Torrefaction Treatment on Fuel Properties of *Bambusa vulgaris* and *Gigantochloa scorthecinii*

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Abstract*: There is a great potential for bamboo to be applied as a biofuel for the future due to its good fuel properties with low alkali index and fast growth rate. Torrefaction treatment can increase the fuel quality of biomass in terms of the calorific value, energy density and storability. The aim of this research was to explore the effect of torrefaction temperature and reaction time on the fuel properties of B. vulgaris and G. scorthecinii. The bamboos were treated at various torrefaction temperatures (200, 250 and 300˚C) and reaction time (15, 30, 45 mins). In overall, the highest higher heating value was obtained from bamboos torrefied at 300ºC for 45 mins. In general, the temperature used in torrefaction has a relatively stronger effect on the higher heating value while the impact of the residence time was considerably lesser.

***Index Terms*: Bioenergy; Lignocellulosic Biomass; Bamboo; Torrefaction**

I. INTRODUCTION

Lignocellulosic biomass is characterized as an organic and manageable material from plants. Lignocellulosic biomass such as bamboo is highly potential to be used as future source for biofuel due to its good fuel properties with low alkali index and fast growth rate [1,2]. Utilizing lignocellulosic biomass such as bamboo for power generation may be one of the options to reduce the fossil fuel reliance. There are numerous methods, to convert lignocellulosic biomass into fuel such as thermal treatment, chemical treatment and biological treatment. Thermal treatment is the most common used process to increase the fuel quality of the lignocellulosic biomass. The process in the thermal treatment include phases of combustion, gasification and pyrolysis of biomass which produce different end products [3,4].

Torrefaction is a low-temperature thermal treatment on the lignocellulosic biomass that capable to increase the fuel properties in terms of the energy density, grindability and storability [5,6]. In this method, biomass was carbonized with the temperature extended around 200˚C to 300˚C in an inert atmosphere. Throughout the thermal treatment process, the moisture content (MC) in the lignocellulosic biomass is significantly diminished and low.

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The torrecfaction treatment destroy the fibrous structure and tenacity of the constituents, but it additionally benefits to enhance the higher heating value [7]. Organic volatile matter components are released during torrefaction treatment and produced hydrophobic solids with higher fixed carbon content [7,8]. The biomass devolatilizes that leads to decrement in weight while conserving the initial energy content in the form of solid.

II. MATERIALS AND METHODOLOGY

Matured *Bambusa vulgaris* and *Gigantocholoa scortechini* bamboo within 5 years to 6 years of time were obtained from a field in Raub, Pahang. Harvested bamboo were chosen randomly from the stands with the diameter of culms ranging between 90 - 110 cm and were cut at a height of 30 cm from the ground. The node and internode were separated and oven dried at 110˚C for 24 hrs. The bamboos were cut into strips with the size of 1 cm width and 3 cm length. All the samples were stored in cold rooms at a temperature of 4 °C to prevent fungal attack.

The samples were oven dried before the torrefaction treatment. The torrefaction conditions used in this study were 200, 250 and 300ºC for 15, 30 and 45 mins, respectively. Each of the torrefaction treatment were performed in triplicate.

Torrefied biomass were tested on the volatile content. The weight of the crucible and the biomass were recorded. The crucibles containing the biomass were then heated in a furnace at 900°C for 7 mins. The volatile content (VM) was calculated according to Eq. 1:

$$\text{Volatiles (\%)} = \frac{100\, x\, (w2-w3)}{(w2-w1)} \qquad \text{(Eq. 1)}$$

Where, w1 is the mass of the crucible, w2 is the mass of oven-dry biomass and w3 is the mass of biomass after heated at 900°C for 7 mins. The ash content was obtained using CEN/TS 14775 method. The oven-dried biomass was inserted in the furnace at 550 ± 10°C for 4 hr.

The fixed carbon (FC) content was determined using Eq. 2:

FC (%) = 100 – (VM % + Ash content % + MC %)(Eq. 2)

Higher heating value (HHV) was determined with a bomb calorimeter using BSI standard EN 14918. The torrefied samples (0.50 g) were combusted under 3000 kPa pressured oxygen atmosphere. Statistical Package for the Social Science (SPSS) was used to analsed the fuel properties of the torrefied bamboos. The differences on the effects of the treatment were determined by Tukey test (HSD) multiple comparison test when significant difference was observed between treatments. When the p-value was higher than 0.05 ($p > 0.05$) at 95% confident level, the treatment effects were considered to be insignificant.

III. RESULTS AND DISCUSSIONS

Table 1 and Table 2 show the fuel properties of the untreated and torrefied bamboos according to node and internode. The HHV are slightly higher in the node section for both bamboo species. Slightly lower HHV was obtained from the bamboo species when compared to woody biomass, however, higher than most grasses and straw reported by Nordin [9].

Table 1: The fuel properties of untreated bamboos according to node and internode.

Species	Section	HHV (MJ/kg)	VM (%)	FC (%)	Ash (%)
B. vulgaris	Node	18.41[a]	75.54[b]	18.27[a]	1.57[a]
	Internode	17.07[b]	85.54[a]	16.97[b]	1.06[b]
G. scorthecinii	Node	18.44[a]	80.34[b]	18.44[a]	1.76[a]
	Internode	17.52[b]	82.10[a]	16.64[b]	1.15[b]

Note: Means followed by the same letter in the same column for each species are not significantly different at p≤ 0.05 using Tukey (HSD) analysis.

The volatile content was higher in the internode section with the value of 85.54% for *B. vulgaris* and 80.34% for *G. scorthecinii*). The carbon (FC) and ash content were higher in the node section for both species. The ash content of the species used in this study is higher than the woody plants but lower than most of the herbaceous plants such as grass and straw which are reported by Scurlock et al. [4]. Compared to B. vulgaris, *G. scorthecinii* overall has a higher value in all the fuel properties regardless of the sections (node and internode).

Table 2. The fuel properties of torrefied bamboo according to node and internode.

Species	Section	HHV (MJ/kg)	VM (%)	FC (%)	Ash (%)
B. vulgaris	Node	22.08[a]	70.72[b]	21.77[a]	1.90[a]
	Internode	18.14[b]	79.03[a]	19.29[b]	1.66 [b]
G. scorthecinii	Node	21.22[a]	77.21[b]	22.03[a]	1.71[a]
	Internode	18.59[b]	79.73[a]	19.25 [b]	1.29 [b]

Note: Means followed by the same letter in the same column for each species are not significantly different at p≤ 0.05 using Tukey (HSD) analysis.

The torrefaction temperature used in this study were 200, 250 and 300ºC. The average values of the fuel properties are shown in Table 3. The HHV increased with the increasing of temperature which ranged from 18.90 MJ/kg to 21.91 MJ/kg for *G. scorthecinii*. While, the HHV values for *B. vulgaris* were ranged from 18.68 MJ/kg to 21.56 MJ/kg. According to Rousset et. al. [3], lignin which has a higher HHV value deteriorated at a more drastic temperature in comparison to hemicellulose and cellulose. Lignin accommodate in the torrefied biomass even after high temperature treatment which increased the overall HHV value of the biomass [10].

The volatile content decreased, with the increased of treatment temperature. With the temperature increased from 200 to 300ºC, the amount of volatile matter reduced from 78.79% to 77.04% for *G. scorthechini* and 78.74% to 76.12% for B. vulgaris (Table 3). This is due to the effect of the temperature on the degradation of organic matters in the bamboo. The organic matters in the lignocellulosic biomass devolatilized during torrefaction, thus reduced the amount of volatile content in the biomass [11,12]. The increased temperature from 200˚C to 300˚C, increased the ash content ranging from 1.65% to 1.44% for B. vulgaris and 1.62% to 1.91% for *G. scorthecinii*.

Table 3. Effect of torrefaction temperature on the fuel properties according to Tukey's test analysis.

	B. vulgaris		
	200ºC	250ºC	300ºC
HHV (MJ/kg)	18.90[c]	19.95[b]	21.91[a]
VM (%)	78.79[a]	78.72[b]	77.04[c]
FC (%)	19.52[c]	21.07[b]	22.30[a]
C (%)	34.08[c]	34.67[b]	36.20[a]
N (%)	0.66[a]	0.65[ab]	0.61[c]
Ash (%)	1.52[b]	1.44[c]	1.65[a]
	G. scorthecinii		
	200ºC	200ºC	200ºC
HHV (MJ/kg)	18.68[c]	18.68[c]	18.68[c]
VM (%)	78.74[a]	78.74[a]	78.74[a]
FC (%)	19.52[c]	19.52[c]	19.52[c]
C (%)	33.29[c]	33.29[c]	33.29[c]
N (%)	0.54[a]	0.54[a]	0.54[a]
Ash (%)	1.62[b]	1.62[b]	1.62[b]

Note: Means followed by the same letter in the same row for each species are not significantly different at p≤ 0.05 using Tukey (HSD) analysis.

The increasing percentage of carbon content with the increased of temperature, contributed to a higher HHV. Carbon oxidized during combustion which causes exothermic reaction. Therefore, with the percentage of carbon increased, the HHV is as well increased [13]. The percentage of nitrogen decreased when the temperature increased. However, nitrogen content has no effect on the HHV.

The residence time is one of the important parameters that affect the fuel characteristics of bamboo during torrefaction treatment. The residence time used in this study were 15, 30 and 45 mins. The mean value of fuel properties are shown in Table 4. With the increased of residence time, the volatile matter content dropped from 79.48% to 77.20% for *G. scorthecinii* and 78.65% to 75.49% for *B. vulgaris*. The carbon content increased in both species by prolonging the torrefaction time. Meanwhile, nitrogen content reduced with the increased of residence time, from 0.68% to 0.65% for B. vulgaris and 0.47% to 0.43% for *G. scorthecinii*. The ash content increased with the increased of residence time. The ash content ranged from 1.46% to 1.62% for *G. scorthecinii*, and 1.70% to 1.85% for B. vulgaris. In overall, with extended reaction time, the higher the HHV.

Table 3. Effect of reaction time on the fuel properties according to Tukey's test analysis.

	B. vulgaris		
	15 mins	30 mins	45 mins
HHV (MJ/kg)	19.25^{c}	19.86^{b}	21.19^{a}
VM (%)	79.48^{a}	78.35^{b}	77.20^{c}
FC (%)	19.65^{c}	20.70^{b}	22.02^{a}
C (%)	33.94^{c}	34.81^{b}	35.78^{a}
N (%)	0.68^{a}	0.66^{b}	0.65^{c}
Ash (%)	1.46^{c}	1.50^{b}	1.62^{a}
	G. scorthecinii		
	15 mins	30 mins	45 mins
HHV (MJ/kg)	19.44^{c}	20.18^{b}	20.72^{a}
VM (%)	78.65^{a}	77.48^{b}	75.49^{c}
FC (%)	19.27^{c}	20.47^{b}	21.85^{a}
C (%)	33.46^{c}	34.21^{b}	35.25^{a}
N (%)	0.47^{a}	0.45^{ab}	0.43^{c}
Ash (%)	1.70^{c}	1.79^{b}	1.85^{a}

Note: Means followed by the same letter in the same row for each species are not significantly different at $p \leq 0.05$ using Tukey (HSD) analysis.

IV. CONCLUSIONS

Torrefaction is a pre-processed technique that have a positive impact on the bamboo as an alternative source of bioenergy. In general, torrefaction was found effective in increasing the quality of solid fuel produced from the bamboos. The torrefaction temperature has a relatively stronger effect on the HHV, while, the impact of the residence time was considerably lesser. The highest HHV was achieved using torrefaction temperature 300ºC with the residence time of 45 mins. Both of the species shows a positive effect after torrefaction treatment.

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