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Hydrogen-rich gas production from a biomass pyrolysis gas by using a plasmatron

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ABSTRACT

Pyrolysis and gasification is an energy conversion technology process that produces industrially useful syngas from various biomasses. However, due to the tars in the product gases generated from the pyrolysis/gasification of biomass, this process damages and causes operation problems with equipment that use product gases such as gas turbines and internal engines.

Therefore, in this study, a continuous-screw-type pyrolyzer was manufactured and the plasmatron was connected to its rear end through the pyrolyzer. And experiments were performed according to increasing the tar conversion and the hydrogen yield of the product gas. To conduct the parametric studies, experiments were performed on the variations in the steam feed rate, plasma input power and sawdust feed rate (i.e., change for tar concentration in the product gas) to show the performance of plasmatron. The light and gravimetric tars and gases were analyzed to examine the behavior of the products against the hydrogen-rich gas production and tar destruction from the pyrolysis gas.

When the steam feed rate of the plasmatron was 1.0 L/min, the plasma input power was 0.17 kW and the sawdust feed rate to the pyrolysis was 0.7 g/min, the conversion rates of the representative light tar components were 80.9% for benzene, 97.6% for naphthalene, 90.7% for anthracene and 90.6% for pyrene. Furthermore, the conversion rate of gravimetric tar was 99.7%.

The reformed gas after the plasmatron reaction contained 9% hydrogen, 8.9% carbon monoxide, 2.8% carbon dioxide, 0.55% methane, 0.07% ethylene, 0.01% ethane and 0.12% propane. The hydrogen increased 87.5%, while carbon dioxide decreased 12.5%.

1. Introduction

The rapid increase in the global demand for fossil fuels causes environmental problems due to their burning. Therefore, diversifying energy sources and using clean fuels should be demanded to solve the problems. According to this backdrop, a biomass is drawing attention as a clean energy source. There have been many attempts to use it as a carbon-neutral clean energy source. It contains less environmental pollutants, such as sulfur and nitrogen, than the fossil fuels. In particular, it has been found that it is efficient to use biomass through syngas production by pyrolysis and gasification. Pyrolysis and gasification technology is known to be capable of recovering energy from the biomass. The syngas generated from this

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process can be applied to various areas such as the biogas fuel for gas turbines, internal engines, fuel cells, and the feedstock for production of methanol, hydrocarbon fuels, synthetic natural gases, etc.

However, the product gas generated from the pyrolysis and gasification of biomass contains about 30% tar, which can increase the burden or difficulty of dust collection for the refinement of the product gas [1]. The tar causes various problems in the follow-up processes that use the product gas in gas turbines and internal combustion engines. The tar components in the product gas in this compression process are condensed, which blocks the conduit and damages the engine and turbine [2,3]. Furthermore, because tar itself consists of heavy hydrocarbons, the more tar which means lower syngas production, is generated, the more energy itself is lost from the pyrolysis and gasification process. Therefore, the processing of the tars generated from the pyrolysis and gasification of biomass is very important for the tar removal.

Various studies have been conducted on the products generated from the pyrolysis and gasification of biomass [1,4,5]. They were mostly about catalyst cracking [6,7] and thermal cracking [8,9] to reduce the tars in the producer gases. However, for the catalyst cracking, the catalyst has problems in the carbon deposition and the sintering by thermal heat. Furthermore, for economic power, the catalyst must be easily regenerated, but there are many restraints in the achievement of high strength. And for the thermal cracking, the heat sources needed to maintain a high temperature of 800–1000 °C and the size of the equipment required to achieve sufficient detention time are the restraints.

Therefore, studies are being conducted on tar decomposition technology for various plasma techniques such as corona discharge and arc discharge to attain high tar reduction and energy efficiency [10,11]. Among these, gliding arc plasma has many advantages such as fast start and response characteristics of only a few seconds, maintenance of an optimal operation status for various gas properties, and compact design. The gliding arc plasma forms an electric field for the dielectric breakdown between the electrodes when a high voltage is supplied to the fan-shaped electrodes. Plasma discharge is formed by the flow of gas injected between the electrodes, and the gas is converted into active chemical species and ions. Furthermore, because the gliding arc plasma simultaneously has an equilibrium region, which is a high-temperature region, and a non-equilibrium region, which is a low-temperature region, it is often applied to researches on complex hydrocarbon reforming and the decomposition of non-biodegradable materials [12–14].

Therefore, in this study, a plasmatron was developed to remove the tars generated from the sawdust in a continuous-screw-type pyrolyzer, and was connected to the rear end of the pyrolyzer. Experiments were conducted on the variations in the steam feed rate to the plasmatron, plasma input power and sawdust feed rate on the pyrolyzer, respectively, and the behavior of the hydrogen-rich gas production and tar destruction in the pyrolysis gas were examined by analyzing the light and gravimetric tars and syngas gas.

2. Experiment apparatus and method

2.1. Experiment apparatus

Fig. 1 shows the experiment apparatus, which consisted of the biomass pyrolyzer, the plasmatron, the power supply equipment, the control and monitoring system, and the measuring and analysis line.

The biomass pyrolyzer was only used to produce the pyrolysis gases which are a feedstock for the reforming tests in the plasmatron. The characteristics of the sawdust that was used as wood biomass in this experiment are revealed by ultimate analysis. The sawdust contains the carbon of 42.98%, hydrogen of 6%, and oxygen of 47.31%.

The length and diameter of the pyrolyzer were 1000 mm and 45 mm, respectively, and an electric heater that could raise the temperature to up to 1000 °C was used for the main heater that was attached to the outside of the tube-type reactor. The controller (Model UP35A, Yokogawa, Japan) controlled the temperature and the screw connected to the motor feeds sawdust.

The plasmatron had three blade-shaped electrodes (width: 20 mm; height: 95 mm; and thickness: 2 mm) at 120° inside it that were fixed to the cylindrical ceramic (Al_2O_3, wt. 96%), which is an insulator. The outer shell of the plasmatron was made of a quartz tube (diameter: 55 mm and length: 200 mm) for the insulation and observation of the inside. In addition, a set amount of distilled water was supplied from the water tank to the steam generator by a water pump to generate steam. The steam generated from the steam generator was mixed with the gas and tar generated from the pyrolysis, and then was injected into the plasmatron [15,16].

The power supply equipment consisted of a power supply (Model UAP-15K1A, Unicon Tech., Korea), a high-voltage probe (Model P6015, Tektronix, USA), a current probe (Model A6303, Tektronix, USA), a current amplifier (Model TM502A, Tektronix, USA) and an oscilloscope (Model TDS-3052, Tektronix, USA). The power supply had a capacity of 0.6 kW, used a three-phase alternating current and could supply up to 13 kV to the plasmatron.

The control and monitoring system controlled the steam generator, pyrolyzer, heater, etc. to their respective settings through the controller. Then the temperature change of each device was monitored continuously with the data logger (Model Hydra data logger 2625A, Fluke, USA).

The measuring and analysis line consisted of a glass wool filter, an impinger, an isothermal bath, a chiller (Model ECS-30SS, Eyela Co., Japan), a wet gas meter (Model W-NK-1A, Shinagawa, Japan) and a metering pump (Model N-820.3FT 18, KNF, Switzerland). The analysis system consisted of GC-FID (Model GC-14B, Shimadzu, Japan) for tar analysis and GC-TCD (Model CP-4900, Varian, The Netherlands) for gas analysis.

2.2. Experiment methods and analysis

The pyrolyzer was set at the temperature of 800 °C to constantly generate a pyrolysis product gas. The sawdust as a feedstock was continuously fed at 0.7 g/min to the pyrolyzer. Nitrogen gas as a carrier gas was fed at 3 L/min to keep the inside of the pyrolyzer oxygen-free and to prevent the reverse