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Investigation on the ignition and burnout temperatures of bamboo and sugarcane bagasse by thermogravimetric analysis

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HIGHLIGHTS

- Ignition and burnout temperatures of bamboo and sugarcane bagasse are investigated.
- Thermogravimetric analyses (TGA) at five different heating rates are performed.
- A higher heating rate leads to a pronounced thermal lag in biomass particles.
- 99% of biomass conversion is an appropriate point to identify the burnout temperature.
- The heating rates in TGA between 20 and 30 °C min^{-1} are suggested.

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ABSTRACT

Ignition and burnout temperatures are important properties of solid fuels for their applications in industry. In this study, the thermogravimetric analyses (TGA) of bamboo and sugarcane bagasse at five different heating rates of 5, 10, 20, 30, and 40 °C min^{-1} are performed. The intersection method (IM) and deviation method (DM) are employed to approach the ignition temperatures of the two biomass species, while IM and the conversion method (CM) are adopted to analyze their burnout temperatures. In IM and CM, both the ignition and burnout temperatures increase with increasing heating rate, as a consequence of the pronounced thermal lag in biomass particles at high heating rates. The measured ignition temperatures based on DM are lower than those based on IM, and there is no correlation between the temperature and heating rate. The determined burnout temperatures from IM are close to those obtained from CM, while the difference in the burnout temperatures of the two biomass samples is small. The ignition temperatures of the two biomass species measured from IM are between 250 and 300 °C, and their burnout temperatures are close to 500 °C. As a whole, IM is recommended for determining the ignition temperature of biomass, while CM is a feasible and simple route to approach the burnout temperature. The heating rates in TGA between 20 and 30 °C min^{-1} are suggested because of their accurate and time-saving operations.

1. Introduction

Global warming and anthropogenic carbon dioxide emissions have received tremendous attention due to their notable impact on both the human society and ecosystem [1]. To reduce carbon dioxide emissions, alternative fuels for replacing depleting fossil fuels have been studied and developed worldwide. Biomass is able to fix carbon dioxide in the atmosphere while it grows. Therefore, biomass may be able to be considered as a carbon–neutral fuel and can effectively mitigate carbon dioxide emissions when it is burned [2–4]. The development of bioenergy technology in the European Union (EU) is one of the well-known cases. According to the policy of EU, every EU country aims to produce 10% of their road fuels from renewable sources such as biofuels by 2020 [5]. When biomass is used as the feedstock for bioenergy, solid (e.g., torrefied wood and charcoal), liquid (e.g., bioethanol, biodiesel, biobutanol, and bio-oil), and gas (e.g., syngas, biogas, and biohydrogen) biofuels can be produced.

The investigation of biofuel properties plays an important role in fulfilling their utilization. In this aspect, ignition and burnout temperatures are two crucial properties of fuels. For instance, the co-firing of biomass and coal has been widely employed in industry [6]. The combustion behavior of fuel blends in burners will be

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Table 1
Literature review of the ignition of biomass and its blends.

Test method	Materials	Particle size	Carrier gas	Flow rate (ml min^{-1})	Heating rate (°C min^{-1})	Ignition temp. (°C)	Ref.
TGA[a]	Scrap automobile tire + high ash coal	2.2–1.6 mm	Air	20	20	350–458	[12]
	Wheat straw, aspen wood sawdust	80 μm	Air	–	10, 15	277, 279	[13]
	Pine sawdust	200 μm	Air	20	20	210–290	[14]
	Rice, wheat straw	30–200 mm	Air	100	30	256, 231	[33]
	Hydrothermally treated municipal solid waste	180 μm	Air	150	10	269	[15]
	Wood chips, olive cake, hazelnut shells	250 μm	Air	40	20	180, 190, 185	[29]
	Tobacco residue	80 μm	Air	20	10	–	[16]
	Bamboo	212 μm	Air	-	25	202	[34]
	Olive tree pruning, cardoon, sewage sludge	250 μm	Air	45	10	258, 261, 237	[18]
TGA[b]	Bituminous coal and petroleum coal	106–125 μm	Air and nitrogen	300	10	–	[11]
DSC[c]	Miscanthus, poplar wood, rice husk residue	–	Air	50	5, 10, 15, 25, 50	250–290	[19]
DTA[d]	Reed canary grass, wheat straw residue	–	Air	50	20	197, 212	[20]

[a] Intersection method (using air as the carrier gas).
[b] Deviation method (using air and nitrogen as the carrier gases).
[c] Differential scanning calorimeter.
[d] Derivative thermal analyzer.

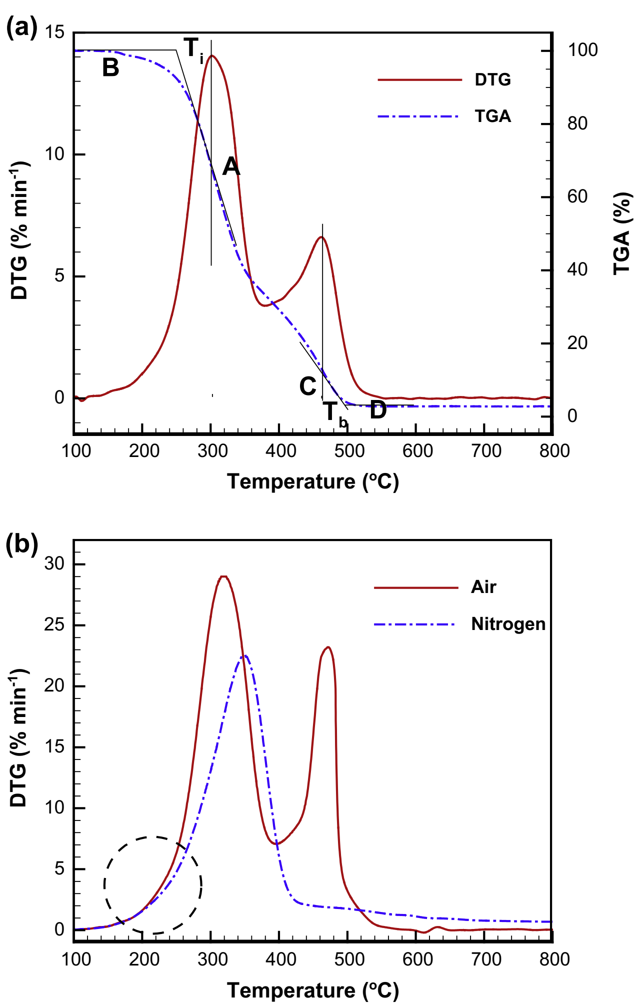

Fig. 1. Schematics of determining (a) ignition and burnout temperatures (T_i and T_b) from the intersection method and (b) ignition temperature from the deviation method.

affected by the individual ignition characteristics of biomass and coal. The ignition temperature is defined as the minimum temperature at which a fuel ignites spontaneously in an environment without external source of ignition [7]. The ignition temperature of biomass is highly related to its safety in storage and delivery when it is utilized as a fuel in industry. The burnout of a fuel is an indicator to stand for its reaction degree. The higher the burnout, the fewer the combustible components left in the fuel [8]. The burnout temperature refers to the temperature at which the fuel is almost completely consumed. Accordingly, the recognition of the burnout temperature of biomass is able to provide a useful insight into the operation of biomass combustion. Moreover, both the ignition and burnout temperatures are key parameters to evaluate fuel selection, consumption, and combustor design [9,10].

In the past, a number of methods have been developed to figure out the ignition temperatures of fuels. The ignition temperature of a fuel can be identified by use of a thermogravimetric analyzer (TG) [11–18], a differential scanning calorimeter (DSC) [19], or a derivative thermal analyzer (DTA) [20]. Table 1 summarizes a number of studies of ignition temperatures of biomass through the aforementioned methods. The listed thermogravimetric analysis (TGA) methods were conducted at the heating rates of 5–50 °C min^{-1}, mostly at 10–20 °C min^{-1}. In TGA, two different means in terms of derivative thermogravimetric (DTG) curves can be used to identify the ignition temperature. One is based on the intersection of two tangent lines along a TGA curve for biomass heated in air; the other is established in accordance with the deviation of two DTG curves for biomass heated in both air and nitrogen.

In the present study, bamboo and sugarcane bagasse will be chosen for the investigation of biomass ignition and burnout. Bamboo is thought of as a promising energy crop because of its high growth rate [21]. In 2012, bamboo possessed an annual

Table 2
Proximate, fiber, and calorific analyses of bamboo and sugarcane bagasse.

Biomass	Bamboo	Sugarcane bagasse
Proximate analysis (wt%)		
Volatile matter (VM)	67.02	73.70
Fixed carbon (FC)	25.45	12.09
Moisture	3.57	2.86
Ash	3.96	11.35
Fiber analysis (wt%, dry-ash-free)		
Hemicellulose	23.79	36.53
Cellulose	57.84	56.67
Lignin	18.36	6.80
HHV (MJ kg^{-1}, dry basis)	17.13	15.79