Optimization of the torrefaction process for rubberwood

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ABSTRACT - Biomass torrefaction is a thermochemical pretreatment process at a temperature range of 200-300^{0}C in an inert environment. Moisture and hemicellulose are released during the process resulting in an energy densified solid fuel. In this research, rubberwood is used to make torrefied wood inside a batch reactor. Temperature and the residence time are the two operating variables optimized. 250, 275 and 300 are considered as the experimentation temperatures kept at residence times of 30, 45 and 60min. A mass loss of 12% for rubberwood was observed. It can be observed that the higher heating value (HHV) increases with the increase of torrefaction conditions. From the experimentation results it can be concluded that the torrefaction conditions of 300^{0}C, 60min gives the optimum results.

Key words: Biomass torrefaction; Optimization; Rubberwood

INTRODUCTION

Fossil fuel is the main source of non-renewable energy that will eventually run out within the 21st century. Moreover, environmental pollution, global warming, green-house gases, SOx, NOx, particulate matter emission and public health issues influence to search for alternative energy sources which are renewable, environmentally sustainable, cost effective and healthy. Biomass is one such alternative energy source that is using throughout the world. Raw biomass which has a hydrophilic nature, high moisture, low energy density should be properly treated in order to use as an energy source in industrial applications.

Torrefaction is used as the pretreatment technology at a temperature range of 200^{0}C-300^{0}C in an inert environment to produce energy densified honey blond to dark blackish brown solid depending on the torrefaction conditions along with non-condensable gases and liquid products. Torrefied biomass can be used for co-firing applications in coal power plants and it may not only improve energy security and reduce emissions but also economically favorable if implemented with a structured supply chain. Industries with biomass boilers and furnaces can also be benefited by using torrefied biomass due to improved combustion process and reduction of the logistic cost. Many biomass types have been evaluated for torrefaction including woody biomass, forestry by-products, agricultural biomass and even municipal solid wastes. Rubberwood is a commonly used woody biomass type in Sri Lanka. It is used as a fuel after its latex yielding period of 25 years. Rubberwood is yet to be evaluated for torrefaction performance and therefore considered in this study.

METHODOLOGY

Torrefaction Process

Rubberwood was torrefied at 250^{0}C, 275^{0}C and 300^{0}C at atmospheric pressure under an inert environment for 30, 45 and 60min. The torrefaction was done in a stainless-steel horizontal batch reactor with a nickel-chrome heating coil. The reactor was insulated by porcelain accompanied by K-wool. N_2 gas was fed continuously throughout the process at a constant flow rate in order to maintain the inert environment and the required temperature.

Biomass Characterization

First, a thermogravimetric analysis (TGA) was performed for raw rubberwood from room temperature up to 800^{0}C in inert media to identify the thermal decomposition behavior of the wood. Based on the results suitable temperatures were selected for experimentation. Proximate analysis of torrefied biomass was performed using standard test methods ASTM E871, E872 and E830 for moisture content, volatile matter and ash content respectively and the balance was considered as the fixed carbon content. For the ultimate analysis, solid Perkin Elmer 2400 series II CHN analyzer was used and the remaining was considered as the O content.

The equation 1 was used to determine the higher heating value of torrefied biomass.

$$HHV = 34.91Y_C + 117.83Y_H + 10.05Y_S - 1.51Y_N - 10.34Y_O - 2.11Y_{ash} \quad (1)$$

Where,
HHV = Higher Heating Value (MJ/kg)
Y_x = Mass fraction of x

RESULTS AND DISCUSSION

TGA curves

According to the figure 1, during the moisture content release, the weight loss is about 5%. Then the hemicellulose starts to decompose around 260^{0}C. At 300^{0}C, which is the maximum operating temperature of torrefaction, 22% of Rubberwood has decomposed. Therefore, by analyzing these results, torrefaction was carried out within 250-300^{0}C for rubberwood.

Table 1. Ultimate analysis results

Wood type	Condition	C (%)	H (%)	N (%)	O (%)	HHV (MJ/kg)
Rubber	Raw	44.13	6.70	0.28	48.9	18.24
	275,30	45.15	6.46	0.25	48.10	18.39
	275,60	45.98	6.50	0.27	47.30	18.81
	300,30	45.58	6.38	0.22	47.80	18.48
	300,60	47.64	6.23	0.35	45.80	19.23

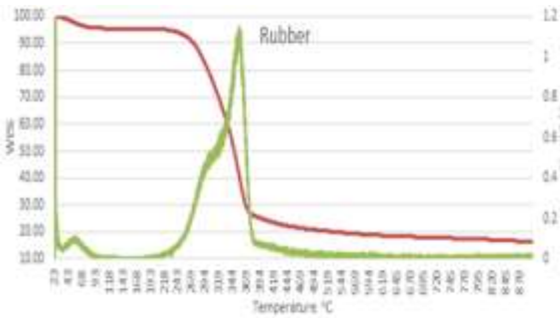

Figure 1. TGA curve for Rubberwood

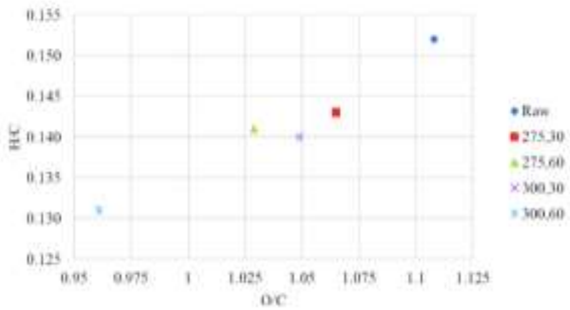

Figure 2. Van Krevelen diagram for Rubberwood

During decomposition of hemicellulose and cellulose, oxygen and hydrogen components are reduced while carbon is increased as in table 1. This results in lower H/C and O/C ratios. Figure 2 shows a similar pattern to the Van Krevelen diagram.

Table 2. Proximate analysis.

	Sample	Ash (%)	Volatile Matter (%)	Moisture (%)	Fixed C (%)
Rubber	Raw	0.4	73.2	11.2	15.2
	250,30	1.3	78.7	7.5	12.5
	250,45	1.6	77.2	8.1	13.1
	275,30	1.5	76.9	7.7	13.9
	275,45	2.1	76.3	8.4	13.2
	275,60	3.3	73.9	8.4	14.4
	300,30	3	75.4	8.4	13.2
	300,60	3.3	72.8	7.3	16.6

It can be seen that the moisture content and volatile matter decrease with the increase in temperature and residence time. But the ash content and fixed carbon content increase with the increase in temperature and residence time. These variations can be clearly seen from the table 2.

Table 3. Torrefaction experimentation results

Rubber	HHV (MJ/kg)	Mass Yield (%)	Energy Yield (%)
Raw	18.24		
275,30min	18.39	96.7	97.74
275,60min	18.81	93.7	96.86
300,30min	18.48	94.4	95.87
300,60min	19.23	87.9	92.88

Based on energy yield and mass yield results from the table 3, Energy Mass Co-benefit Index (EMCI) can be calculated.

EMCI = Energy Yield – Mass Yield (2)

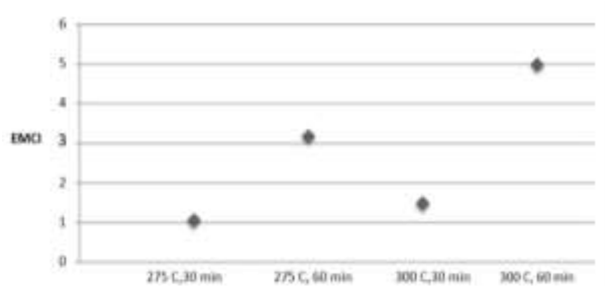

Figure 3. EMCI for Rubberwood

CONCLUSION

Mass yield, volatile matter, moisture content, oxygen and Hydrogen percentage reduce with the increase of torrefaction conditions while fixed carbon, ash content, carbon percentage and higher heating value increase with the increase of torrefaction conditions. A mass loss of 12% for rubberwood is observed generally. Our aim is to obtain a maximum energy yield. From the results obtained it can be concluded that the torrefaction conditions of 300^0C, 60min gives the best results because of maximum EMCI as in figure 3. Also torrefaction at 275^0C, 60min gives better results than 300^0C, 30min. EMCI increases with a higher residence time and with a higher temperature.

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