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Wild reed of Suncheon Bay: Potential bio-energy source

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ABSTRACT

Threat of global warming and imminent exhaustion of fossil fuels call for development of alternative carbon-neutral energy sources. Among others, bio-oil, which can be produced from various biomass, can be used not only as an alternative fuel but also as a feedstock for production of high-value chemicals. In this study, the potential of wild reed growing in Suncheon Bay Ecological Park area as a bio-energy source was evaluated. Fast pyrolysis of reed for bio-oil production was carried out using a lab-scale reactor system. The effects of pyrolysis conditions were investigated. The produced gas, liquid and solid products were analyzed. The effect of carrier gas flow rate was shown to be not significant. The most important parameter determining the product yields was shown to be the reaction temperature in this study. The bio-oil yield was highest (52%) at 520 °C. The bio-oil yield was higher and the char yield was lower for a larger sample particle size, possibly due to the enhanced heat transfer to individual particles for larger particles packed loosely. The bio-oil was shown to be comprised of acids, alcohols, ketones, aldehydes, phenolics, aliphatic hydrocarbons, and aromatics, with phenolics and aromatics accounting for considerable fractions. The fast pyrolysis of reed is expected to be useful for obtaining valuable chemicals.

1. Introduction

During the last decade, renewable energy has drawn large attention in response to increasing use of fossil fuels and its contribution to global warming. Biomass is the renewable energy source that humans have used for the longest time. It is carbon-neutral if it is used in a sustainable way. Different from any other renewable energy sources, biomass can be used to produce not only energy but also fuels and chemicals.

Technologies utilizing biomass energy can be divided into three categories based on their methodologies: biochemical, thermal, and thermochemical conversions. In biochemical conversion, biomass is decomposed via anaerobic digestion to produce methane or is fermented into ethanol. In thermal conversion, direct combustion of biomass is used to produce steam which in turn is used to rotate the turbine powering the generator. Thermochemical conversion includes liquefaction, gasification and pyrolysis [5]. Liquefaction is used to obtain liquid product by heating biomass in a reducing environment often using supercritical fluid. Gasification produces gaseous products including H_2, CO, and CH_4 through partial oxidation of biomass. In pyrolysis, biomass is decomposed into gas, liquid, and solid products in the absence of oxygen. Yields and characteristics of the pyrolysis products vary depending on the biomass feedstock used and the process conditions [7].

Fast pyrolysis, developed to enhance the yield of liquid product, is drawing large attention. In fast pyrolysis, biomass is heated at high temperature in the absence of oxygen. Compared to conventional pyrolysis process, very short residence time in reactor and high temperature rising rate are required to minimize secondary reactions and maximize the liquid product yield [1]. The liquid product generated from pyrolysis is called bio-oil. Bio-oil is considered a promising renewable energy source because it can replace fuel oil in any heating or power-generation applications and, moreover, can be easily stored and transported before being used [12]. Many different kinds of biomass, including agricultural residues, forest residues, organic wastes, and biomass crops, can be used to produce bio-oil. Bio-oil can be used not only as an alternative fuel but also as a feedstock for production of high-value chemicals.

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Wild reed (Phragmites australis) growing in Suncheon Bay Ecological Park area, Korea constitutes high-density colonies with the total area of about 100 ha. It is regularly cut down to control the ecological balance and improve the scenery. Only some of the waste reed is recycled as building material, with the remainder landfilled or incinerated. Phragmites australis is a C3 perennial grass that has a high potential as biomass for energy production due to its high lignin and cellulose contents and high yields. Therefore, fast pyrolysis of Suncheon Bay reed can be a way of renewable energy production using local biomass while reducing wastes.

In this study, pyrolysis characteristics of Suncheon Bay reed were investigated to find the optimal pyrolysis conditions. Pyrolysis experiments were conducted by heating the reed samples in the absence of oxygen to produce gas, liquid and solid products. Analyses on the products were carried out.

2. Experimental

2.1. Analyses of raw material

The reed sample was ground and screened to different sizes of 0.85 mm (0.7–1 mm), 2 mm (1–3 mm), 4 mm (3–5 mm), and 7.5 mm (5–10 mm). The samples were then dried in an oven at 105 ± 5 °C for 24 h to reduce the water content.

Proximate and ultimate analyses were performed for the reed sample prepared (Table 1). All the values for proximate and ultimate analyses results presented in this paper are dry basis. Proximate analysis results shown in Table 1 are the average values of data in triplicate obtained by following the methodology of ASTM (American Standard Test Method D3173 and D 3175). The sample was shown to contain 4.34 wt.% of moisture, 78.57 wt.% of volatile matter, 12.54 wt.% of fixed carbon, and 4.54 wt.% of ash.

The elemental composition was analyzed using an automatic elemental analyzer (Flash EA 2000 series, CE Instruments). The oxygen content was computed by subtracting all the other elements' fractions from 1. The elemental composition measured was used to calculate the higher heating value (HHV). There are three different methods to calculate HHV found in the literature [3]: Dulong's equation (Eq. (1)), Scheurer-Kestner's equation (Eq. (2)), and Steuer's equation (Eq. (3)).

$$\mathrm{HHV(kcal/kg)} = 81\mathrm{C} + 342.5[\mathrm{H} - \mathrm{O}/8] + 22.5\mathrm{S} \tag{1}$$

$$\mathrm{HHV(kcal/kg)} = 81[\mathrm{C} - (3/4)\mathrm{O}] + 342.5\mathrm{H} + 22.5\mathrm{S} + 57 \times [(3/4)\mathrm{O}] \tag{2}$$

$$\mathrm{HHV(kcal/kg)} = 81[\mathrm{C} - (3/8)\mathrm{O}] + 342.5[\mathrm{H} - \mathrm{O}/16] + 25\mathrm{S} + 57[(3/8)\mathrm{O}] \tag{3}$$

where C, O, H and S represent the fractions of carbon, oxygen, hydrogen and sulfur, respectively. Eq. (1) assumes that all oxygen atoms contained in the sample exist as water molecules. On the other hand, Eq. (2) assumes that all oxygen atoms contained in the sample exist as carbon monoxide. Eq. (3) is a compromise of Eqs. (1) and (2); it assumes that a half of total oxygen atoms exist as water and the other half as carbon monoxide. In this study, the water content was measured, so the fraction of oxygen atoms existing as water is known. Therefore, with the assumption that all oxygen atoms which do not exist as water exist as carbon monoxide, the following equation was used to calculate the HHV in this study.

$$\mathrm{HHV(Kcal/kg)} = 81[\mathrm{C} - (3/4)\mathrm{O_{CO}}] + 342.5[\mathrm{H} - (\mathrm{O_{H2O}}/8)] + 57[(3/4)\mathrm{O_{CO}}] + 22.5\mathrm{S} \tag{4}$$

where O_{CO} is the fraction of oxygen existing as carbon monoxide and O_{H2O} the fraction of oxygen existing as water.

Table 1
Main characteristics of reed.

Proximate analysis		Ultimate analysis	
Component	Content (wt.%)	Component	Content (wt.%)
Moisture	4.34	C	53.90
Volatile matter	78.57	H	7.00
Fixed carbon	12.54	O[a]	36.10
Ash	4.54	N	3.00
HHV (MJ/kg)	24.98	S	0

[a] by difference.

2.2. TGA analysis

In order to determine the temperature range for experiments, thermogravimetric analysis (TGA) was conducted with TGA analyzer (TGA 2050 TA Instrument), using nitrogen carrier gas with the flow rate of 100 ml/min. During the analysis, the sample was heated up to 830 °C at a temperature rising rate of 30 °C/min under a nitrogen atmosphere.

2.3. Pyrolysis reactor system

Pyrolysis experiments were carried out using a packed tube reactor system (Fig. 1). A quartz U-tube reactor, with an internal volume of 50 ml, height of 160 mm, and diameter of 5 mm, was filled with 10 g of reed sample and purged for 5 min with nitrogen gas flow. Three different nitrogen gas flow rates were used: 30, 50 and 100 ml/min. The reactor was inserted into an electrical furnace that heats up the reactor to a prescribed temperature within 400–560 °C and remained there for 1 h for complete pyrolysis reaction. The temperature of the furnace was controlled using a PID temperature controller, monitored by a K-type thermocouple. The uncertainty of the temperature measurement is ±5 °C. Gaseous products of pyrolysis were cooled down quickly in a condenser (RW 1025G, JEIO TECH) to prohibit re-polymerization reactions.

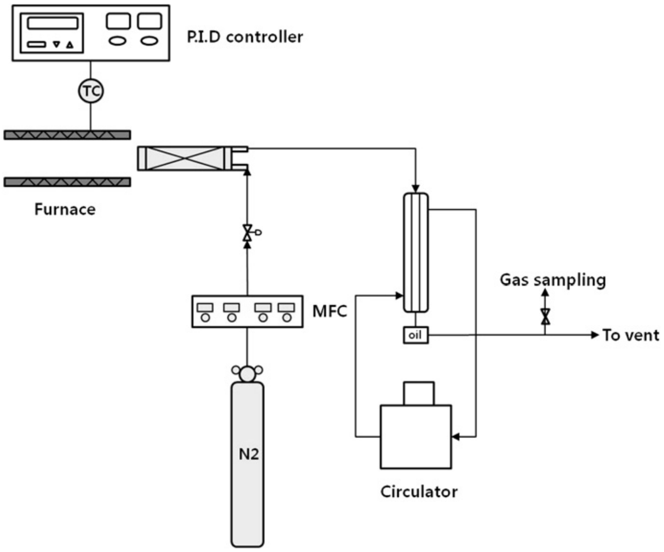

Fig. 1. Schematic of pyrolysis reactor system.