



## Influence of reaction conditions on bio-oil production from pyrolysis of construction waste wood



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### ABSTRACT

The pyrolysis characteristics of construction waste wood were investigated for conversion into renewable liquid fuels. The activation energy of pyrolysis derived from thermogravimetric analysis increased gradually with temperature, from 149.41 kJ/mol to 590.22 kJ/mol, as the decomposition of cellulose and hemicellulose was completed and only lignin remained to be decomposed slowly. The yield and properties of pyrolysis oil were studied using two types of reactors, a batch reactor and a fluidized-bed reactor, for a temperature range of 400–550 °C. While both reactors revealed the maximum oil yield at 500 °C, the fluidized-bed reactor consistently gave larger and less temperature-dependent oil yields than the batch reactor. This type of reactor also reduced the moisture content of the oil and improved the oil quality by minimizing the secondary condensation and dehydration. The oil from the fluidized-bed reactor resulted in a larger phenolic content than from the batch reactor, indicating more effective decomposition of lignin. The catalytic pyrolysis over HZSM-5 in the batch reactor increased the proportion of light phenolics and aromatics, which was helpful in upgrading the oil quality.

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### 1. Introduction

Fossil fuels account for by far the largest proportion of global energy use. Fossil fuels are also the most important supplier of raw materials for the chemical industry. The greatest difficulty in efforts to tackle global warming is the huge reliance on fossil fuels. Considering the limited reserves of fossil fuels, it is important to develop alternative resources to prepare for the exhaustion of fossil fuels.

In recent years, biomass has been recognized as a renewable and environment-friendly energy source because it can not only reduce the dependency on fossil fuels, but also contribute to reducing greenhouse gas emission by fixing CO<sub>2</sub> [1–9]. Because biomass rarely contains heavy metals and sulfur, it does not cause catalyst poisoning and its combustion does not emit large amounts of SO<sub>x</sub>. Energy production from biomass can be achieved through

bio-chemical or thermo-chemical processes. Ethanol production based on fermentation is a representative bio-chemical process. Thermo-chemical processes can be divided into pyrolysis, gasification and combustion depending on the oxygen supply [10–12]. Compared to combustion and gasification, pyrolysis has the advantages of a low process temperature, low emission of air pollutants and recovery of bio-oil with a high heating value. This has prompted extensive investigations on the production of bio-oil from the pyrolysis of biomass [12–20].

Construction waste wood refers to waste wood resulting from the construction, renovation and demolition of buildings and public works. Only 4% of construction waste wood is used to manufacture recycled board or fuel; the other 96% is sent to landfill or incinerated. The generation of construction waste wood in Korea increased steadily until 2005, from which it has been decreasing due to the inactive construction market. According to the data for 2009, however, 183,351 tons/day of construction waste is still being generated, of which waste wood accounts for 1125 tons/day [21].

In this study, experiments were carried out to determine the optimal temperature for the pyrolysis of construction waste wood

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to maximize the bio-oil yield for the first time. The yields and characteristics of the pyrolysis products, i.e., gas, oil and char, were investigated. Two different types of reactors, a batch reactor and a fluidized-bed reactor, were used and the product characteristics were compared. The effect of a catalyst (HZSM-5) on the pyrolysis of construction waste wood was also investigated.

## 2. Experimental

### 2.1. Sample preparation

The construction waste wood collected at Sudokwon Landfill Site in Incheon, Korea was used for the pyrolysis experiments. Although the construction waste wood used in this study was composed of a range of wood materials including plywood, particle board, scantlings and natural wood, it was assumed that its composition was uniform in all experiments. The construction waste wood was pulverized and particles with a size of 0.2–2 mm were used. The particles were dried at 110 °C for 24 h before the pyrolysis experiments. Ultimate analysis was performed using an elemental analyzer (Flash EA 1112series/CE Instruments) to quantify the carbon (C), hydrogen (H), oxygen (O), nitrogen (N) and sulfur (S) contents. Proximate analysis was carried out using a thermogravimetric analyzer (pyris1 TGA, Perkin Elmer).

### 2.2. Thermogravimetric analysis (TGA)

The thermal characteristics of construction waste wood were examined by TGA. The temperature was changed from room temperature to 600 °C. Three different heating rates were used: 20 °C/min, 30 °C/min and 40 °C/min. N<sub>2</sub> gas with a flow rate of 60 ml/min was used as the carrier gas. A 6–11 mg sample was used for each analysis.

### 2.3. Pyrolysis experiment using batch reactor

Fig. 1 shows a schematic diagram of the batch reactor system used in this study. A U-type quartz reactor with a volume of 50 ml, height of 160 mm, and an inlet/outlet diameter of 15 mm was used. The reactor was purged with nitrogen gas with a flow rate of 50 ml/min for 30 min before each experiment to create an oxygen-free condition. Two condensers connected in series were used to collect the bio-oil. The condensers were maintained at –20 °C to allow species with low volatility to condense. The gaseous

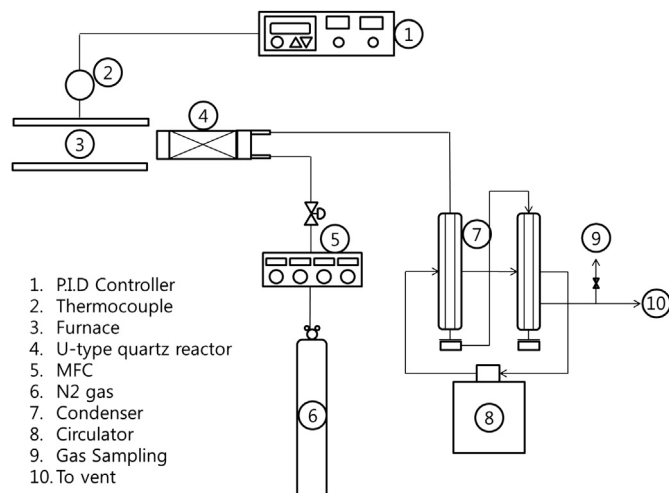


Fig. 1. Schematic diagram of batch type reactor system.

products that passed through the condensers were collected in a Teflon gas bag. The experiments were carried out under a range of operation conditions: four different temperatures (400 °C, 450 °C, 500 °C and 550 °C) and three different gas flow rates (15 ml/min, 30 ml/min and 50 ml/min). Each experiment was performed for 1 h with a 5 g sample.

Catalytic upgrading was performed using a batch reactor system. Commercial HZSM-5 (SiO<sub>2</sub>/Al<sub>2</sub>O<sub>3</sub> = 23) purchased from Zeolyst was used. The reaction temperature was set at 500 °C. The ratio of catalyst/wood was 1/10. The detailed experimental procedure can be shown in the literature [22].

### 2.4. Pyrolysis experiment using fluidized-bed reactor

Fig. 2 shows a schematic diagram of the fluidized-bed reactor system used in this study. The general layout is similar to that of the batch reactor system except that the preheated nitrogen flow rate was 5 l/min to maintain the level of fluidization. The fluidized-bed reactor used in this study had an inner diameter of 85 mm and a height of 400 mm. The tube connected to the reactor outlet was heated with heating tape that can increase the temperature to 450 °C to prevent the condensation of pyrolysis vapor. A cyclone was used to collect the particulate matter. The product oil was collected in two glass condensers in series maintained at –20 °C. An electrostatic precipitator was installed after the condensers to collect the tar particles. The gas-phase species that had not condensed in the two condensers were collected every 20 min using a gas sampling system. 1000 g of Al<sub>2</sub>O<sub>3</sub> powders with a mean diameter of 150 μm were used as a filler.

To create oxygen-free conditions, the reactor was purged with nitrogen gas for 3 h before increasing the temperature. After turning the cooling system on, the temperatures of the reactor, pre-heater, and heating band were increased to the set temperatures. Once the temperature indicated by the thermocouple installed in the reactor had become stable, it was assumed that uniform fluidization had been reached and the screw feeder was turned on. For each experiment, 120 g of sample was used with a feeding rate of 2 g/min.

### 2.5. Analysis of products

The gaseous products collected in a Teflon gas bag were quantified using a GC equipped with a TCD and a FID. CO, CO<sub>2</sub>, H<sub>2</sub> and CH<sub>4</sub> were analyzed by the TCD equipped with a Carboxen 1000 column, whereas the hydrocarbons were analyzed by the FID

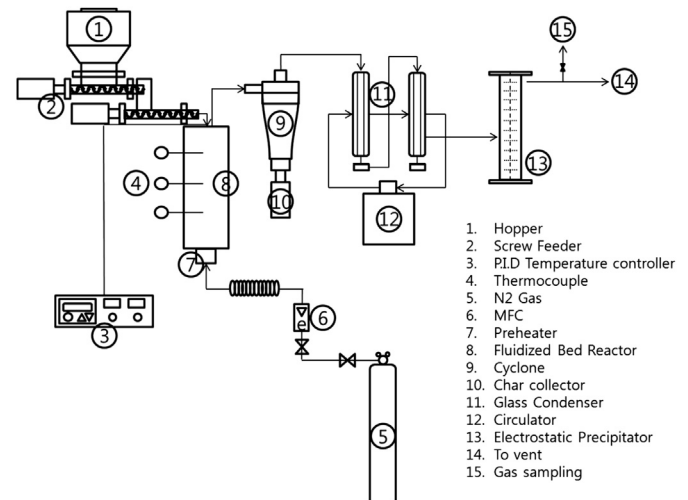


Fig. 2. Schematic diagram of fluidized bed reactor apparatus.

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