure 1. Effect temperature on HHV value](image1)

![Figure 2. (A) Control; (B) Torrefaction 250 °C; (C) Torrefaction 275 °C; (D) Torrefaction 300 °C](image2)

With an increase in temperature, it was also observed that the torrefied product turned darker from the raw brown color after torrefaction [6]. One indicator of the success of the torrefaction process was changing the physical appearance of the biomass, in this case, the palm shell. Figure 2 (B), (C) and (D) which were the results of torrefaction show different physical appearance colors from the control shell (Figure 2 (A)). This is due to the process of carbonization and reduction of water content during torrefaction resulting in darker shell color. The higher the temperature of the torrefaction, the palm shell color seems darker and more evenly distributed, so according to the physical appearance can be said that the torrefaction process with the existing equipment is succeeded.
4. Effect of the temperature on the efficiency parameter process.

Weight loss at 200 °C was attributed to loss of remaining bound and unbound moisture [18], the devolatilization of organics process that starts at 210 °C when the hemicellulose starts to breakdown by bond breakage. As hemicellulose breaks down, H₂O is produced from its -C-O-H bond, leading also to production on non-condensable gases like CO and CO₂ [6,16]. The higher the temperature the higher the weight loss and results in smaller mass yield. In addition to moisture, this is due to the degradation of hemicellulose, cellulose, and lignin with increasing temperature. Seen at a temperature of 300 °C the value of weight loss is higher than the mass yield.

Energy yield is a parameter that is influenced by the value of HHV and also mass yield. If the value of energy yield is above 100%, the torrefaction process has been able to increase the energy that can be used in biomass [19,20]. A large mass loss due to an increase in temperature causes the energy yield to decrease even though the heating value increases. Figure 3 shows the energy yield at a temperature of 250 °C of 98%, a small mass loss and a significant increase in heat causing a higher heat value than the others but the value has not exceeded 100%.

3.2. Effect residence time on torrefaction

The effect of residence time in torrefaction on the palm kernel shell was done with time variations of 20, 30 and 40 minutes with a constant temperature of 275 °C has no different with the influence of temperature. In general, the longer the residence time, the calorific value will increase as shown in Figure 4. This is due to the more time for carbonization so that the heating value will increase as well. As residence time increases, O₂ and H will be used up to form water vapor, CO and CO₂ that were then released into the atmosphere. This results in high C/O and C/H ratios caused higher calorific values [19]. An increase in contrast HHV values was seen at the holding time of 40 minutes, this was because at 20 and 30 minutes it was still dominant for moisture and hemicellulose degradation. This can be seen from the weight loss where at a temperature of 20-30 minutes the difference is 6.5 % while 30-40 was smaller at 4.8 %, meaning that mild volatile has reduced significantly.

The effect of residence time on the process efficiency parameters is shown in Figure 5. Based on these data, weight loss increases with an increase in residence time which results in decreased mass yield. Energy yield decreases due to increased residence time, but at 40 minutes it is higher than 30 minutes. This is due to HHV values which are much higher than 30 minutes time, while HHV values between 20 and 30 minutes do not differ greatly. Based on the data, the holding time of 20 minutes has a higher energy yield of 87 %, because in these conditions the mass yield is higher and the mass loss is smaller.
4. Conclusions
An increase in temperature will increase the value of HHV but causes a large mass loss. An increasing in residence time also shows a similar thing where the heating value increases followed by a large mass loss. Based on the HHV value and energy yield, the optimum conditions for the batch method torrefaction process that have a high calorific value and a moderate mass loss is 275 °C and 20 minutes holding time.

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6. References
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