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Influence of bio-solution pretreatment on the structure, reactivity and torrefaction of bamboo

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ABSTRACT

A bio-solution of natural organic enzyme-7F (NOE-7F) is used to pretreat bamboo, with emphasis on the influence the pretreatment upon the structure, reactivity, and torrefaction of the biomass. Two different operating modes accompanied by five different soaking durations are considered. In Mode 1 the bamboo is ground followed by pretreated by the bio-solution, and an inverse procedure is used in Mode 2. The results indicate that, with the operation of Mode 1, NOE-7F removes hemicellulose in the bamboo significantly, thereby improving the homogeneity of the biomass. This pretreated bamboo may be feasible for enzymatic hydrolysis to produce bioethanol. The penetration of the bio-solution into block bamboo becomes the controlling mechanism under Mode 2 operation, and therefore relatively less hemicellulose is consumed from Mode 2. The ignition and burnout temperatures of the pretreated bamboo are higher than those of the raw bamboo, revealing the lower reactivity and higher storage safety of the former. The atomic H/C and O/C ratios as well as the calorific value of the bamboo are insensitive to the pretreatments, whereas the crystalline structure of cellulose is affected by the bio-solution to a certain extent, regardless of Mode 1 or Mode 2 operation. This suggests that torrefaction is required if the pretreated bamboo is employed as a fuel. The pretreated bamboo with Mode 2 is more suitable for torrefaction because of higher torrefaction severity.

1. Introduction

On account of the increase in energy demand and the requirement alternative to fossil fuels for sustainable environment, the development of renewable energy has become a remarkable issue. Bioenergy has several advantages over other types of renewable energy such as the continuous or intermittence-free growth of biomass, the versatility of biofuel production, and the stabilization of the atmospheric greenhouse gas concentration [1,2]. The potential provision of lignocellulosic bioenergy was estimated to increase to a range from less than 100 EJ/year to 1500 EJ/year for 2050 [2,3]. Therefore, under the optimization of the interrelationship between crops for food and bioenergy, the importance of the latter is likely to become more considerable.

Pretreatment is a crucial process to upgrade the properties or improve the recalcitrant characteristics of lignocellulosic biomass for producing biofuels. For instance, dewatering and drying is an essential step to remove water from moist biomass for its subsequent thermochemical conversion such as combustion, gasification, and pyrolysis [4,5]. Pulverization or grinding can be employed to reduce and homogenize biomass sizes for the co-firing of biomass and coal [6]. Densification or pelletization is an effective method to increase the volumetric energy density and facilitate the storage and transport of biomass [7]. Currently, wood pellets are considered as a major transportable renewable energy source [8]. When one is concerned with lignocellulosic bioethanol production, pretreatment plays a key role in disrupting the naturally resistant carbohydrate-lignin shield which limits the enzyme accessibility for improving digestibility of cellulose [9].

It is known that hemicellulose, cellulose, and lignin are three main components in lignocellulosic biomass, and their amount depends on the type of biomass. The combination of the aforementioned three components leads to rigid and compact structure of plant cell wall so that lignocellulosic biomass is recalcitrant to biodegradation. When dilute sulfuric acid pretreatment is applied in lignocellulosic biomass, hemicellulose in biomass can be effectively removed and converted into xylose [10–12]. Furthermore, the pretreated biomass is conducive to subsequent enzyme hydrolysis, whereby cellulose is into converted glucose which can be fermented into bioethanol. In recent years, torrefaction has attracted

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much attention inasmuch as this technique is able to improve the quality of biomass-derived solid fuels. After biomass undergoes torrefaction, the thermally treated materials possess a number of merits such as lower moisture content, lower atomic H/C and O/C ratios, and higher calorific value. As a result, the properties of torrefied biomass approach those of coals [13,14]. When the structure of upgraded biomass is examined in detail, the biomass is also characterized by higher homogeneity in that hemicellulose in biomass is destroyed greatly and relatively more cellulose and lignin are retained in torrefied biomass [15]. This homogeneity is beneficial to biomass applications in industry.

As described earlier, pretreatment is of great concern to bioenergy development in that the efficiency of bioenergy conversion is highly related to the pretreatment process. Instead of physical, chemical, or thermochemical pretreatment, the interest of this study is on the biological pretreatment of bamboo using a bio-solution. In the studies of Lin et al. [16,17], a bio-solution of natural organic enzyme-7F, termed NOE-7F, was employed in the combustion of emulsified diesel and/or biodiesel fuels. They found that adding the bio-solution could reduce the emissions of polycyclic aromatic hydrocarbons (PAHs) and increase the combustion efficiency of a diesel engine. These results revealed that there was a significant interaction between the bio-solution and fuels when they were burned. To the authors' knowledge, the pretreatment of biomass using bio-solutions has yet been explored. Inspired from the studies of Lin et al. [16,17], the bio-solution NOE-7F will be used to pretreat a bamboo species in this study. It is known that the particle size of biomass and pretreatment duration are two important factors of affecting the performance of biomass pretreatment [10,18]. Therefore, two different operating modes of pretreatment along with five different durations will be considered. The impact of the pretreatments on the structure, reactivity, and torrefaction of the bamboo will be evaluated using a variety of instruments. The obtained results are able to provide a useful insight into the applications of biological pretreatment and bio-solution for biofuel production.

2. Materials and methods

2.1. Material preparation and pretreatment

Phyllostachys makinoi, a kind of common bamboo species in Taiwan, was adopted as the raw material in the present study. The diameter and thickness of the bamboo were approximately 45–50 mm and 5 mm, respectively. To minimize the effect of sampled section of biomass on the study [19], the bottom part of the bamboo was selected. Meanwhile, a bio-solution NOE-7F was used to pretreat the bamboo. The bio-solution was produced by mixing molasses, rice wine, acetic acid, water and an anti-oxidant enzyme, followed by adding lactic acid bacteria and yeast to domesticate the mixture. Finally, the mixture was put through a separation and purification process [17]. The analysis of GC/MSD (gas chromatograph/mass selective detector) suggested that the main oxygenated compounds in the bio-solution included C_2H_6O (ethanol or ethyl hydrate), C_3H_6O (acetone or pyroacetic ether), and $C_4H_8O_3$ (ethyl hydroxyacetate or ethyl glycolate) [20].

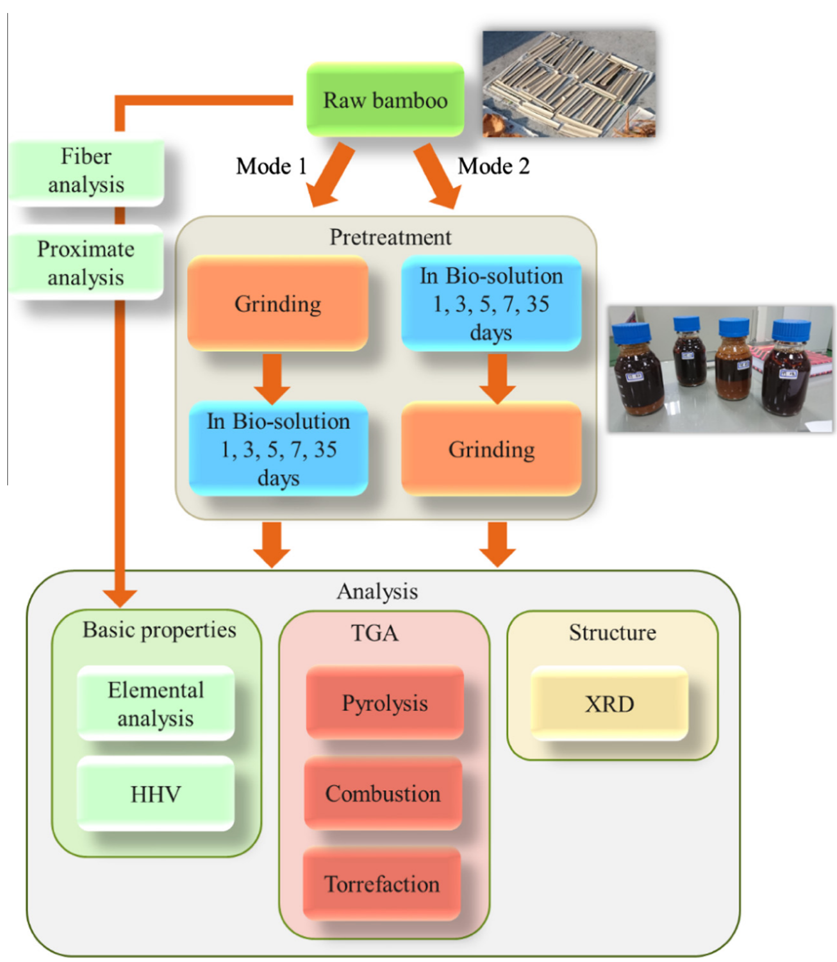

Fig. 1. A schematics of experimental procedure.

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