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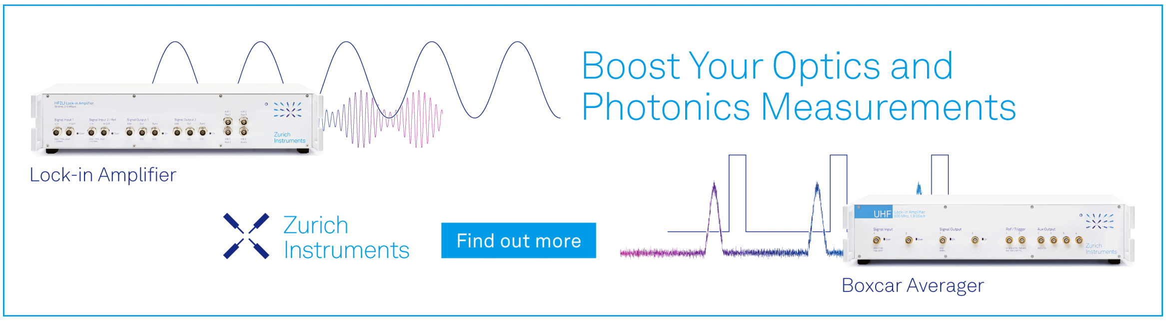

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Effect of Torrefaction Process on the Coconut Shell Energy Content for Solid Fuel

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Abstract. Indonesia was one of largest coconut producers in the world with an average coconut production of 3 million tons per year and an estimated coconut shell waste were produced 360 thousand tons per year. Certainly, Coconut shell produced in large numbers require initial processing to be saved in the long term with stabilized quality. Quality of coconut shell can be maintained by changing the characteristics of the properties of coconut shell from easily absorbed water (hydrophilic) to difficult absorbed water (hydrophobia) as well as reduce the smoke of burning through torrefaction. Torrefaction technology carried out the biomass at a temperature of 200-300°C. The goal of this research was to observe the effect of operating conditions of torrefaction and the size of a coconut shell to the quality of coconut shell as a solid fuel which had high quality and low environmental impact. The variables in this study was the size of coconut shell (1.5 cm, 3 cm, and 4 cm), temperature (250^{o}C, 300^{o}C and 350^{o}C) and torrefaction holding time (15, 30, and 45 minutes). Fresh coconut shell will be analyzed using proximate, ultimate analysis, and calorific value to know the initial condition. Torrefaction product will also be analyzed by proximate analysis and heating value. The highest calorific value was obtained on the size of coconut shell medium (3 cm) with operating conditions at a temperature of 350^{o}C and torrefaction holding time 30 minutes at 7635 kcal /kg with the increasing percentage in calorific value 40.76%, fixed carbon 82.73%, and the volatile matter content 10.88%. But that condition of the torrefaction product has produced the low mass yield around 31%. The optimum conditions were at temperature 250^{o}C, torrefaction holding time 30 minutes, and coconut shell size 1.5 cm.

INTRODUCTION

The Indonesian government has issued Presidential Decree No. 5 of 2006 on the National Energy Mix that 17% of national energy resources by 2025 comes from the New and Renewable Energy. Then, this presidential decree was reinforced by the National Energy Vision that 25% of national energy sources in 2025 came from the Renewable Energy including biomass. Biomass can be processed into energy through a process such as briquetting, gasification and direct combustion. The potential of biomass crops and plantations in Indonesia theoretically amounted to 32654 MWe (BPPT, 2016). With the government's program to build a power plant of 35 000 MW, the biomass has the potential to fuel power plants small and medium scale.

Utilization of biomass including coconut shells for fuel in the boiler in the power plant has few shortcomings that dispersed biomass resources, biomass quality of different, low biomass heating value so that the cost of distributing the biomass to be expensive (Uemura, 2011). General utilization of biomass did not pay attention to the pre-treatment of biomass conditions so that biomass decreased quality such as increased water content will reduce the amount of energy (kJ / kg biomass) and the impact on the environment during the process of storage with the release of ozone-depleting gas (CH_4). The quality of biomass can be maintained by changing the characteristics of the biomass that naturally easy to absorb water (hydrophilic) towards inherently difficult to absorb water (hydrophobia) using torrefaction technology. Torrefaction was a method for pre-processing of biomass in order to increase the quality and biomass can be used in a long time (Basu, 2013).

Torrefaction was the thermochemical processing of raw materials containing carbon that takes place at atmospheric pressure with a temperature range of 200 - 300^{0}C (Bergman, 2005). Torrefaction was used for initial processing of the

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biomass so that the quality of the biomass will increase. Characteristics of biomass by torrefaction process will decrease the water content, reduced oxygen, and hemicellulose content. The nature of the biomass becomes difficult to absorb water, thus make the energy content increased. Under the Torrefaction process, the characteristic of biomass will close to the coal ((Van der Stelt, 2011).

In general, the torrefaction was a mild pyrolysis process with the occurrence of a reaction in series and continued with heat and mass transfer. Degradation of components of the biomass has become more intense at temperatures above 200°C by starting from decreasing hemicellulose components. During torrefaction, the color of biomass becomes darker. The factors that affect the quality of the product of the Torrefaction process of biomass were the biomass size, temperature, torrefaction reactor and residence time within the reactor. The longer of torrefaction process can cause loss of energy from biomass component that will decrease energy content (Irawan, 2014).

Then, the torrefaction product can be stored as a source of high-quality solid fuel. During the storage process, this solid fuel still has a good quality eventhough it was stored for a long time. Solid fuel of torrefaction can be used in the process of combustion, gasification or carbon material for the steel industry (Chen, 2015). The addition of biomass products of torrefaction would accelerate the process of burning the coal in the furnace (Park, 2012). Biomass of torrefaction can be used as raw material in the gasification process and it can reduce the agglomeration and tar in the gasification reactor (Strege et al., 2011).

Conditions of biomass feedstock and torrefaction process affected the quality of products such calorific value. Biomass with a high content of hemicellulose will be difficult to change its characteristics through torrefaction process because the content of hemicellulose was the component that opens pores of biomass and closed again (Chen, 2011a). Temperature of torrefaction process also affected the quality of biomass products. Temperature of torrefaction process below 200°C will produce a high ability to absorb water due to the hemicellulose that did not degraded at that temperature. Then, the temperature of torrefaction above 300°C will produce lower energy product due to some parts of combustible gas of volatile matter carried by the flow of gas. Temperature was instrumental in removing the hemicellulose content that will change the characteristics of biomass becomes difficult to absorb water. With the condition of Indonesia which has a high humidity, the product of the torrefaction process must have high levels of hydrophobic (Chen, 2015). Experiments for the ability to absorb water from the torrefaction product has been conducted on Biomass Oil Palm Empty Fruit Bunch (EFB) showed that the biomass without torrefaction can absorb water from the air around 15% while through the torrefaction process of absorption dropped by nearly 3% (Irawan, 2015).

Indonesia produced a large number of coconut products around 3 million tons per-year (DGT, 2014) with an estimated waste coconut shell about 360 thousand tons per year. Many benefits can be derived from coconut such as foods, beverages, energy and cooking oil. Coconut shell was a waste of coconut processing and included in the class of hardwood. Some of the benefits of coconut shell were for fuel in the boiler as well as an adsorbent for liquid waste. Torrefaction process of the wood has been done with the experiment in the temperature range 225 - 300°C to determine the torrefaction kinetics. The results showed mass yield about 70 -88% with further decreasing temperature (Prins, 2006). Experiments conducted of torrefaction of wood with variations of holding time up to 2 hours and showed the mass loss of more than 50% (Chen, 2011b). The use of inert gas (nitrogen) also affect the mass loss of wood biomass for torrefaction process (Eseltine, 2013). Some studies of torrefaction of wood used temperature and residence time as variables showed the torrefaction temperature more influential than the holding time (Stranberg, 2015).

EXPERIMENTAL SETUP

Material and Equipment

Coconut shell as raw materials derived from coconut plantations in the area of Mancak, Cilegon. Then, Coconut shell was reduced in size to the average of 1.5; 3; and 4 cm. This coconut shell was weighed as much as 25 grams for each experiment. Raw materials prior to use will be analyzed of the proximate and energy content. Then, 25 grams of coconut shells are inserted into the torrefaction reactor. Torrefaction reactor in this study as in Figure 1. The torrefaction reactor equipped with temperature control devices that are connected to the thermocouple located inside the torrefaction reactor. The type of thermocouples used were of type K. The heating of the reactor can generate heat up to the temperature inside the reactor reaches 450°C. In this study, the temperatures will up to 350°C temperature. In addition, the torrefaction reactor was also equipped with a digital scale and a basket of raw materials.

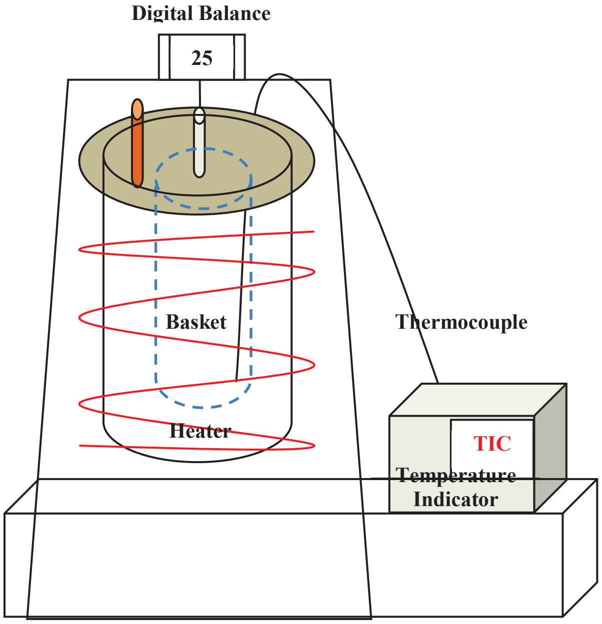

FIGURE 1. Schematif of Torrefaction Reactor of Biomass

Procedure

25 grams of coconut shell inserted into the basket, and then fed into the torrefaction reactor. A balance digital placed above the reactor to determine the change in mass of coconut shell in the reactor for every minute. The heating heater was controlled to obtain the conditions of temperature of 250, 300 and 350°C at torrefaction process and a holding time of torrefactin measured using a stop watch. Mass and temperature changes are recorded every minute for torrefaction process variation of 15, 30 and 45 minutes. Torrefaction products checked to know the content of biomass by using proximate, ultimate and calorific value. Proximate analysis and calorific content did in TEKMIRA Bandung using Thermal Gravimetry Analysis (TGA). With the TGA analysis, composition and rate of mass reduction-component constituent components of a biomass can be known. The stages of analysis by TGA was biomass coconut shell inserted into the TGA with the results starting from the analysis of water content, volatile matter, and ash. The content of fixed carbon-component represents a reduction of other components. The energy content of coconut shells obtained by using a system of Adiabatic Bomb Calorimeter.

RESULTS AND DISCUSSION

Proximate and ultimate analysis performed on the raw material coconut shells to get the initial conditions of the raw materials experiencing torrefaction. Proximate analysis is used to obtain component content of the water content, volatile matter, fixed carbon and ash. Table 1 showed the content of volatile matter of the coconut shell is so high that torrefaction process will eliminate most of the content of the volatile matter containing no energy. Ultimate analysis was also conducted to determine the content of elements from coconut shells. The element oxygen is an element of biomass that must be removed to increase the energy content of coconut shell so the quality will approach the quality of coal (Van der Stelt, 2011).

Torrefaction product can be observed from the physical appearance such as a color change from the original color to the dark brown. Figures 2 and 3 showed the colorful appearance of the variations in size of 1.5 cm and 4 cm and temperature at 250°C with a variety of holding time of torrefaction process. At short holding time of torrefaction process (15 minutes), the color of torrefaction product was not too dark for both coconut shell size (1.5 cm and 4 cm). This situation showed the process of the removal of volatile matter has not been effectively removed the volatile matter so the fixed carbon content did not dominate the the volatile matter. At the size of a small coconut shell (1.5 cm), the color of the torrefaction product was blacker than at larger sizes (4 cm), especially at holding time of torrefaction process 30 and 45 minutes. This condition was caused by volatile matter of the pore coconut shell released in a larger amount and left only the fixed carbon and ash. In the large size of coconut shell (4 cm), color of torrefaction product was still in its original condition and accompanied by a little black so that the torrefaction process on the size of 4 cm were not an option to remove volatile matter due to the high resistance of heat and mass transfer.

TABLE 1. Proximate Analysis, Ultimate Analysis and Calorific Value of Coconut Shell

Proximate Analysis (%-weight)	
Moisture in Dried Sample	7.40
Volatile Matter	74.27
Fixed Carbon	17.60
Ash	0.73
Ultimate Analysis (%-weight)	
Carbon	48.02
Hydrogen	6.5
Nitrogen	0.1
Total Sulphur	0.01
Oxygen	44.64
Gross Calorific Value (Kcal/kg)	4523

Calorific value (kcal/kg) of torrefacation product on coconut shell size 4 cm in average has lower value than in 1.5 and 3 cm. Thus, the size of a coconut shell of 4 cm were not a good size due to the large size for the heat transfer by convection to the outer wall was followed by the mass transfer process from the pores of coconut shell towards the outside wall. Figure 4a showed that the calorific value of the size of 1.5 cm was relatively uniform throughout the temperature and holding time. Thus, the torrefaction process of coconut shell of the size of 1.5 cm is homogeneous, especially at holding time 30 and 45 minutes. Then on the size of 3 cm (Figure 4b) showed that the highest calorific value was obtained at temperature 350°C for the entire time-temperature resistant (15, 30 and 45 minutes).

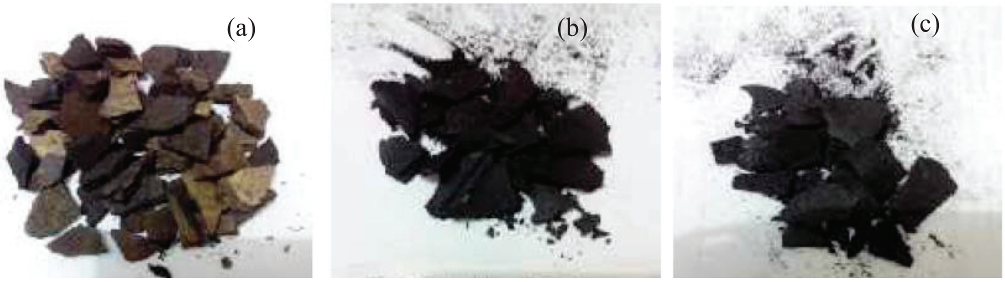

FIGURE 2. Torrefaction product of coconut shell at temperature 250°C and size 1.5 cm at the holding time (a) 15 minutes, (b) 30 mintues and (c) 45 minutes

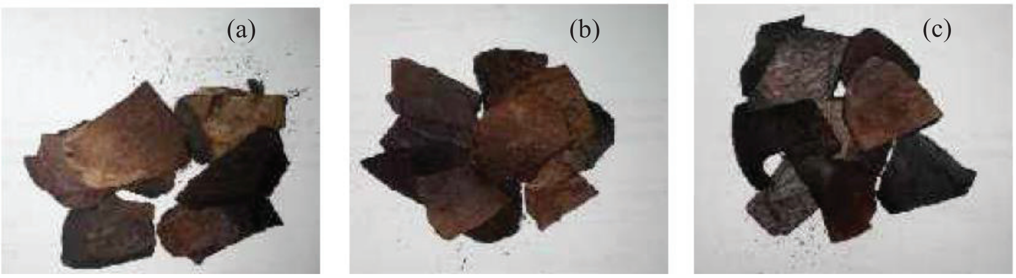

FIGURE 3. Torrefaction product of coconut shell at temperature 250°C and size 4 cm at the holding time (a) 15 minutes, (b) 30 mintues and (c) 45 minutes

Torrefaction product quality of coconut shell was not only observed on energy content but also on the mass yield at the end torrefaction process. The mass of coconut shell decreased due to the the loss of a constituent component of coconut shell then some combustible gas in volatile matter releasing from coconut shell. The loss of volatile matter of combustible gas was influenced by the torrefaction temperature. At high temperatures (350°C), the pores were wide open so more component of volatile matter that fills the pores comes out from inside of coconut shell. At highest temperature (350°C) resulted lowest mass yield by an average of around 30% (Figure 5). Then, at a temperature of 300°C also still showed many of the components making up the lost component mass average yield of about 40%. At the lower temperature conditions 250°C showed still high mass yield an average of 65%. Thus, the torrefaction process of coconut shell is very effectively took place at a temperature of 250°C.

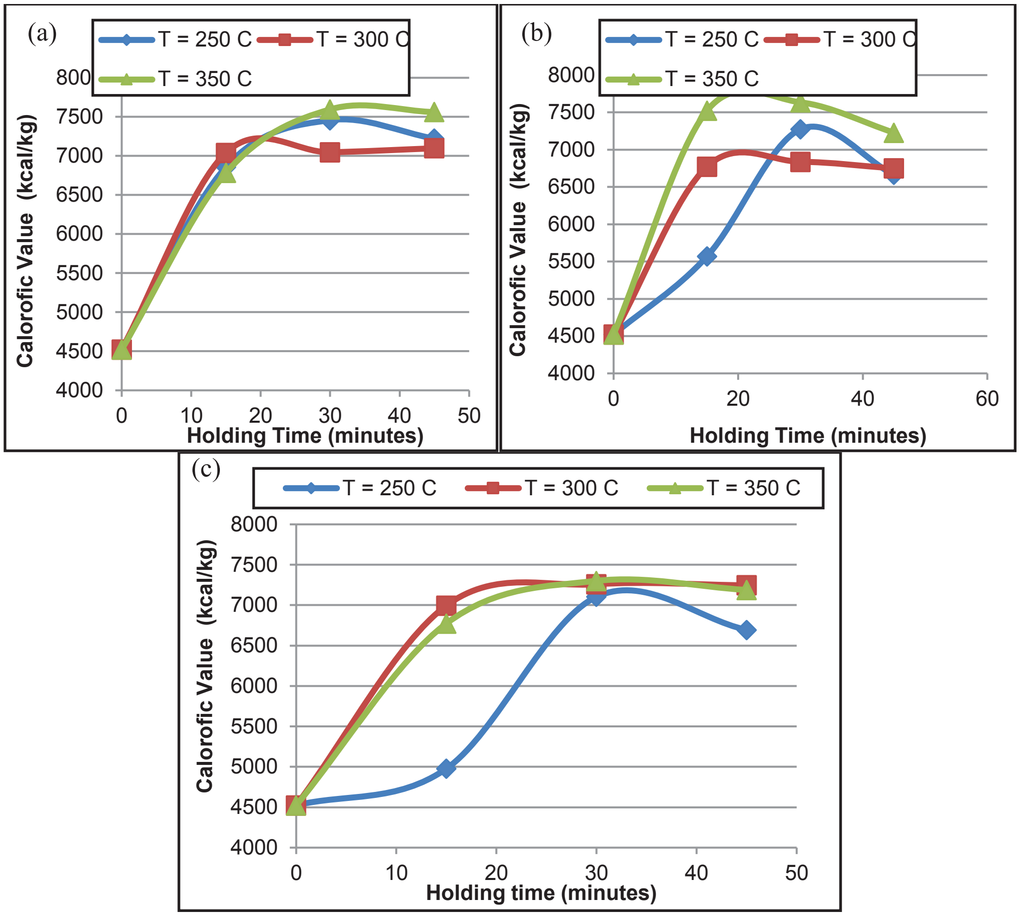

FIGURE 4. Influence of Holding Time to the Calorific Value of Coconut Shell Torrefaction for Torrefaction Temperature 250, 300, 350°C and size (a) 1.5 cm (b) 3 cm and (c) 4 cm

From Figure 4a and 4b, torrefaction temperature at 250°C showed that the conditions of coconut shell size at 1.5 cm has a calorific value above 7000 kcal / kg at holding time 30 and 45 minutes. But the shell size of above 3 cm the calorific value of 7000 kcal / kg was achieved only at the holding time of 30 minutes. This situation shown that the size of the coconut shell 1.5 cm was more stable to achieve a homogeneous conditions compared to coconut shell size 3 cm. Coconut shell on the size of 3 cm have a longer distance to the process of heat and mass transfer between the location of the agent to fly to the outer wall of a coconut shell. Thus coconut shell size 1.5 cm more optimal at torrefaction process, especially at a temperature of 250°C.

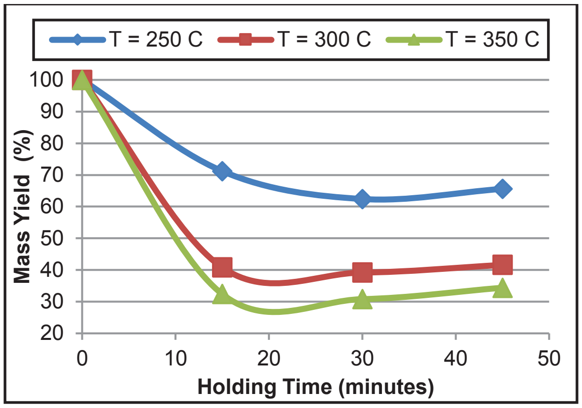

FIGURE 5. Influence of Holding Time to the Mass Yield (%) of Coconut Shell Torrefaction by Varying the Torrefaction Temperature (250, 300, 350°C) at Size 3 cm

Further analysis holding time of torrefaction process at temperature 250°C. Table 2 showed that the size of 1.5 cm was more effective than 3 cm of torrefaction coconut shell in calorific value, energy yield and mass yield. Coconut shell on the size of 1.5 cm would be more effective of torrefaction process to be taken place at holding time of 30 minutes compared to the holding time of 15 or 45 minutes. At the holding time 15 minutes indicated the calorific value was still low because there is some non-combustible gas of volatile matter that has not come out of the pores of coconut shell. Then on 45 minutes holding time, combustible gas from volatile matter went out more than in the coconut shell pores so that the calorific value is lower than the holding time of 30 minutes. Thus, the optimum conditions for torrefaction of coconut shell was temperature 250°C, holding time 30 minutes and coconut shell size 1.5 cm.

TABLE 2. Calorific Value, Energy Yield and Mass Yield of Coconut Shell Torrefaction at temperature 250°C

Operation Condition		Size (cm)	Calorific Value (kkal/kg)	Energy Yield (%)	Mass Yield (%)
Temperature (°C)	Holding Time (minutes)				
250	15	3	5570	87.68	71.2
	30		7275	100.37	62,4
	45		6664	96.65	65.6
	15	1.5	6859	101.30	66.8
	30		7458	108,17	65.6
	45		7221	101.54	63.6

CONCLUSION

Torrefaction of coconut shell can produce high colorific value and more uniform coconut shell especially small size of coconut shell. High temperature of torrefaction can release more mass of coconut shell although the calorific value was high. The holding time of torrefaction can change the composition of volatile matter. The shortest of holding time of torrefaction can produce low calorific value but the longest of holding time of torrefaction can produce high calorific value with high mass loss.

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