Some Laboratory Studies on the Carbonization of Briquetted Tropical Wood Sawdust

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ABSTRACT

Commercially produced tropical wood sawdust briquettes were carbonized in our laboratory using a muffle furnace. The carbonization was done at different terminal temperatures with different rates of temperature increase. The emissions produced during the carbonization process were also condensed and collected. The results indicate that charcoal, of higher yield, lower moisture and with fewer numbers of cracks appearing on the product, are produced when the rate of heating is slower. Fixed carbon contents (dry basis) as high as 86% can be achieved when the sample is carbonized at a terminal temperature of 650 °C. The amount of condensate collected was found to be quite independent of the terminal carbonization temperature when the heating rate was low but decreased as terminal temperature increased when the heating rate was higher. The pH value of all condensates was found to be 3.

1. INTRODUCTION

As we are all aware, tropical rain forests are home to hundreds of tree species. In Malaysia, some of these species are harvested for their timber. The harvested trees are then processed into sawn timber or plywood and in the process large quantities of wastes such as bark and sawdust are produced. Lim et al.[1] estimated that in 1995 the timber industry in Malaysia generated roughly 0.226 billion kg of dry sawdust. Some of these sawdust are used as fuel within the timber and plywood mills while substantial quantities are briquetted and carbonized to produce charcoal. Presently in Malaysia, there are 10 such operations doing the latter and together they produce some 2 million kg per month of export quality charcoal [2]. Even so such commercial operations still encounter problems in that at times numerous cracks appear on the charcoal product. In addition the quality of the charcoal produced is also below expectation in certain runs. As such a project was initiated in our laboratory to determine the effect of the rate of temperature rise and terminal carbonization temperature on the quality of the charcoal produced. In addition, the amount of condensates obtainable from the emissions of the carbonization process was also investigated. The following is a report of that study.

2. METHOD

Sawdust briquettes from a commercial operation in Mentakab in the state of Pahang, Malaysia were used in our study. The briquettes were of hexagonal cross-section with a circular hole in the centre (see Figure 1). The width of the briquettes was about 0.053 m while the diameter of the central hole was about 0.018 m. For our study the briquettes were cut into lengths of about 0.118 m so as to fit the sample holder as explained below.

A muffle furnace (Thermolyne F6000) was used for carbonizing the briquettes. The cut briquettes were first placed in a cylindrical stainless-steel sample holder that had a cap that could be screwed on tight and an outlet port for the escape of volatiles. This sample holder was then placed inside the muffle furnace with its outlet port exiting the furnace via an opening at the furnace top. The furnace was programmed to heat at 2 constant rates of 2 ^oC min^{-1} and 15 ^oC min^{-1} to various predetermined terminal temperatures. When the preset terminal temperature was attained, carbonization was allowed to continue at that temperature for 1 hour. Terminal temperatures of 400 ^oC to 650 ^oC (in steps of 50 ^oC) were chosen for the study. Emissions from the carbonization process which exited via the outlet port of the sample holder were led through a condenser which also had an outlet for gaseous products, that could not be condensed, to escape to the outside of the laboratory. The amount of condensate produced was determined immediately after the completion of each carbonization experiment.

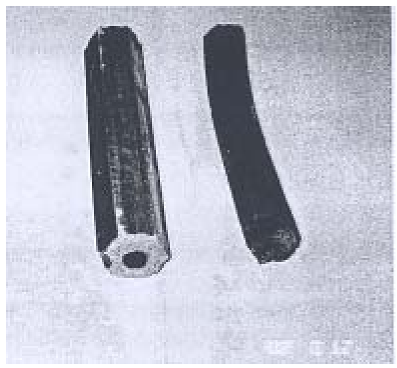

Fig.1 Commercially produced tropical wood sawdust briquettes before (left) and after (right) carbonization.

For each of the 12 sets of carbonization conditions, 3 runs were carried out. Before the start of each experiment, the moisture content of the sample used was determined. The values found varied from about 6.5% to 7.3% of the sample weight. After each carbonization experiment, the sample holder was left to cool for about 24 hours before it was opened and the yield as well as the number of cracks on the carbonized briquette determined. The charcoal produced was left exposed in the laboratory for a further 2 days before being analyzed for moisture, ash and volatile contents as per ASTM D 3173 [3], D 3174 [4] and D 3175 [5] respectively. The fixed carbon content was then calculated. Corresponding values for the raw uncarbonised briquettes were similarly determined.

3. RESULTS AND DISCUSSION

The average density of the sawdust briquettes used in our studies was around 1290 kg m^{-3} and proximate analyses provided the following average values (dry basis) for the raw briquettes:

Ash content 1.3%
Volatile content 79.1%
Fixed carbon 19.6%

Charcoal yield is defined as

$$\frac{\text{Weight of the charcoal produced}}{\text{Weight of the sawdust briquette used}}$$

Table 1 is a summary of the results found for the experiments performed at the 2 different rates of temperature rise or heating rates. Each entry under the yield and total number of cracks columns is the average of 3 runs while each entry for the proximate analyses is the average of 6 determinations as 2 determinations were done for each run.

For both the heating rates, yield decreased as terminal temperature increased. This observation is to be expected as more volatiles are released at higher temperatures thus lowering yields. The yield values for the 15 ^{o}C min^{-1} temperature rise were observed to be consistently lower than the values found at the 2^{o}C min^{-1} temperature rise. This therefore indicates that to maximize yield a slower rate of heating is desirable.

For the slower rate of temperature rise the total number of cracks found on the product does not appear to be dependent on the terminal temperature. The largest number of cracks observed in our samples was 10. However at the faster rate of temperature rise, the number of cracks found on the product was much higher and the number also increased with the terminal temperature. A value of 73 was found at a terminal temperature of 650 ^{o}C. This observation indicates that product appearance can be improved with a slower heating rate. That more cracks appear as the temperature rises faster may be due to the rapid expansion of components such as moisture, within the sample.

Since the products were allowed 2 days to equilibrate with the laboratory environment, the moisture values are perhaps of little significance. Any variation observed is a reflection of the state or condition of the product. A product with more cracks on it would be slightly more porous and therefore would absorb a greater amount of moisture from the environment. This explains the slightly higher moisture content of the products from the 15 ^{o}C min^{-1} runs.

Table 1 Yield and Properties of Charcoal Produced at Two Different Heating Rates
(Numbers within Brackets Denote Standard Deviations)

Temperature rise / Terminal temperature (°C)	2 °C min^{-1}						15 °C min^{-1}					
	Charcoal yield (%)	Total number of cracks	Moisture content (%)	Ash content (%)^{b}	Volatile content (%)^{b}	Fixed carbon content (%)^{b}	Charcoal yield (%)	Total number of cracks	Moisture content (%)	Ash content (%)^{b}	Volatile content (%)^{b}	Fixed carbon content (%)^{b}
400	33.8 (0.58)	4 (0.2)	5.1 (0.28)	3.1 (0.11)	34.3 (0.76)	62.7 (1.88)	31.4 (0.37)	33 (3.9)	5.7 (0.22)	2.5 (0.08)	32.7 (0.41)	64.8 (1.43)
450	32.2 (0.26)	9 (3.3)	5.2 (0.26)	3.0 (0.11)	30.6 (1.13)	66.5 (2.46)	29.8 (0.14)	36 (3.9)	6.0 (0.39)	2.8 (0.19)	25.6 (0.95)	71.6 (3.58)
500	29.9 (0.08)	10 (0.6)	4.7 (0.18)	3.2 (0.27)	19.8 (0.96)	77.1 (5.40)	28.2 (0.17)	51 (4.1)	5.8 (0.22)	3.0 (0.17)	22.8 (1.30)	74.2 (4.23)
550	28.5 (0.09)	9 (2.5)	4.2 (0.56)	3.1 (0.15)	18.6 (1.32)	78.3 (4.70)	26.0 (0.43)	63 (2.1)	5.3 (0.25)	3.3 (0.21)	19.4 (1.20)	77.3 (4.79)
600	27.4 (0.11)	5 (1.6)	4.7 (0.47)	3.3 (0.25)	13.1 (0.53)	83.6 (5.18)	25.0 (0.25)	69 (3.7)	6.0 (0.34)	3.4 (0.16)	15.4 (1.30)	81.3 (5.28)
650	26.9 (0.18)	8 (2.5)	6.4 (0.78)	3.8 (0.17)	9.8 (0.62)	86.4 (4.75)	24.3 (0.19)	73 (3.4)	7.1 (0.31)	4.2 (0.13)	9.8 (0.81)	86.1 (5.17)

^{b}Dry basis

The ash contents for both the heating rates appear to be comparable though there seems to be a slight increase when the terminal temperature increases. This trend is more pronounced at the faster heating rate. This observation suggests that when a higher terminal temperature is desired a slower rate of heating is preferred. The data for volatiles and fixed carbon contents indicate that as terminal temperature increases, the volatile content decreases while that of fixed carbon increases. This observation is to be expected as at higher temperatures, more volatiles are driven off. The data also indicate that the rate of temperature rise has very little effect on the volatile or fixed carbon contents. This observation is encouraging in that it is not detrimental to the contention above that to produce charcoal of higher yield, lower moisture and with less cracks appearing on the product, a slower rate of temperature rise is desired. A slower rate of heating would imply that for a given production time, the quantity of charcoal produced would be smaller thus there would be an impact on the overall economics of the operation. Whether this impact is positive or negative needs to be evaluated further.

Table 2. Charcoal and condensate yields and their total.
(numbers within brackets denote standard deviations).

Terminal temperature (°C)	2 °C min^{-1}			15 °C min^{-1}		
	Charcoal yield (%)	Condensate yield (%)	Total yield of charcoal and condensate (%)	Charcoal yield (%)	Condensate yield (%)	Total yield of charcoal and condensate (%)
400	33.8 (0.58)	43.8 (0.67)	77.6	31.4 (0.37)	47.8 (0.15)	79.2
450	32.2 (0.26)	44.8 (0.92)	77.0	29.8 (0.14)	46.3 (1.28)	76.1
500	29.9 (0.08)	44.8 (1.49)	74.7	28.2 (0.17)	45.8 (0.59)	74.0
550	28.5 (0.09)	45.1 (2.56)	73.6	26.0 (0.43)	44.5 (1.31)	70.5
600	27.4 (0.11)	45.0 (2.62)	72.4	25.0 (0.25)	43.3 (0.77)	68.3
650	26.9 (0.18)	45.5 (1.77)	72.4	24.3 (0.19)	41.8 (1.38)	66.1

Table 2 shows the average results of the emissions collected as condensates.

Condensate yield is defined as

$$\frac{\text{Weight of condensate collected}}{\text{Weight of the sawdust briquette used}}$$

The amount of condensate collected, when expressed as a percentage of the original weight of the sawdust briquette used, appears to be independent of the terminal temperature when the rate of temperature rise is low. However when the rate of temperature rise is faster, the condensate yield decreases as terminal temperature increases. When both the yields of charcoal and condensate were summed, it was found that the total decreased as terminal temperature increased and for the lower rate of heating case, the decrease appeared to asymptote to a constant value. As discussed earlier, as terminal temperature increases, more volatiles from the raw material will be driven off. However this is not reflected in the quantities of condensates collected. Our results therefore imply that as terminal temperature increases, more and more non-condensable gaseous products are produced instead. It was also found that the pH value of all the condensates collected was 3

4. ACKNOWLEDGEMENTS

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