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Effect of hot vapor filtration on the characterization of bio-oil from rice husks with fast pyrolysis in a fluidized-bed reactor

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ABSTRACT

To produce high quality bio-oil from biomass using fast pyrolysis, rice husks were pyrolyzed in a 1–5 kg/h bench-scale fluidized-bed reactor. The effect of hot vapor filtration (HVF) was investigated to filter the solid particles and bio-char. The results showed that the total bio-oil yield decreased from 41.7% to 39.5% by weight and the bio-oil had a higher water content, higher pH, and lower alkali metal content when using HVF. One hundred and twelve different chemical compounds were detected by gas chromatography–mass spectrometry (GC–MS). The molecular weight of the chemical compounds from the condenser and the EP when the cyclone was coupled with HVF in the separation system decreased compared with those from the condenser and EP when only cyclone was used.

1. Introduction

Biomass is a clean, cost-effective, CO_2 neutral and low sulfur content renewable material which can be used for heat and fuel production. It is one of the largest energy sources in the world. Conversion of biomass to energy is undertaken using two main process technologies: thermochemical or biological. Within thermochemical conversion technology, four process options are available: direct combustion, pyrolysis, gasification and liquefaction (Peter, 2002). Fast pyrolysis is a high temperature process in which the feedstock is rapidly heated in the absence of air, vaporizes and condenses to a dark brown liquid, called bio-oil, which has a heating value of about half that of conventional petroleum-derived fuel oil. In addition, non-condensable gases and solid char are also produced simultaneously in this process. If the process is carefully controlled, high yields of liquid can be achieved (Bridgwater and Peacocke, 2000; Liu et al., 2007).

There is extensive literature on pyrolysis of biomass (Seon et al., 2010; Hyeon et al., 2010; Liu et al., 2010; Bridgwater, 1999; Putun et al., 2008; Charles et al., 2008; Lievens et al., 2009; Smith et al., 2009; Oasmaa et al., 2005). In the above studies, bio-oils were obtained by decomposing biomass samples at different pyrolysis conditions and characteristics of the obtained bio-oil were also investigated by various instrumental techniques. Because bio-oil is easy to transport, it is a dominant choice for the replacement of fossil fuels (Nader et al., 2009). It is used as a fuel in boilers and engines (Oasmaa et al., 2001; Chiaramonti et al., 2003).

Properties and chemical composition of bio-oil are distinct from petroleum fuel because of its relatively high content of water and solids, acidity and instability when heated. These disadvantages limit the use of bio-oil. The presence of high concentrations of sub-micron char particles in bio-oils make them problematic for combustion in steam boilers, diesel engines, and turbine operations because of the potential release of ash and alkali metals during combustion (Agblevor and Besler, 1996). During the fast pyrolysis process, the solids content in the bio-oil can be reduced by efficient char removal. The HVF is a system to remove particles from the hot gases. It appears to be a promising technique to reduce the ash and bio-char in the bio-oil. Using HVF, bio-char (including ash) is filtered from the hot pyrolysis vapors. A decrease in ash content in pyrolysis oil was observed by several researchers (Elly et al., 2009; Lee et al., 2005; Diebold et al., 1994).

In the previous research (Chen et al., 2010), the effect of selective condensation on the characterization of bio-oil from pine sawdust with fast pyrolysis was investigated to obtain condensed fractions of organics for higher commercial value. The main objective of this research was to investigate the effect of HVF on the characteristics of bio-oil from rice husks with fast pyrolysis in a fluidized-bed reactor (a laboratory scale 1–5 kg/h) to improve the quality of the bio-oil. Physical and chemical properties of bio-oil analyzed included water content, pH, density, higher heating value (HHV), kinetic viscosity, and chemical

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Table 1
The proximate and ultimate analyses of rice husk.

Proximate analysis		Elemental analysis	
Moisture (wt.%)	8–10	Carbon (wt.%)	40.93
Volatiles (wt.%)	62.44	Hydrogen (wt.%)	4.84
Ash (wt.%)	13.61	Nitrogen (wt.%)	0.42
Fixed carbon (wt.%)	14.58	Oxygen[a] (wt.%)	53.81
Cellulose (wt.%)	36.79		
Hemicellulous (wt.%)	20.56		
Lignin (wt.%)	14.88		

[a] By difference.

composition. In addition, the characteristics of non-condensable gases and bio-char were also examined.

2. Methods

2.1. Feedstock analysis

Rice husks were used as the biomass feedstock in this experiment and its particle size ranging within 0.2∼0.6 mm was selected for bio-oil production using fast pyrolysis. The proximate and ultimate analyses of rice husk are listed in Table 1. Prior to the experiment, the feedstocks were put into an oven to outgas the water at the temperature of 378 K for 12 h.

2.2. Experimental apparatus and procedure

The fully controlled fluidized-bed reactor fast pyrolysis system with a biomass throughput of 1–5 kg/h was constructed at Shanghai JiaoTong University. The schematic diagram of the fluidized-bed fast pyrolysis system is shown in Fig. 1. The fluidized-bed reactor fast pyrolysis system consists of four main sections: feeding section, reactor section, separation system and condensation section.

Biomass is put into the feeding hopper. It is conveyed from the hopper by a variable twin-screw feeder to inject biomass into the fluidized-bed reactor at the center of the sand. The throughput of biomass is within the range of 1–5 kg/h. The reactor was made of stainless steel and was temperature controlled. At the elevated reactor temperatures, biomass was unstable and decomposed into vapors which were rapidly removed from reactor. Nitrogen was used as the carrier gas, and its flow rate was 60 L/min.

In the separation section, a cyclone coupled with HVF was used to filter the pyrolysis vapor. A pulse cleaning system of ceramic filter candle was designed into the HVF. The condensation section contains two parts: the condenser and the electrostatic precipitator (EP). Cooling water circulation was used to cool the condenser. The EP is a highly efficient filtration device that minimally impedes gas flow. It is used after the condenser to eliminate the smoke in the gases. To investigate the effect of HVF on the characterization of bio-oil, firstly, only the cyclone was used to remove the bio-char and the bio-oils in the condenser and the EP are labeled as C_1 and C_2, respectively. Then, the cyclone coupled with HVF in the separation system was used and the bio-oils are labeled as F_1 and F_2. Throughout experiments, gas samples were collected after the cyclone and the HVF using gas bags and the gases were analyzed by a packed column gas chromatograph.

2.3. Analysis methods

The characterization of bio-oil condensed in the condenser and in the EP includes measurement of elemental content, alkali metal, water content, density, pH, higher heating value (HHV), kinetic viscosity and chemical composition. The composition of the gases from fast pyrolysis was determined by a GC. Char characteristics were determined by ultimate analysis using Fourier transform infrared (FTIR) spectrometry methods.

2.3.1. Elemental analysis

The elemental content of the pyrolysis oils and bio-char were determined by a Model 240C Perkin–Elmer Elemental Analyser. In the method, carbon, hydrogen and nitrogen were simultaneously determined as gaseous products (carbon dioxide, water vapor and nitrogen). The oxygen content was found by difference. Na, K, Ca, Mg metal analysis is performed by ICP-OES with reference to ICP general rule JY/T015-1996 method.

2.3.2. Water content

Water content of bio-oil is analyzed according to ASTM E 203 by Karl-Fischer titration (precision 0.01%) (KFT 870, Swiss Manthon Instrument Factory).

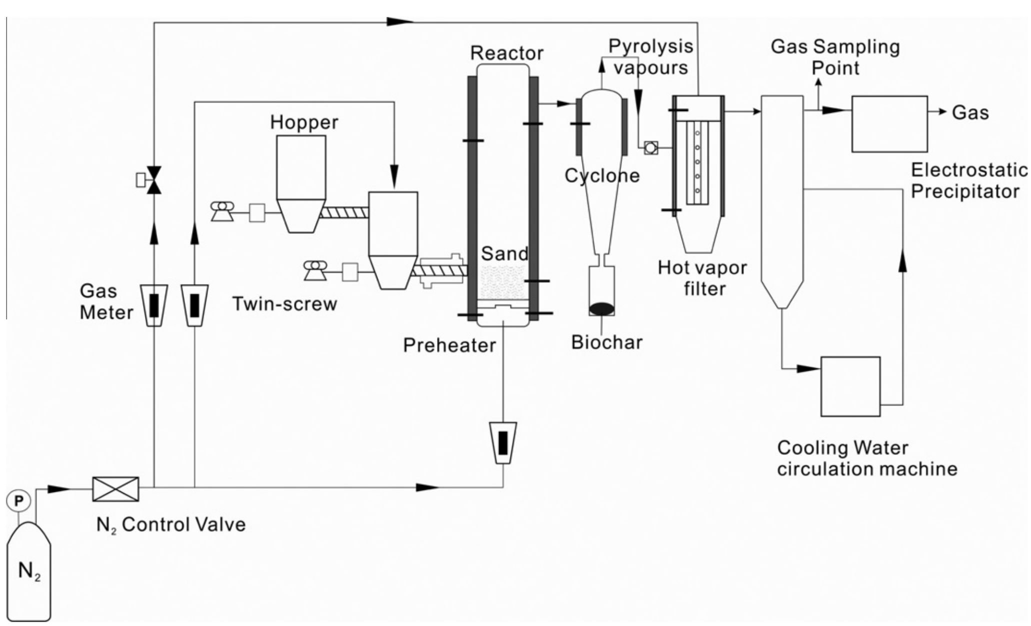

Fig. 1. The schematic diagram of the fluidized-bed reactor fast pyrolysis system.