



Effects of lignocellulosic composition and microwave power level on the gaseous product of microwave pyrolysis



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ARTICLE INFO

Article history:

Received 19 October 2014

Received in revised form

12 May 2015

Accepted 11 June 2015

Available online 3 July 2015

Keywords:

Microwave pyrolysis

Agricultural residues

Lignocellulose

Power level

Gas yield

ABSTRACT

Agricultural residues are abundant resources to produce renewable energy and valuable chemicals. This study focused on the effects of lignocellulosic composition and microwave power level on the gaseous product of microwave pyrolysis of agricultural residues. When agricultural residues were under microwave radiation within 10 min, the maximum temperatures of approximately 320, 420, and 530 °C were achieved at the microwave power levels of 300, 400, and 500 W, respectively. Gas yield increased with increasing microwave power level, whereas solid and liquid yields decreased. Besides, gaseous products with higher H₂ content and higher calorific values can be obtained at higher microwave power levels. In addition to microwave power level, lignocellulosic composition was also an important factor. H₂ and CO₂ yields increased with increasing hemicellulose content, whereas CH₄ and CO yields increased with increasing cellulose content. Four empirical equations were derived to present the contributions of lignocellulosic materials to the yields of gaseous components.

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1. Introduction

Renewable energy has attracted increasing interest in recent years because of the concerns for high worldwide demand for energy, unstable and uncertain petroleum fuels, and global climate change [1]. One of the promising energy sources is biomass which provides an attractive option for the production of renewable biofuels and valuable chemicals [2–4]. Biomass feedstocks produced with lower greenhouse-gas emissions than fossil fuels and with little or no competition with food production can include: agricultural residues, perennial plants grown on degraded lands abandoned from agricultural use, sustainably harvested wood and forest residues, double crops and mixed cropping systems, and municipal and industrial wastes [5]. Agricultural residues such as straw, bagasse, coffee husks, and rice husks are biomass materials with high energy potential, and over three billion tonnes per year can be generated worldwide [6]. The utilization of agricultural residues is a promising alternative to fossil resources for the production of energy carriers and chemicals, thus mitigating climate change and enhancing energy security [7].

Agricultural residues are primarily composed of lignocellulosic components (i.e., cellulose, hemicellulose, and lignin). Cellulose and hemicellulose are both polysaccharides. Cellulose is a linear polysaccharide of β -D-glucopyranose units [8,9]. Hemicellulose is a mixture of various polymerized five- and six-carbon monosaccharides such as glucose, mannose, galactose, xylose, arabinose, methylglucuronic acid, and galacturonic acid [8,10,11]. Lignin is an amorphous polymer with no exact structure and consists of an irregular array of variously bonded phenylpropane units [10]. Cellulose is generally the largest fraction, representing approximately 40–50 wt.% of the biomass, and the hemicellulose portion represents approximately 20–40 wt.% of the biomass [12]. Plants, consisting of approximately 60–80 wt.% polysaccharides, are attractive as feedstocks for fermentation to produce large amounts of free sugars [8]. However, biomass recalcitrance, which is the natural resistance of plant cell walls to microbial and enzymatic deconstruction, is largely responsible for the high cost of lignocellulose conversion [1]. Besides, lignin is not yet generally considered fermentable, and thus thermochemical means are usually proposed for its conversion [8]. Therefore, thermochemical methods (e.g., combustion, pyrolysis, and gasification) would be more favorable to convert the biomass into heat, power, biofuels, or chemicals more quickly and more completely.

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Microwave heating offers a number of advantages over conventional heating because of its rapid, selective, volumetric, and uniform heating [13–16]. Pyrolysis assisted by microwave heating is a promising attempt to resolve the challenges in terms of improving the yield and quality of the resultant liquid biofuels and increasing energy efficiency of the whole process [17]. Pyrolysis or torrefaction (a mild pyrolysis) induced by microwave has been utilized to deal with various biomass feedstocks, including scrap tire [16], wood [18], sewage sludge [19], coffee hulls [20], rice straw [21], corn stalk bale [22], oil palm biomass [23], microalgae [24], sugarcane bagasse [25,26], wheat straw [27], and corn stover [28,29]. Either bio-oil [17], biochar [25], or fuel gas [29] can be the primary product from the microwave pyrolysis or torrefaction of biomass feedstocks, which depends on the operational parameters such as microwave power levels, processing time, biomass characteristics, and the presence of catalysts or microwave absorbers [30].

There have been a lot of researches focusing on the gaseous products from biomass pyrolysis by using either conventional or microwave heating. However, there is no work for the effect of lignocellulosic composition on the gas yield from microwave pyrolysis. In this study, microwave pyrolysis of agricultural residues was carried out to observe and discuss the yields and compositions of the gaseous products and their correlations with the lignocellulosic content of the biomass feedstocks.

2. Material and methods

2.1. Materials

The biomass samples of this study were seven different agricultural residues: 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 agricultural residues were naturally air-dried, shredded, and sieved by a 50-mesh (0.297 mm) screen. The moisture content of all the biomass samples was approximately

5–10 wt.%. The proximate analyses of the agricultural residues were performed according to the standard test method D7582-12 of the American Society for Testing and Materials (ASTM). The ultimate analyses were performed with a Perkin–Elmer 2400 Elemental Analyzer. Hemicellulose, cellulose, lignin, and alcohol-benzene extractives were determined in accordance with the analytical method of Li et al. [31]. The calorific values of the agricultural residues were determined by using a CAL2K ECO calorimeter. Xylan and cellulose were provided by Sigma–Aldrich.

2.2. Experimental device and procedure

This study used a single-mode microwave oven operated at 2.45 GHz frequency. A schematic diagram of the overall microwave pyrolysis system is shown in Fig. 1. 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. Reflection microwave power levels were decreased to be as low as possible by adjusting a three-stub tuner and a short circuit during the whole experiment period. When the prescribed processing time was reached, the power supply was turned off, and the carrier gas purging was stopped. The vapor produced during the experiment was immediately cooled by a condenser whose temperature was controlled at 4 °C by a thermostat. The condensable and incondensable parts of the vapor were regarded as liquid product and gaseous product, respectively. After self-cooled down to the room temperature, solid residues remained in the crucible were removed and placed in a desiccator for hours. All of the experiments were performed in triplicate at least to obtain average values for the results.

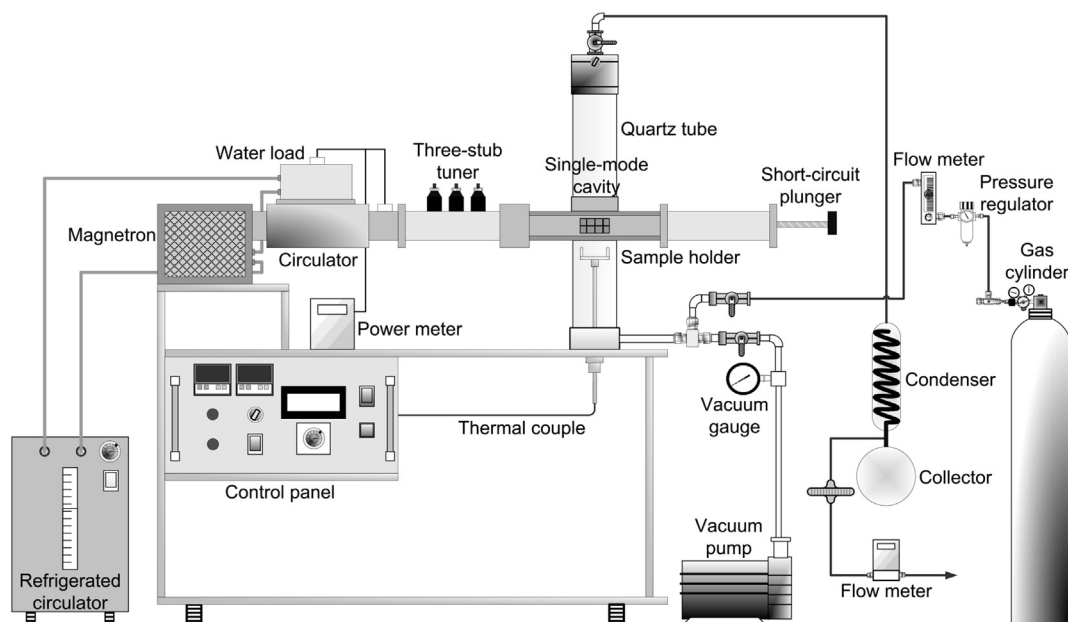


Fig. 1. Schematic diagram of the overall microwave pyrolysis system.

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