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Characterization of bio-oil and bio-char obtained from sweet sorghum bagasse fast pyrolysis with fractional condensers

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HIGHLIGHTS

- Properties of bio-oil and bio-char of sweet sorghum bagasse were investigated.
- The Properties of bio-oil were found to vary across the fractional condensers.
- Using fractional condensers gave bio-oils with different compositions.
- Bio-char has a higher carbon content, pore structure and potassium content.

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ABSTRACT

Fast pyrolysis serves as an alternative and eco-friendly method to dispose of biomass waste and to get bio-oil, bio-char and syngas simultaneously. In this study, sweet sorghum bagasse was pyrolyzed in a fluidized bed reactor with biomass throughput of 1–5 kg/h using fractional condensers and an electrostatic precipitator. GC–MS analysis showed an annulation feature of bio-oil compositions and the fractional condensers proved to be an effective way to separate water and chemical compounds from bio-oil. Surface morphology of bio-char was conducted using scanning electron microscopy and energy dispersive X-ray analysis (EDS). Bio-char is carbon rich with high K content and vesicular structure. Additionally, proximate, ultimate, elemental and the FTIR analysis were carried out on sweet sorghum bagasse and its products to investigate the chemical changes after the fast pyrolysis process.

1. Introduction

Nowadays, people pay much attention to renewable energy because of the shortage of fossil fuels and carbon emission problems. Among the different kinds of energy forms, biomass is widely considered to be a major potential energy source for the future. In the past, biomass was the main energy resource for human beings until the industrial revolution when petroleum begun to be widely used. Compared to conventional fossil fuels, biomass is abundant, easy to store and carbon neutral. Over the last two decades, many researches have been carried out on the conversion of residual biomass into bio-oil. Bio-oil has a high energy density, and can be easily stored, transported and utilized. In addition, the byproduct bio-char is considered as a feed-stock for the production of activated carbon, a soil amendment to improve soil properties, and a material for soil carbon sequestration [1].

As an energy crop, sweet sorghum has a high photosynthetic efficiency. Its grain and juice contain a large percentage of sugars which can be fermented to produce ethanol. The sweet sorghum bagasse is also a vital supplementary material for energy production, which is mainly composed of cellulose, hemicellulose and lignin. It requires pre-treatment prior to enzymatic hydrolysis for conversion to ethanol. In our previous research, five pre-treatment methods have been investigated to improve the enzymatic digestibility of sweet sorghum bagasse and bioethanol production [2]. However, the shortcoming of these pre-treatment methods is that they have a high energy requirement and are costly. Thus it is considered that converting sweet sorghum bagasse to bio-oil and bio-char may be a good alternative way for sweet sorghum bagasse utilization.

Many biomass materials have been tested to produce bio-oil and bio-char in different kinds of reactors [3–6]. However there are few researches on the pyrolysis of sweet sorghum bagasse and its bio-oil and bio-char properties [7,8]. The objectives of this study are to investigate the physicochemical properties of bio-oil and bio-char obtained from fast pyrolysis of sweet sorghum bagasse in a fluidized bed reactor. In addition, gas chromatograph

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and mass spectrometer analysis (GC–MS), Fourier transform infrared spectrometer (FTIR) were used to analyze the characteristics of the pyrolysis products of sweet sorghum bagasse.

2. Methods

2.1. Feed stock preparation

Sweet sorghum (Chongming No. 1 variety) was harvested in Qibao campus, Shanghai Jiao Tong University, China. The stalks were squeezed by a three-roller mill to obtain the liquid phase and the bagasse was produced. The bagasse was dried in the air and then ground to pass through sieve with 40 meshes and stored in plastic bag at room temperature. Before the pyrolysis experiment, sweet sorghum bagasse powders were put into an oven to dry the water at 105 °C for 12 h to make the water content consistently in each pyrolysis work.

2.2. Pyrolysis reactor system

A bench-scale fluidized bed reactor fast pyrolysis system with a feedstock throughput of 1–5 kg/h has been designed and constructed by our laboratory. The schematic diagram of the fluidized bed reactor fast pyrolysis system is shown in Fig. 1. The pyrolysis system comprises of the reactor section and associated auxiliary systems for biomass feeding and injection, pyrolysis products separation and vapor condensation. It has been previously described in detail in Chen et al. [9].

The reactor and the pre-heater are heated by heating jackets. The fluidized medium is silica sand and rests on a distributor plate. Fluidization is accomplished by N_2 administered through a mass flow controller. In the separation section, a cyclone is used to separate the pyrolysis vapor and bio-char. The vapor condensation consists of four condensers in series using a water cooling system and an electrostatic precipitator (EP). The purpose of using fractional condensers is to preliminarily separate the components of bio-oil. The bio-oil from different condenser may have different properties so that it can be utilized accordingly. An EP is used to remove fine particulate matter, such as the smoke in the gases, using the force of an induced electrostatic charge. At the beginning of the pyrolysis work, sweet sorghum bagasse is put into the feeding hopper. It is conveyed from the hopper by a twin-screw feeder to keep the biomass injected to the fluidized bed reactor at the center of the sand. According to our previous work [8], the reactor temperature was set at 500 °C. The flow rate of carrier gas was 60 L/min. At the elevated reactor temperature, sweet sorghum bagasse was pyrolyzed and decomposed into vapors and bio-char, which were rapidly removed from the reactor. The pyrolysis vapors first entered a cyclone to remove bio-char. Then, the pyrolysis vapors were passed to four fractional condensers and EP to trap the liquid oil. During experiment, the temperatures of the fractional condensations were monitored with time. The average temperature of the condensers I, II, III, IV were 310 K, 298 K, 296.5 K, 297 K, respectively, and the residence time of pyrolysis vapors in each condenser was 3.4 s. The bio-oil samples were collected from four condensers separately and labeled bio-oil 1, 2, 3 and 4 at the end of the experiment. The bio-oil from the EP was named as bio-oil 5. Throughout experiments, the yield of bio-oil can be determined from the condensed liquid and the feedstock used on dry bases. The solid char was removed and weighed. The non-condensable gas yield was then calculated by difference [10].

2.3. Analysis methods

2.3.1. Water content

The water content of the bio-oil is measured using Karl-Fischer titration (precision 0.01%) (KFT 870, Swiss Manthon Instrument Factory) according to ASTM E 203.

2.3.2. Acidity

The pH value is tested using pH meter (PHS-3C, Shanghai Lei Ci Instrument plant) at room temperature. The instrument is calibrated with liquid calibration standards of pH 4 and 6.86 prior to the measurement.

2.3.3. Density

The density of the bio-oil is analyzed using a density meter (precision 0.0001 g/cm^3) (Anton Paar, DMA 4100 M, ASTM D4502).

2.3.4. Solids content

The solids content of bio-oil was defined as ethanol insoluble and determined by Millipore filtration system. About 1–10 g of bio-oil was dissolved in 100 mL ethanol and filtered through a pre-dried and pre-weighed 1 μm pore size filter. The filter with the solids was then air-dried for 15 min and further dried in an oven at 105 °C for 30 min. Finally, the filter was cooled in a desiccator and weighed. The solids content was calculated by the original bio-oil sample. This method was recommended by Oasmaa and Peacocke et al. [11].

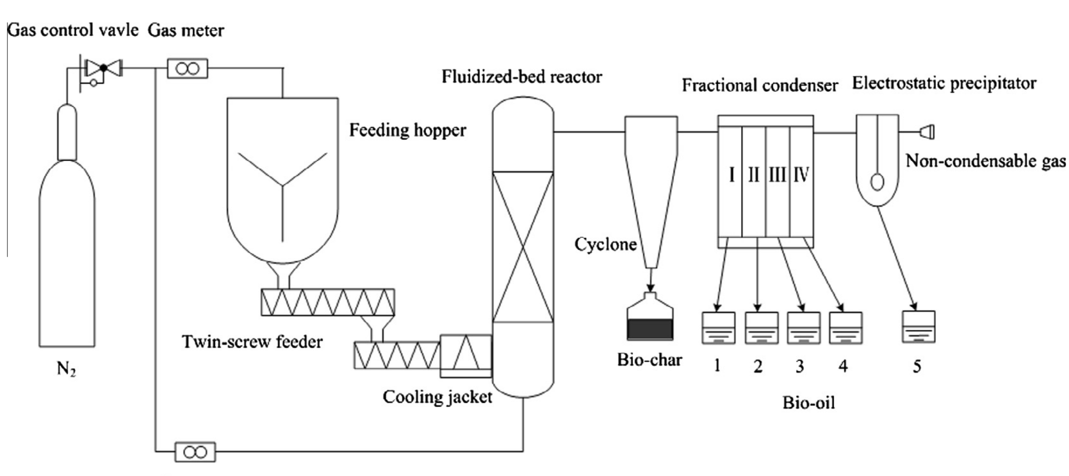

Fig. 1. The schematic diagram of the fluidized bed reactor fast pyrolysis system.