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Microwave torrefaction of *leucaena* to produce biochar with high fuel ratio and energy return on investment

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Abstract

In this study, microwave torrefaction of *leucaena* was studied to find out the potential applications and energy usage benefit of this technique. Both maximum temperature and heating rate increased with increasing microwave power level. Processing time was also an important operational parameter, but its effect was weaker than that of microwave power level. The heating value of torrefied product was higher at higher power level and longer processing time, but the mass and energy yields were lower due to higher energy input and thus more severe reaction. Heating value was approximately 30 MJ/kg at a microwave power level of 250 W for 30 min processing time. The fuel ratio of torrefied *leucaena* was up to 3.7, which is much higher than that of bituminous coal and thus can be regarded as an alternative fuel to replace or co-fire with coal. The energy return on investment of microwave torrefaction of *leucaena* can be 1.4, 17, and 34 when handling capacities are 8, 100, and 200 g, respectively. Therefore, microwave torrefaction of *leucaena* is a promising technique, and it can be more competitive when it is scaled up.

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Keywords: Microwave torrefaction; *Leucaena*; Biochar; Fuel ratio; Energy return on investment; Reaction kinetics

1. Introduction

The utilization of renewable energy has become an important and urgent issue due to the continuously increasing consumption of fossil fuels and the worsening global climate change situation. With the increasing population and industrialization, more carbon dioxide is emitted by the combustion of fossil fuels to worsen the climate change. The worse climate change would make the summer hotter and the winter colder, and thus more electricity and fossil fuels are required. This vicious circle could lead to an irreversible consequence, which may make it impossible to survive on the earth for all the lives. One of the promising renewable energy sources is biomass. Biomass is an abundant carbon-neutral renewable

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resource to produce bioenergy and biomaterials, and its enhanced utilization can address some societal demands [1]. In addition to being an alternative energy, the use of bioenergy can offset anthropogenic carbon dioxide emissions. In the next few decades, massive growth of the bioenergy industry will be required to address societal needs to reduce net carbon emissions [2].

The woody biomass feedstock used in this study was *Leucaena leucocephala*. *Leucaena* is a fast growing tree with very high biomass production and re-sprout capacity, and it is capable of growing with high yield on arid soils [3–7]. Therefore, *leucaena* has a high potential for the production of bioenergy [3], and it can be an alternative to the use of traditional biomass feedstocks [5]. In this study, the reactivity of *leucaena* torrefaction using microwave heating and the properties of torrefied products were studied to find out the potential applications and energy usage benefit of this technique.

2. Methods

2.1. Material

Leucaena wood was provided by the Kenting National Park, Taiwan. Before applying to microwave torrefaction experiments, the *leucaena* wood was shredded and ground into powdered samples.

2.2. Experimental device and procedure

This study used a single-mode microwave oven operated at 2.45 GHz frequency. Reaction tube and sample holder were both made of quartz. The shredded and sieved (50 mesh) biomass feedstock (approximately 8 g) was added to a quartz crucible and then placed inside a quartz tube that was located in the pathway of the microwaves. A thermocouple sensor was placed at the bottom of the quartz crucible to measure the temperature of the biomass sample. To maintain anoxic conditions, nitrogen gas was purged into the system at a flow rate of 35 mL/min. After sufficient purging was performed to maintain an inert atmosphere, the power supply was turned on and switched to a microwave power level of 100, 150, 200, or 250 W, and the processing time was 15, 20, 25, or 30 min.

2.3. Product analysis

The proximate analyses of raw and torrefied *leucaena* were performed according to the standard test methods D7582-12 and D3172-07a of the American Society for Testing and Materials (ASTM). The ultimate analyses were carried out by using a Perkin–Elmer 2400 II CHNS/O elemental analyzer. The higher heating values (HHV) of biomass samples were measured in a Parr 1341 adiabatic oxygen bomb calorimeter. The surfaces of the biochar were observed by using a Hitachi S-4800 field emission scanning electron microscope (SEM).

3. Results and discussion

3.1. Characteristics of leucaena

The main characteristics of the raw and torrefied *leucaena* samples are listed in Table 1. After microwave torrefaction, part of the volatile matter of *leucaena* was thermally decomposed, and the decomposition extent increased with increasing microwave power levels. The decomposition of volatile matter is mainly owing to the thermochemical reaction of hemicellulose that primarily happens in the temperature range of 200–300 ºC for biomass torrefaction [8,9]. When the microwave power level was