The Prediction of Optimal Torrefaction Condition Palm Kernel Shell based on Elemental Composition

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Abstract: Utilization of biomass as an energy source is very important, especially by-products from forestry, plantations, and livestock. Biomass as fuel still has many disadvantages, both in terms of water content, calories, and weight. To overcome this, a thermochemical process is needed, namely Torrefaction. Torefaction 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. 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 0C - 300 0C and 20-40 minutes then analyzed ultimate. The high heating value is predicted using ultime data calculated by the equation of Chang Dong and Azevedo, Fried, and Özyuğuran then used to determine energy yield. The optimum process for torrefaction of palm kernel shell according to calorific value and energy yield is 275 0C with residence time 20 minutes.

1 INTRODUCTION

Utilization of biomass as an energy source is very important, especially by-products from forestry, plantations and livestock (Mafu et al. 2016; Mamvura, Pahla, and Muzenda 2018; Mohd Faizal et al. 2018). Based on the Intergovernmental Panel on Climate Change (IPCC) declaration on the Climate Change Synthesis Report indicated 25% of greenhouse gases came from the electricity and heat industry, where 40% came from the coal industry. Under these conditions, potential raw materials that are environmentally friendly and sustainable and can be integrated with steam power plants are biomass. Compared to other environmentally friendly energy such as solar and wind cells, biomass has advantages instability and can be controlled according to needs.

Biomass as fuel still has many disadvantages, both in terms of water content, calories, and weight. To overcome this, a thermochemical process is needed, namely Torrefaction (Z.c, H.j, and D.m.j 2017; Barta-Rajnai et al. 2017; Pahla et al. 2017). 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 (Thaim and Rasid 2016; Bach, Skreiberg, and Lee 2017).

The heating value of biomass is an important parameter for the planning and the control of power plants using this type of fuel (Friedl et al. 2005). 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 (Mamvura, Pahla, and Muzenda 2018). Thus, the focus was on finding the optimized torrefaction parameters, which has an energy yield of more than 100%.

In this study of palm kernel shell torrefaction was carried out from 0.5 cm sieve with three variations in

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temperature, and residence time follows 250 ^{0}C - 300 ^{0}C and 20-40 minutes then analyzed ultimate. The high heating value (HHV) is predicted using ultimate data calculated by the equation of Chang Dong and Azevedo, Fried, and Özyuğuran then used to determine energy yield.

2 METHODS

2.1 Preparation and Torrefaction

Palm kernel shells dried in the sun for 3 days to reduce the moisture content. The feedstock size is reduced to a size of ± 0.5 cm. Torrefaction process is then performed. The torrefaction process is shown in Figure 1, with an inert condition (Thaim and Rasid 2016), the torrefaction temperature varied from 250°C, 275°C, 300°C (Pahla et al. 2017), with residence time varied 20, 30 dan 40 minutes (Mamvura, Pahla, and Muzenda 2018; Pahla et al. 2017; Pahla, Ntuli, and Muzenda 2018).

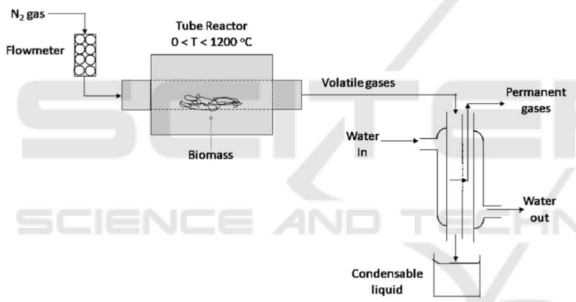

Figure 1: Schematic of Terrefaction Proces (Mamvura, Pahla, and Muzenda 2018)

2.2 Ultimate Analysis

The ultimate analysis is done using the TruSpec CHN tool from Leco Inc. based on ASTM D 5373-16 standards (to determine the composition of carbon, hydrogen, and nitrogen). The proximate and ultimate analysis is carried out on samples before treatment and after the torrefaction on the process. (Mohd Faizal et al. 2018; Susanty, Helwani, and Zulfansyah ' 2016; Nyoman Sukarta and Sri Ayuni 2016)

2.3 Prediction HHV and Energy Yield

2.3.1 Prediction of HHV

The high heating value is predicted using ultime data calculated using following the equation of Chang Dong and Azevedo, Fried, and Özyuğuran:

(Chang Dong and Azevedo 2005)

$$HHV(MJ/Kg) = -1.3675 + 0.3137C + 0.7009H + 0.0318O$$

(Friedl et al. 2005)

$$HV(MJ/Kg) = 0.00355C^2 - 0.232H - 2.23H + 0.0512CH + 0{,}131N + 20.6$$

(Özyuğuran, Yaman, and Küçükbayrak 2018)

$$HHV(MJ/Kg) = -4.6246 + 0.2732N + 0.4120C + 0.5992H + 0.01841O$$

Where: C = percentage of carbon; H = percentage of hydrogen; N= percentage of nitrogen; O = percentage of Oxygen

2.3.1 Prediction of Energy Yield

Two parameters are used to determine the success of the torrefaction process are mass yield and energy yield. The focus in the torrefaction process is to get a high HHV value and low mass loss due to this process (Lau et al. 2018; Mohd Faizal et al. 2018; Rodrigues, Loureiro, and Nunes 2018).

1) Mass yield computed as

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

Where M_r is mass of raw biomass and M_t is mass of torrefied biomass.

2) 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 biomass after and before torrefaction.

3 RESULTS AND DISCUSSION

3.1 Ultimate Analysis and Prediction HHV Value

Palm Kernel shell was ultimately analyzed before and after torrefaction to obtain the elemental composition and predict the HHV value. An increase in carbon and hydrogen, while the decrease in nitrogen and oxygen levels of palm shell were obtained after torrefaction, as shown in Table 1.

It was known that hydrogen (H_2) and oxygen (O_2) are the main components in biomass that most lost during the torrefaction process. Oxygen (O_2) is the main component in the formation of the volatile compound, which can produce an abundant phenol at a temperature range of 200-300 ^oC. Whereas hydrogen (H_2) is the main component of liquid smoke (condensate) constituents as a result of the torrefaction process. It has been reported that the ratio of carbon (C) to hydrogen (H_2) will increase and volatile levels will decrease with reducing hydrogen and oxygen levels which is indicated that the high quality of fuels has low O/C and H/C (Chen et al., 2017).

The ratio of O/C has a large influence on the heating value of materials. Pahla et al. reported that a decrease in the O/C ratio would result in an increase in heating value. When the ratio of O/C was so huge, the chemical energy was also relatively high, thereby reduce in gasification efficiency due to excessive oxidation. Moreover, in the combustion process, carbonization causes increasing carbon and hydrogen content and decreasing oxygen content. Therefore, torrefaction plays an important role in obtaining the low heating value of palm shell.

As shown in Table 1, the highest carbon value was ultimately obtained at a temperature of 275^{o}C, and the oxygen was significantly decreased causes the O/C ratio is lower than other temperatures. The prediction of HHV values based on three different equations also shows that the HHV value at 275^{o}C is greater than the others. The holding time of 30 minutes has the lowest H/C and O/C ratio and the highest HHV value. This result indicates that the temperature of 275^{o}C was used to get the optimum time of the torrefaction process.

There was a difference in the results of the final analysis between the effect of temperature and residence time. Whereat temperature of 275 ^{o}C and residence time 40 minutes the ratio of H / C and O / C is higher compared to the conditions during time variation. This is due to different water levels at the end of the torrefaction process, which affects the calculation of O.

Table 1: Elemental composition and prediction of HHV value

Condition of Torrefaction	**N (%)**	**C (%)**	**H (%)**	**O (%)**	**O/C**	**H/C**	**HHV (MJ/Kg)**		
							Chang-Dong and Azevedo	**Fried**	**Özyuğuran**
Control	0,42	36,69	3,74	47,4	1,29	0,10	14,27	15,61	13,72
Temperature effect (40 minutes resident time)									
250 °C	1,05	44,93	5,54	44,05	0,98	0,12	18,01	17,87	18,31
275 °C	0,98	52,38	5,58	37,79	0,72	0,11	20,18	20,84	21,26
300 °C	1,10	52,01	5,32	38,91	0,75	0,10	19,91	20,58	21,01
Resident time effect (temperature 275 ^{o}C)									
20 minute	1,29	63,43	4,99	26,49	0,42	0,08	22,87	25,42	25,34
30 minute	1,32	65,47	4,87	24,83	0,38	0,07	23,37	26,26	26,08
40 minute	1,20	61,61	4,62	29,30	0,48	0,07	22,13	24,21	24,39

3.2 Prediction of Energy Yield

To determine the optimal conditions of the torrefaction process not only based on calorific values but also must consider the mass lost or mass yield of the process (Mamvura, Pahla, and Muzenda 2018; da Silva et al. 2018). 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 1 or 100%, the torrefaction process has been able to increase the energy that can be used in biomass. Based on the HHV values, the energy yield results are shown in Table 2, Table 3, and Table 4.

Table 2: Energy yield prediction base on Chang-Dong and Azevedo equation

Condition of Torrefaction	Mo (g)	Mt (g)	Cvi (MJ/Kg)	CVt (MJ/Kg)	Weigh Loss	Mass Yield	Energy Yield
Temperature effect (40 minutes resident time)							
250 °C	500	371	14,27	18,01	25,80	74,20	0,94
275 °C	500	313	14,27	20,18	37,40	62,60	0,89
300 °C	500	236	14,27	19,91	52,80	47,20	0,66
Resident time effect (temperature 275°C)							
20 minute	500	327	14,27	22,87	34,60	65,40	1,05
30 minute	500	295	14,27	23,37	41,00	59,00	0,97
40 minute	500	271	14,27	22,13	45,80	54,20	0,84

Table 3: Energy yield prediction base on Fried equation

Condition of Torrefaction	Mo (g)	Mt (g)	Cvi (MJ/Kg)	CVt (MJ/Kg)	Weigh Lost	Mass Yield	Energy Yield
Temperature effect (40 minutes resident time)							
250 °C	500	371	15,61	17,87	25,80	74,20	0,85
275 °C	500	313	15,61	20,84	37,40	62,60	0,84
300 °C	500	236	15,61	20,58	52,80	47,20	0,62
Resident time effect (temperature 275 °C)							
20 minute	500	327	15,61	25,42	34,60	65,40	1,06
30 minute	500	295	15,61	26,26	41,00	59,00	0,99
40 minute	500	271	15,61	24,21	45,80	54,20	0,84

Table 4: Energy yield prediction base on Özyuğuran equation

Condition of Torrefaction	Mo (g)	Mt (g)	Cvi (MJ/Kg)	CVt (MJ/Kg)	Weigh Loss	Mass Yield	Energy Yield
Temperature effect (40 minutes resident time)							
250 °C	500	371	13,72	18,31	25,80	74,20	0,99
275 °C	500	313	13,72	21,26	37,40	62,60	0,97
300 °C	500	236	13,72	21,01	52,80	47,20	0,72
Resident time effect (temperature 275ºC)							
20 minute	500	327	13,72	25,34	34,60	65,40	1,21
30 minute	500	295	13,72	26,08	41,00	59,00	1,12
40 minute	500	271	13,72	24,39	45,80	54,20	0,96

Generally, based on the HHV values of the three equations used to show similar results. Based on the results of temperature variations, the highest energy yield value is at 250 ºC and continues to decline with increasing temperature. This is caused by the length of residence time, which causes a large mass loss. In these conditions, there is no energy yield value that exceeds 1, meaning that the process of torrefaction under these conditions cannot increase the amount of energy that can be used. A different result is shown by energy yield with the variation of time at a temperature of 275 ºC with a residence time of 20 minutes at the torrefaction process can produce energy yields bigger than 1, which means that under these conditions the torrefaction process can increase the value of calories and energy that can be used.

4 CONCLUSIONS

The torrefaction process is not only concerned with the value of HHV obtained but also causes the mass lost. Based on the results of HHV value and energy yield, the optimum conditions were achieved using the Batch method with a temperature of 275 ºC and the residence time of 20 minutes. In this condition, the torrefaction process succeeded in reducing the O/C and H/C ratios and increasing the fuel energy of the palm kernel shell.

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