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Investigation on Co-combustion Characteristics of Cassava Rhizome and Eucalyptus Bark using Thermogravimetric Analysis

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Abstract

Decomposition behavior and (co-)combustion characteristics of pelletized cassava rhizome, eucalyptus bark, and their mixtures were studied with a thermogravimetric analyzer. A 15-mg biomass/blend sample was heated in the analyzer furnace with different heating rates and flowrates of the furnace gas (dry air/nitrogen). Characteristic temperatures (ignition and burnout temperatures) were obtained from the analysis of TG/DTG curves for the selected fuel options (blends) and operating conditions. From the study, eucalyptus bark has higher thermal and combustion reactivity, compared to cassava rhizome, thus showing its suitability as a secondary fuel in co-firing systems.

***Keywords**:* Thermogravimetric analysis, co-combustion, cassava rhizome, eucalyptus bark

1. Introduction

With an energy potential of 100 PJ/year, cassava is one of the major biomass energy resources in this country [1]. One of the cassava components, rhizome, is a waste biomass, characterized by a substantial calorific value. However, cassava rhizome includes a noticeable proportion of fuel-N, likely results in significant NO_x emissions when burning this biomass in a combustion system.

Co-firing of a biomass producing elevated NO_x with a low-potential (high-moisture) biomass in a single combustion technique is reported to result in the NO_x emission reduction, the rate of which is dependent on the combustion technique (co-firing of premixed fuels, or using fuel staging or using a reburning method) [2,3]. Eucalyptus bark seems to be a suitable biomass (with high moisture content) available in Thailand on a large scale.

A thermogravimetric analysis (TGA) is a tool widely used to investigate and compare the thermal and combustion reactivity of different biomasses [4,5]. The TG/DTG tests provide important data on devolatilization and combustion behavior, as well as on combustion characteristics (such as the ignition and burnout temperatures), of a biomass fuel. They can be used to support an interpretation of a co-combustion process in a real combustion system.

This study was aimed at investigating the thermogravimetric characteristics of cassava rhizome and eucalyptus bark and their mixtures with the aim to assess their thermal and combustion reactivity.

2. Materials and Methods

2.1 Properties of the biomasses

Table 1 shows the major properties of pelletized cassava rhizome (PCR) and eucalyptus bark (EB): the proximate and ultimate analyses, the composition of major chemical components (structural analysis), and the lower heating value (LHV). It can be seen in Table 1 that both biomasses had a substantial amount of volatile matter, a relatively low proportion of fixed carbon. From Table 1, the moisture content in PCR was rather low, whereas it was substantial in EB. The two biomasses had an elevated/high

Table. 1 Properties of PCR and EB

Fuel	Ultimate analysis (wt.%, on as-received basis)					Proximate analysis (wt.%, on as-received basis)				Chemical structure (wt.%, as dry and ash free)			LHV (MJ/kg)
	C	H	N	O	S	W	VM	FC	A	Hemi-cellulose	Cellulose	Lignin	MJ/kg
PCR	33.71	4.44	0.69	29.02	0.07	7.98	55.81	12.12	24.09	9.80	62.62	27.57	11.86
EB	26.85	3.14	0.17	23.84	0.02	37.67	43.68	10.34	8.31	0.52	70.88	28.60	9.22

content of ash (about 8% in EB, and 24% in PCR). As a result, LHV of the two biomasses was rather low: 11.86 MJ/kg for PCR, and 9.22 MJ/kg for EB. Note that the chemical structure of the fuels was obtained according to Ref. [6]. Like other lignocellulosic biomasses, PCR consisted mainly of three components, namely hemicellulose, cellulose and lignin. However, EB contained mainly cellulose and lignin with insignificant content of hemicellulose.

2.2. TG/DTG analysis

A “Mettler Toledo” TGA/DSC1 thermogravimetric analyzer was employed to obtain the thermogravimetric characteristics (TG and DTG curves) of the selected biomasses. Dry air or nitrogen gas, supplied into the analyzer furnace at a specified flow rate was used as the furnace medium. Prior to testing, both biomasses were ground and sieved to ensure fine particle sizes, less than 200 μm, and they were then well mixed to obtain PCR–EB blends with different mass proportions: 100% PCR, 75%PCR+25%EB, 50%PCR+50%EB, 25%PCR, and 100%EB. During a thermogravimetric test, a biomass/blend sample of 15 mg was heated from 30 °C to 900 °C at a specified heating rate (10, 20, 30, and 40 °C/min) and flow rate of the furnace gas (20, 30, 40, and 50 ml/min). Important thermogravimetric characteristics, such as the ignition temperature (T_{ign}), the peak temperatures (T_p), and the burnout temperature (T_b), were determined from the TG/DTG curves [7,8], and then compared between the fuel options.

3. Results and Discussion

3.1 Thermogravimetric characteristics of original biomass fuels

Fig. 1 shows the TG/DTG curves of PCR and EB tested individually at the heating rate of 20 °C/min when using dry air and nitrogen as a furnace gas at the 30 ml/min flow rate. As seen in Fig. 1, the TG curves of both PCR and EB showed similar trends, apparently exhibiting three sequent stages (or temperature regions) basically associated with: (1) dewatering of the biomass samples, (2) volatilization of high-reactive chemical components of the biomasses (cellulose, hemicellulose and partly lignin) accompanied by volatile oxidation, (3) volatilization of the rest lignin and other high-molecular extractives accompanied by oxidation of volatile matter and char (when using nitrogen gas as the furnace medium) or low-rate oxidation of chars (when using dry air).

For the first region (dewatering), the initial mass losses due to evaporation of fuel moisture were found to be 6 wt.% for PCR and about 40 wt.% for EB. The dewatering temperatures (T_w), at which biomass moisture was completely vaporized, of both biomasses were quite close about 120 °C, regardless the furnace gas type.

When using air as the furnace atmosphere (the main experimental option in the current study), the DTG curve of each biomass showed two important peaks within the second and third regions: (1) the first (main) peak temperature ($T_{p,1}$) that corresponded to the highest volatilization rate of the light biomass constituents (hemicellulose and cellulose) and (2) the second peak temperature ($T_{p,2}$) observed at the highest decomposition rate of lignin (including the effects of char oxidation). An occurrence of three more minor peaks on the DTG curve of EB indicated at presence of some minor extractives in this fuel, which, however, were ignored in this TGA analysis as producing negligible effects on the EB behavior at high temperatures.

Note that the main peak of PCR (318 °C) was apparently lower than that for EB (340 °C), and this result can be explained by a greater proportion of total hemicellulose and cellulose in PCR compared to EB. On the contrary, the second peak temperature of PCR (475 °C) was higher than that of EB (383 °C), which was likely associated

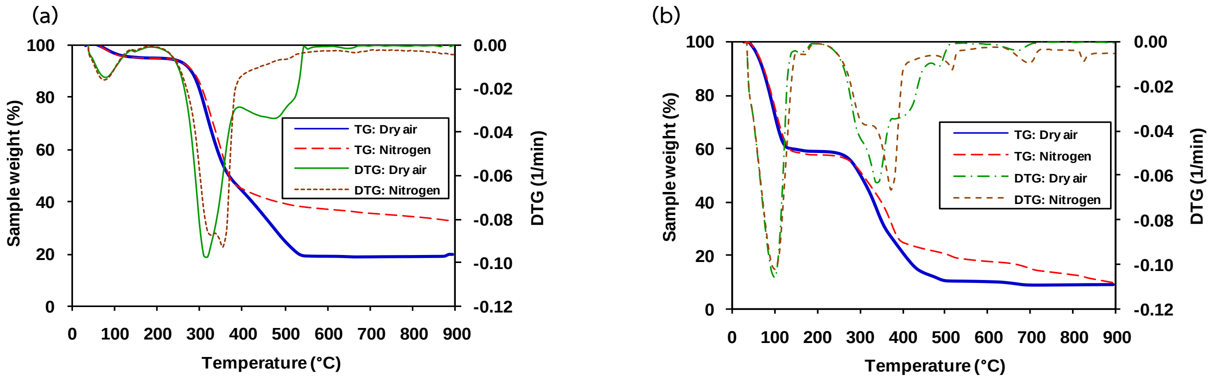

Fig. 1 TG and DTG curves of (a) PCR and (b) EB tested individually at 20 °C/min under dry air/nitrogen gas of 30 ml/min

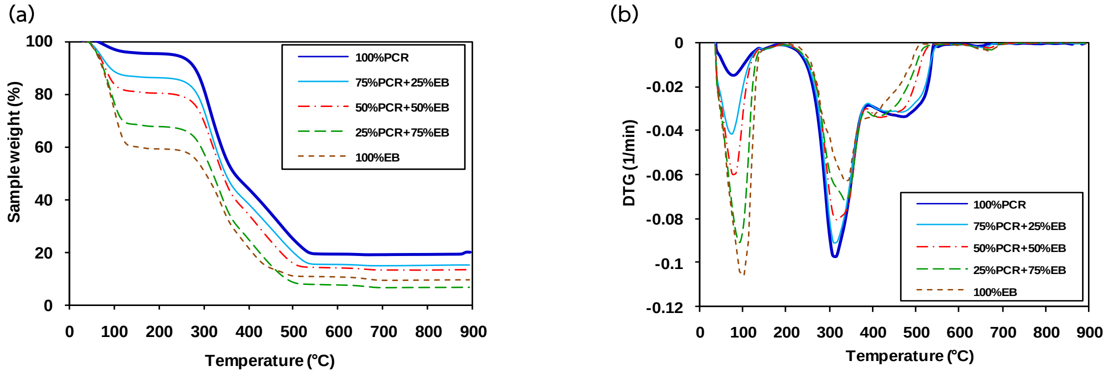

Fig. 2. (a) TG and (b) DTG curves of the PCR–EB blends at different proportions tested at the 20 °C/min under dry air of 30 ml/min

Table. 2 Specific temperatures of the PCR–EB blends for different fuel proportions

PCR:EB	Temperature (°C)				
	Dewatering	Ignition	Peak 1	Peak 2	Burnout
100:0	120	280	318	475	530
75:25	110	280	310	465	525
50:50	110	281	320	420	510
25:75	120	281	340	408	500
0:100	118	281	340	383	460

with the thermal instability of lignin in EB at relatively high temperatures, as shown by the TG curve of this woody biomass when using nitrogen as furnace gas in Fig. 1b.

It can be seen in Fig. 1 that, despite significant difference in the biomass dewatering rate, the ignition temperatures of PCR and EB were quite similar, both 281 °C, indicating similar thermal reactivity (or biomass decomposition) at relatively low furnace temperatures. The burnout temperatures of PCR and EB were found to be 530 °C and 460 °C, respectively. The lower T_b of EB can be explained by the above-mentioned instability of lignin in this biomass fuel, which eventually makes combustion reactivity of EB higher compared to PCR.

3.2 Thermogravimetric analysis of a PCR–EB mixture

Fig. 2 depicts the TG and DTG curves of the fuel blends mixed EB in different proportions, as well as those for pure PCR and EB. As seen in Fig. 2, all TG/DTG curves of the biomass blends were allocated in between the ones for PCR and EB. Like in Fig. 1, TG and DTG curves for fuel blends exhibited the three temperature regions, and the above-mentioned specific temperatures, the latter being listed in Table 2.

As the temperature range of dewatering was nearly the same for all the blends, from 40 °C to about 200 °C, the rate of demoisturizing in Fig.2b showed an apparent increase with a greater proportion of high-moisture EB in the fuel blend. The ignition temperature of all the blends turned out to be quite the same (in most cases 281 °C). It can be seen in Fig.2b that with increasing the proportion of EB in the fuel blend, $T_{p,1}$ was shifted toward higher temperatures, while the (maximum) decomposition rate of hemicellulose and cellulose in the second temperature region showed some decrease. These facts indicated at the lower thermal reactivity of EB compared to PCR in this devolatilization region. However, a higher proportion of EB in a biomass

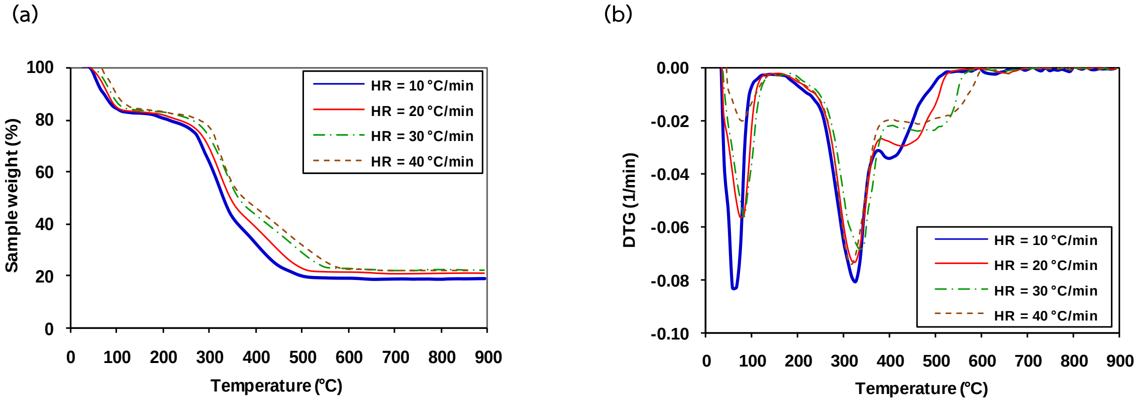

Fig. 3 Effects of heating rate on (a) TG and (b) DTG curves of a 75% PCR + 25% EB blend tested under dry air of 30 ml/min

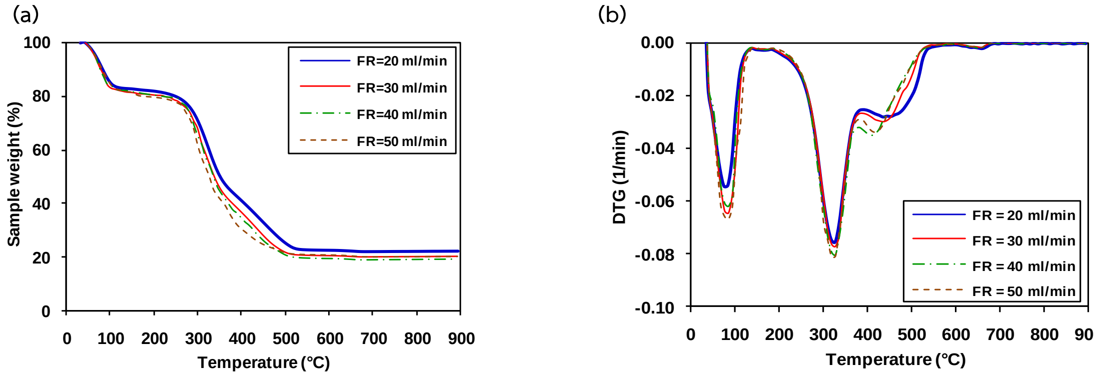

Fig. 4. Effects of furnace medium (dry air) flow rate on (a) TG and (b) DTG curves of a 75% PCR + 25% EB blend tested at heating rate of 20 °C /min.

blend led to the lower $T_{p,2}$ and $T_{b,}$ mainly due to the above-mentioned thermal instability of lignin in EB at relatively high temperatures, resulting in a higher combustion reactivity of the PCR─EB blend. Based on this result, adding eucalyptus bark to cassava rhizome can improve the fuel burnout improve the fuel burnout and, consequently, combustion efficiency of the system.

3.3 Effects of the heating rate on TG/DTG characteristics of a PCR─EB mixture

The TG and DTG curves of a 75% PCR + 25% EB blend tested with 30 ml/min dry air at the heating rates of 10, 20, 30 and 40 °C/min are shown in Fig. 3. As the heating rate increased, both TG and DTG curves were shifted to the higher temperature region. The shift of the curves to the higher temperatures was likely due to the effects of heat transfer which caused the temperature lag between the surrounding gas and the material inside a biomass particle [5]. As a result, the ignition, peak, and burnout temperatures shifted to higher values, as shown in Table 3.

3.4Effects of the flow rate of dry air on TG/DTG characteristics of a PCR─EB blend

Fig. 4 shows the TG ad DTG curves of a 75% PCR + 25% EB trialed at the heating rate of 20 °C/min for variable air flow rates (20, 30, 40 and 50 ml/min) of dry air. As seen in Fig. 4, the influence of the gas flow rate was quite insignificant, with some exemption for the lignin-related region with 400─600 °C temperatures. With higher flow rate of dry air, the oxidation process of lignin was likely intensified, which resulted in a higher rate of lignin decomposition/char oxidation in the above mentioned temperature region. The specific temp eratures for this case study are shown in Table 4. From Table 4, T_w, T_{ig}, $T_{p,1}$ for all air flow rates were quite close. However, the values $T_{p,2}$ increased as flow rate of dry air increased, mainly due to the above-mentioned char oxidation in higher temperature region.

4. Conclusions

Thermogravimetric characteristics of pelletized cassava rhizome, eucalyptus bark and their mixtures have been investigated using thermogravimetric analysis (TGA). From the TGA analysis, both fuels have quite similar ignition temperature, whereas the burnout temperature of EB are lower than of PCR, which eventually makes combustion reactivity of EB to be higher compared to PCR. With increasing EB in a fuel blend, combustion reactivity of the PCR─EB blend can be improved, thus, enhancing fuel burnout rate, and consequently combustion efficiency of the system

5. Acknowledgement

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