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Influence of reactor rotating speed on bamboo torrefaction

Wei-Hsin Chen [a,]*, Ma. Katreena Pillejera [a,b], Mark Daniel de Luna [c]

[a]Department of Aeronautics and Astronautics, National Cheng Kung University, Tainan 701, Taiwan
[b]College of Engineering, University of the Philippines - Diliman, Quezon City 1101, Philippines
[c]Environmental Engineering Department, University of the Philippines, Diliman, Quezon City 1101, Philippines

Abstract

Bamboo torrefaction in a rotating packed bed (RPB) is investigated where three rotating speeds of 0, 900, and 1800 rpm are taken into account. The results suggest that the rotating speed intensifies the torrefaction performance drastically when light and mild torrefaction are practiced. In contrast, the torrefaction performance is affected slightly by the rotating speed when severe torrefaction is carried out. The highest higher heating value (HHV) and its enhancement factor (EF) are 28.389 MJ/kg and 1.61, respectively, yielding a coal-like fuel with the energy yield is 63.51%. The results suggest that torrefaction in a rotating packed bed is a efficient process to upgrade biomass for producing green and sustainable alternative to coal utilized in industry.

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Keywords: Torrefaction; Bamboo; Rotating packed bed (RPB); FTIR; High gravity (Higee) environment; Rotation.

1. Introduction

Burning fossil fuels currently is a prime route to get heat and power in industry [1, 2]. In many countries, energy and power sectors highly rely on coal. However, consuming coal for heat and power generation has led to a number of environmental problems such as air pollution, acid rain, and deterioration of atmospheric greenhouse effect, even global warming and climate change. In a global scale, the emissions declared by the Intergovernmental Panel on Climate Change (IPCC) in the 2014 Climate Change Synthesis Report indicated that 25% of greenhouse gases (GHGs) came from the electricity and heat production (energy sector) where over 40% of it came from coal industries. Moreover, coal has the highest emission factor in comparison to the other conventional energy source. A high value of emission factor implies a higher CO_2 emission.

* Corresponding author. Tel.: +886-6-2004456; fax: +886-6-2389940.
E-mail address: weihsinchen@gmail.com; chenwh@mail.ncku.edu.tw

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Among all the energy sources, one of the most promising alternative to conventional energy is biomass [3]. This alternative energy source is an environmental-friendly and sustainable renewable energy source. In comparison to other energy resources, GHG emissions from burning biomass are low inasmuch as biomass pertains to a carbon-neutral fuel. Bamboo is an abundant and rapidly growing plant and has a number of major fuel characteristics such as low ash and alkali contents [4], it is thus used as a model feedstock for this study. Nevertheless, compared to coal, bamboo and other raw biomass species have the drawbacks of high moisture content, low calorific value, large volume, low bulk density, and hygroscopic and nonhomogeneous nature [5]. This thermal pretreatment process can produce a cleaner fuel with low acid content in the smoke when it is combusted [6].

The examination of reported literature suggests that the important parameters for torrefaction includes temperature, duration (or holding time), particle size, heating rate, and carrier gas flow rate [7]. Meanwhile, a variety of reactors such as rotating drum, heart furnace, microwave reactor, belt dryer, screw conveyor, torbed reactor, compact moving bed and fixed bed have been developed to fulfill torrefaction [8]. The rotating packed bed (RPB) has been extensively employed to enhance the mass transfer in absorption [9], distillation [10], stripping [11], etc., and the reaction environment in a RPB is normally controlled at room temperature. Up to now, however, the RPB has not been applied in torrefaction for upgrading biomass yet, even though many types of reactors have been developed and adopted for biomass torrefaction as described above.

When biomass is torrefied in a RPB the reactor with elevated temperatures, the heat and mass transfer will be intensified due to the induced centrifugal force and the elongation of the path of the reactants [12]. Motivated with the advantages accompanied by RPB, this study in intended to evaluate the feasibility of the new technology in the process of biomass torrefaction and to investigate the effect of rotating speed (0, 900, and 1800 rpm) on the solid yield, HHV, and energy yield of the product under various temperatures (206, 255, and 300 °C) at a fixed holding time (30 min). Also, the study extends the research to the effect of duration (15, 30, 45 min) on the performance of bamboo torrefaction and to figure out the structure variation of the bamboo undergoing torrefaction through the use of FTIR spectroscopy.

2. Materials and methods

The bamboo species *Phyllostachys makinoi* in Taiwan was adopted as a feedstock for biochar production from a RPB. The bamboo was manually cut into chips with dimensions of 2 cm × 2 cm × 5 mm (length × width × length) using a saw. The chips were pre-heated at 65 °C for 24 h to establish a basis for sample tests. The fiber, proximate, elemental, and calorific analyses were performed to figure out the basic properties. The analyses suggest that the biomass has high volatile matter and cellulose contents with the values of 72.09 and 44.55 wt%, respectively. The HHV of the raw bamboo is 17.66 MJ/kg which is typical in that the HHV raw biomass is normally between 15 and 20 MJ/kg [13].

The entire experimental system was composed of breaker, socket, rotating packed bed (RPB), carrier gas inlet, thermocouple, temperature controller, rotameter, carrier gas tank, rotor speed controller, cooling unit, and exhaust gas treatment unit. The RPB was made up of placement of feedstock, rotating plate, RPB wall, rotating plate cover, carrier gas inlet, rubber, high temperature insulator, plate cover screws, thermocouple, pressure reading, cooling unit inlet, and RPB cover screws. The experiments were divided into two parts: (1) varying rotating speed and temperature at a fixed duration (30 min), and (2) altering duration at fixed temperature (255 °C) and rotating speed (900 rpm). The torrefaction operating conditions were established from a calibrating procedure. All the torrefaction experimentations were carried out in a nitrogen environment at a flow rate of 500 mL/min (at STP). In the first part of experiments, three different rotating speeds of 0, 900, and 1,800 rpm, denoted by R1, R2, and R3, respectively, and three different torrefaction temperatures of 206, 255, and 300 °C, termed T1, T2, and T3, respectively, were taken into consideration. Physically, the three temperatures corresponding to light, mild, and severe torrefaction, respectively [14]. In the second part, the experiments were carried out at a fixed rotating speed of 900 rpm along with three different durations of 15, 30, and 45 min, designated as D1, D2, and D3, respectively.

The solid yield, the enhancement factor (EF) of HHV, and the energy yield are three crucial indexes to identify the performance of torrefaction [13]. The solid yield is measured from the weight ratio of torrefied biomass to its parent one, while the EF of HHV is determined from the HHV ratio of torrefied biomass to the raw one. As for the energy yield, it stands for the ratio of energy amount of torrefied biomass to its raw counterpart. An additional evaluation