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Microwave pyrolysis of lignocellulosic biomass

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Abstract

Lignocellulosic biomass is an abundant and carbon-neutral resource for the production of renewable biofuels and green materials. In this study, the pyrolysis of lignocellulosic biomass, including rice straw, rice husk, corn stover, sugarcane bagasse, sugarcane peel, waste coffee grounds, and bamboo leaves, was carried out by using microwave heating. Solid, liquid, and gas yields were in the ranges of 18–22, 40–48, and 30–40 wt%, respectively. The primary components of the gas product were H_2 (18–25 vol%), CH_4 (6–8 vol%), CO (51–59 vol%), and CO_2 (10–14 vol%), and the rest undetermined part was only 3–5 vol%. Empirical equations were determined to predict the product yields and gaseous concentrations of microwave pyrolysis according to the lignocellulosic contents of the biomass feedstocks. The energy return on investment of microwave pyrolysis can be approximately 3.56, so the technique should be energetically and economically feasible.

Keywords: Microwave pyrolysis; Lignocellulosic biomass; Product yield; Energy return on investment

1. Introduction

Nowadays, the world's energy consumption is mostly supplied by non-renewable energy sources, including fossil fuels and nuclear power, which may also cause environmental problems. One of the major environmental concerns is global climate change possible induced by emissions of greenhouse gases. Therefore, renewable energy alternatives, such as solar photovoltaic, wind power, and bioenergy, have gained growing interest. Bioenergy is an attractive option because of its abundant, clean, safe, and carbon-neutral characteristics. Besides, biomass is the only source of renewable solid, liquid, and gas fuels [1]. Lignocellulosic biomass, such as wood, crops, and agricultural and forestry residues, is primarily composed of hemicellulose, cellulose, and lignin.

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Compared with conventional heating, microwave heating is an attractive technique because of its volumetric heating at an improved heating efficiency [2]. Longer heating period, opposite thermal gradient, and energy loss in conventional heating can be avoided during microwave heating [3]. Microwave pyrolysis can produce more syngas [4] but less polycyclic aromatic hydrocarbons [5] than conventional pyrolysis. Therefore, microwave pyrolysis can be a promising technique to convert biomass into valuable biofuels and green materials at a high efficiency. The purpose of this study was to investigate the microwave pyrolysis of various lignocellulosic feedstocks and to evaluate the technique from the viewpoints of product yield and energy usage efficiency.

2. Methods

2.1. Material

The samples of this study were seven different lignocellulosic biomass: rice straw (RS), rice husk (RH), corn stover (CS), sugarcane bagasse (SB), sugarcane peel (SP), waste coffee grounds (CG), and bamboo leaves (BL), which were collected on farms or in factories or markets. Before being added to the microwave pyrolysis system, all the biomass feedstocks were naturally air-dried, shredded, and sieved by a 50-mesh (0.297 mm) screen.

2.2. Experimental device and procedure

This study used a single-mode microwave oven operated at 2.45 GHz frequency. Reaction tube (40 cm length, 5 cm outer diameter) and sample holder (3 cm height, 4 cm outer diameter) were both made of quartz. The grinded and sieved (50 mesh) biomass feedstock (3–5 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 50 mL/min. After sufficient purging was performed to maintain an inert atmosphere, the power supply was turned on and switched to a prescribed microwave power level for 30 min.

2.3. Product analysis

The analyses of the gaseous products produced by microwave pyrolysis of agricultural residues were carried out by a Perkin–Elmer Auto System XL gas chromatography–thermal conductivity detector (GC–TCD) with a Supelco Carboxen 1010 PLOT column. The temperatures of injector, oven, and detector were 120, 100, and 150 °C, respectively. The flow rate of carrier gas (He/N_2) was 10 mL/min (25:1 split). The liquid products were analyzed by a Perkin–Elmer Turbo Mass Gold gas chromatography–mass spectrometry (GC–MS) with a Supelco Equity–5 capillary column. The initial temperature of oven was 45 °C and held for 3 min, and then it was ramped from 45 °C to 300 °C at the rate of 5 °C/min and held for 5 min. The flow rate of carrier gas (He) was 10 mL/min (20:1 split).

3. Results and discussion

3.1. Characteristics of lignocellulosic biomass

The general characteristics of the lignocellulosic feedstocks are listed in Table 1. Their proximate and ultimate contents were not very different. The volatile matter, fixed carbon, and ash contents of the