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Fuel property variation of biomass undergoing torrefaction

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Abstract

The influence of torrefaction operating conditions upon the properties of the residue of a microalga *Chlamydomonas* sp. JSC4 (*C. sp. JSC4*) is explored. The experimental results indicate that the mass losses of hydrogen, oxygen and carbon from torrefaction are characterized by the order of oxygen > hydrogen > carbon. Meanwhile, the three physical quantities of solid yield, higher heating value (HHV) enhancement factor, and energy yield linearly decrease with increasing the mass losses of hydrogen, oxygen and carbon. The ignition and burnout temperatures of the torrefied are analyzed using a thermogravimetric analyzer. The ignition temperature of the biomass is insensitive to the torrefaction severity when the torrefaction degree is not severe, whereas the ignition and burnout temperatures are raised to a certain extent when the torrefaction becomes severe.

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1. Introduction

Torrefaction is a promising technology to upgrade biomass for solid fuel production. When biomass is torrefied in an oxygen-free environment at temperatures of 200-300 °C [1], the pretreated material has lower atomic H/C and O/C ratios and a higher calorific value when compared to its parent biomass. In addition, the grindability and homogeneity of lignocellulosic materials are improved and the hygroscopic

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biomass is converted into hydrophobic one. When biomass is torrefied in a reactor, dehydration and devolatilization reactions are triggered [2], resulting in the liberation of vapors and non-condensable gases. This thermal process is characterized by dehydrogenation, deoxygenation, and dehydroxylation processes [3,4], and, therefore, relative more carbon is retained in the torrefied biomass. In other words, the contents of low-energy H-C and O-C bonds are decreased, whereas the content of high-energy C-C bond is increased [5,6]. For this reason, the atomic H/C and O/C ratios in biomass are lowered and energy densification is achieved when torrefaction severity is raised.

When torrefied biomass is used as a solid fuel for combustion, the recognition of fuel reactivity such as ignition and burnout is of the utmost importance. Bridgeman et al. [7] exposed raw and torrefied willow to a methane-air flame, and found that the latter was ignited more quickly. Pimchuai et al. [8] tested raw and torrefied rice husks in a spout-fluid bed combustor, and observed that the torrefied husks were ignited faster and the bed temperature was raised to a higher level. This improved reactivity is likely due to the low moisture content in torrefied biomass. Du et al. [9] torrefied a number of biomass materials and examined their ignition temperatures by individually mixing these samples with NaNO_2 , and found that an increase in pretreating temperature almost linearly increased the ignition temperature. This was attributed to less volatiles contained in the pretreated biomass. According to the above illustrations, the present study aims to investigate decarbonization, dehydrogenation, and deoxygenation processes of a microalga residue from torrefaction. The thermal degradation, ignition, and burnout characteristics of the biomass will be explored from thermogravimetric analysis.

2. Experimental

An oil-rich microalga *Chlamydomonas* sp. JSC4 (*C. sp.* JSC4) undergoing oil-extraction was adopted as the raw material of torrefaction. The particle sizes of the biomass were controlled less than 0.42 mm. In each torrefaction run, 12 g ($\pm 5\%$) of the microalga residue was loaded in the tube which was heated in the furnace. After the furnace reached the desired temperature, the tube was placed in the furnace and the sample was torrefied for a certain period. Nitrogen was used as a carrier gas to purge the tube for providing an oxygen-free environment in the course of torrefaction. The volumetric flow rate of the carrier gas was fixed at 100 mL min^{-1} ($25 \text{ }^\circ\text{C}$). After the experiment reached the desired holding time, the glass tube was moved away from the furnace and purged continuously by N_2 until it was cooled to room temperature. Three different torrefaction temperatures of 200, 250, and $300 \text{ }^\circ\text{C}$ along with the duration of 30 min were taken into account in the experiments. Meanwhile, the torrefaction temperature of $250 \text{ }^\circ\text{C}$ for three different durations of 15, 30, and 60 min were considered.

To figure out the basic properties of the raw microalga residue, composition, proximate, elemental, and calorific analyses were carried out. The proximate and elemental analyses of torrefied biomass were also performed. Details of the composition and proximate analyses can be found elsewhere [10,11]. The elemental analysis was performed using an elemental analyzer (PerkinElmer 2400 Series II CHNS/O Elemental Analyzer) to measure the weight percentages of C, H, and N in the biomass, while the weight percentage of O was obtained by difference (i.e., $\text{O} = 100 - \text{C} - \text{H} - \text{N}$). The calorific analysis was fulfilled through a bomb calorimeter (IKA C5000). To ascertain the analysis quality, the elemental analyzer, bomb calorimeter, FTIR spectrometer, and thermogravimetric analyzer were calibrated periodically. Moreover, the experiment under any given condition was usually carried out more than twice. The results were fairly uniform between each run and the relative error was controlled below 3%.

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