



Bench-scale production of liquid fuel from woody biomass via gasification

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ABSTRACT

The bench-scale production of hydrocarbon liquid fuel was achieved from woody biomass via gasification. The daily production capacity of the biomass-to-liquid (BTL) plant used in this study was 7.8 L of hydrocarbon liquid from 48 kg of woody biomass (on a dry basis), corresponding to 0.05 barrels. The BTL process involved the following steps: oxygen-enriched air gasification of the woody biomass, wet and dry gas cleaning, gas compression, carbon dioxide removal, and the Fischer–Tropsch (FT) synthesis reaction. In the gasification step, oxygen-enriched air gasification was carried out using a downdraft fixed-bed gasifier. The content of oxygen, which acts as the gasifying agent, was increased from 21.0 to 56.7 vol%; maximum values of the conversion to gas on a carbon basis and cold gas efficiency—approximately 96 C-mol% and 87.8%, respectively—were obtained at an oxygen content of around 30 vol%. With the increased oxygen content, the concentrations of CO, H₂, and CO₂ increased from 22.8 to 36.5 vol%, from 16.8 to 28.1 vol%, and from 9.8 to 14.8 vol%, respectively, while that of N₂ decreased from 48.8 to 16.0 vol%. The feed gas for the FT synthesis reaction was obtained by passing the product gas from the gasification step through a scrubber, carbon dioxide removal tower, and desulfurization tower; its composition was 30.8 vol% CO, 25.2 vol% H₂, 0.9 vol% CO₂, 2.5 vol% CH₄, 40.6 vol% N₂, <5 ppb H₂S, and <5 ppb COS. The hydrocarbon fuel was synthesized in a slurry bed reactor using hexadecane as the solvent and a Co/SiO₂ catalyst. For hydrocarbons with carbon chain lengths of more than 5 carbon atoms (collectively referred to as C₅₊) in the liquid fuel, a selectivity of 87.5% was obtained along with a chain growth probability of 0.84 under the following conditions: 4 MPa, 280 to 340 °C, and a ratio of catalyst weight to feed gas rate (W/F) of 9.3 g·h/mol.

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1. Introduction

In Japan, approximately 40 million kL of diesel fuel derived from fossil fuels is consumed annually. Among the renewable energy sources available in the near future, biomass is expected to be one of the most attractive potential feedstocks for an alternative liquid fuel because of its carbon neutrality and abundance. Recently, the synthesis of liquid fuels such as ethanol from sugarcane and maize has led to an increase in the prices of various food products. Therefore, it is important to develop a technology to convert woody biomass—whose consumption does not affect the price of food products—to liquid fuels. Since woody biomass has a sulfur content lower than that of fossil fuels, clean liquid fuels with low sulfur contents can be synthesized; the use of these fuels would reduce acid rain and extend the lifetime of catalysts for reducing NO_x in diesel exhaust gases. The technology used for the conversion of woody biomass-to-liquid fuel via gasification (biomass-to-liquid: BTL) is very promising; the process generally involves biomass gasification for producing syngas (CO+H₂), gas cleaning, and Fischer–Tropsch (FT) synthesis reaction. Some researchers have reported experimental studies [1–3] and environmental and economic analyses [4,5]. The FT

synthesis reaction used in the gas-to-liquid (GTL) process has been investigated in Japan on a larger scale than the laboratory scale [6]; however, the production of hydrocarbon liquid fuels such as diesel fuels from woody biomass using the BTL process must be established on the bench-scale as a first step toward applying this process in pilot- or commercial-scale plants. We constructed a bench-scale BTL plant consisting of five stages—woody biomass gasification, gas cleaning, gas compression, carbon dioxide removal, and FT synthesis reaction—and succeeded in producing hydrocarbon liquid fuel on the bench-scale [7].

In this study, we operated the woody biomass gasification and FT synthesis reaction under more favorable conditions, and successfully increased the daily production capacity of the total process to 7.8 L of liquid fuel (0.05 barrels). Options for further technical improvements in the proposed BTL process are discussed.

2. BTL process design

Fujimoto et al. performed process design and simulation for a typical BTL system consisting of woody biomass gasification with steam, gas cleaning, gas compression, FT synthesis reaction, hydrocracking, and distillation [5]. When the amount of collected woody biomass was fixed at 100 t/d, 465 GJ/d of heat and 96.2 GJ/d of electricity were required to operate the gasifier and compressors, respectively, corresponding to

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78% and 16% of the required input energy. Steam gasification for producing syngas and gas compression for the FT synthesis reaction need a relatively high input energy.

Fig. 1 shows the flow diagram of the constructed bench-scale BTL plant. The BTL process proposed in the present study comprises the following steps: woody biomass gasification using a fixed-bed gasifier, first gas cleaning using a scrubber, first gas compression up to 0.9 MPa, second gas cleaning under pressurized conditions using a desulfurization tower, removal of carbon dioxide, second gas compression at more than 1 MPa, and FT synthesis reaction using a slurry bed reactor. Two compressors were employed in order to keep the amount of high pressure gas (above 1 MPa) as low as possible.

In the gasification step, syngas has to be effectively produced from woody biomass without steam. In the present study, we used oxygen-enriched air gasification. A downdraft fixed-bed gasifier was employed, taking into account the produced tar concentration, applicability to small- or medium-scale plants, operation control, and operation power. In order to decrease the gas compression power and the amount of high pressure gas, CO₂, which is an inert gas for the FT synthesis reaction, was removed before the second gas compression. In the FT synthesis reaction, the liquid-phase reaction was performed using a slurry bed reactor in order to easily control the reaction temperature and to extend the catalyst lifetime.

3. Experimental

3.1. Materials

Eucalyptus wood chips (size: 20–30 mm) were employed as the feedstock. Table 1 shows the results of the feedstock analysis.

3.2. Woody biomass gasification

Fig. 2 shows the downdraft fixed-bed gasifier (capacity: 40 kg wood/h). By changing the oxygen flow rate, the oxygen content in the oxygen-enriched air was varied from 21.0 to 56.7 vol%. At first air was supplied into the gasifier using a forced fan. After the combustion zone and reduction zone reached the desirable temperature, the forced fan was turned off and air was fed into the gasifier using a roots blower. Subsequently pure oxygen was added to the air using a mass flow controller. Woody biomass was fed through a rock hopper from the top of the gasifier. The height of woody biomass in the gasifier was monitored using a level sensor. The biomass feed rate was changed to keep the height of woody biomass constant; the feed rate increased from 6.9 to 13.6 kg/h as the oxygen content increased. The product gas flow rate was adjusted to approximately 18 Nm³/h (N means values at standard temperature and pressure) using the roots blower. The pressure difference (ΔP) between the input and output streams of the gasifier was controlled at less than 5 kPa by adjusting the swinging speed of the grate at the bottom of the gasifier. The temperatures in the combustion and reduction zones of the gasifier and the product gas flow rate were monitored during the operation. The operation time was 4.5–6 h for air or oxygen-enriched air gasification. Gas, char, dust, and wood vinegar were obtained as the products (Fig. 2). The wood vinegar was collected by cooling the vapor generated in the pyrolysis zone in the gasifier. The char was obtained from the bottom of the gasifier. The dust was collected by a cyclone. The cold gas efficiency was defined as the ratio of the heat content of the effluent gas produced by gasification to the heat content of wood on a higher heating value basis.

$$\text{Cold gas efficiency [\%]} = \frac{(\text{HHV of product gas [MJ/h]})}{(\text{HHV of wood [MJ/h]})} \times 100 \quad (1)$$

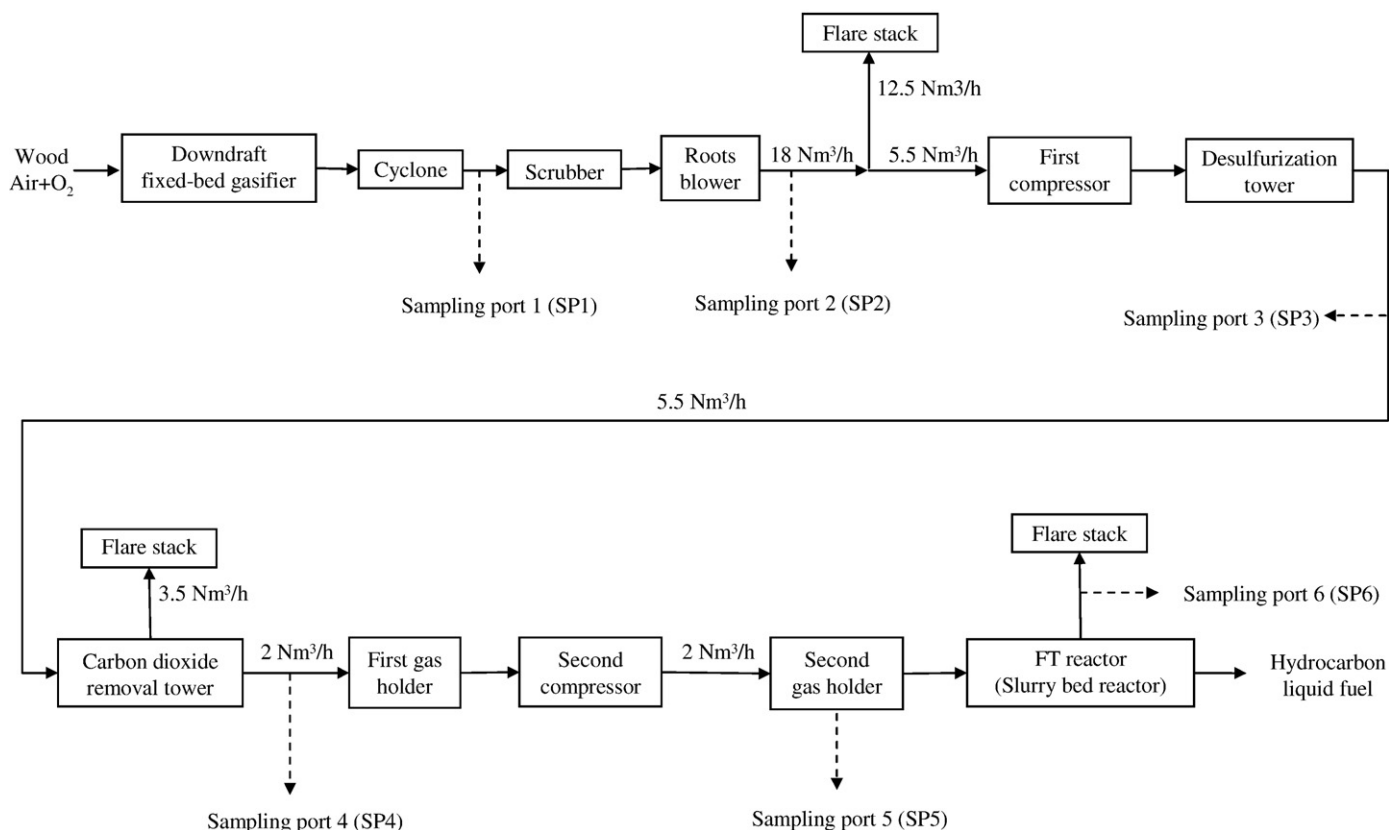


Fig. 1. Flow diagram of a bench-scale BTL plant.

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