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Biomass gasification process with the tar removal technologies utilizing bio-oil scrubber and char bed

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HIGHLIGHTS

- Primary tar removal methods were developed for biomass gasification.
- Utilization of byproducts for tar removal was investigated.
- The bio-oil scrubber and the char bed filter are effective for low-cost tar removal.
- 98% of tar was eliminated by the combination of some secondary methods.

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ABSTRACT

We develop tar removal technologies by using byproducts (bio-oil and char) in order to achieve low-cost and highly effective tar removal using only secondary removal methods in a pilot-scale gasification facility. The tar removal performance of a 100-L bio-oil scrubber and a 13-kg char filter is investigated with an up-draft gasifier. The tar removal rate of the bio-oil scrubber at 40, 50, and 60 °C is measured; the highest removal rate is 64.5% at 50 °C. Furthermore, even though the tar removal performance of water/oily scrubber generally degrades, that of the bio-oil scrubber does not decrease even after use for 22.5 h. The char can also be used as a tar adsorbent, like activated carbon, because of its high porosity. The char bed filter removes 81.5% of the tar from the producer gas at the beginning of the operation. The entire tar removal system, including the bio-oil scrubber and the char bed filter, exhibits a 98% tar removal rate.

1. Introduction

The elimination of biomass tar is the biggest obstacle in the commercialization of the biomass gasification technology. Biomass tar consists of several hundreds of hydrocarbons, which include single-ring to five-ring aromatic compounds. Tar condenses when the temperature falls below its dew point, resulting in the clogging of fuel lines, filters, and engines. The tar concentration in the producer gas varies greatly with the reaction conditions and the type of gasifier [1–3]. Especially, the updraft gasifier produces considerable tar; 10,000–150,000 mg/Nm^3. However, the tar concentration in the producer gas must be less than 100 mg/Nm^3 for a stable operation of internal combustion engines [4–6]. The updraft gasifier also produces high-quality gas with high calorific value, as compared to the downdraft gasifier, due to high char burnout and good internal exchange [4,7]. If tar could be eliminated effectively at low cost, the updraft gasifier would be able to achieve high overall energy efficiency without tar problems at low cost.

Various tar removal technologies have been developed until now. These technologies can be classified into primary and secondary methods, according to the location where the tar is removed. In general, primary methods such as catalytic cracking, thermal cracking, and plasma gasification exhibit a high tar removal rate. In addition, some studies using catalysts showed high tar removal performance. It was reported that 98–99% of the tar in the producer gas was decomposed by Ni catalysts, which also increased the gas heating value [8,9]. Furthermore, various catalysts, such as dolomite and olivine, were investigated for improvement, providing remarkable results [10–13]. However, the primary methods incur comparatively higher initial and running costs due to the high temperature, short lifetime and complicated gasifier constructions of the catalysts [5,14–16].

On the other hand, secondary methods such as using a scrubber, filter, and centrifuge are easier to commercialize because of their low cost and simple procedures. For the wet system, water

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scrubbing is often used in gasification plants, which has a low cost and is easy to perform. However, most tar has less or zero solubility in water, so the rate of tar removal by water scrubbing is low. Moreover, the separation of polar tar components from the water after use is very difficult and expensive. For this reason, oil absorbent was considered as an alternative to water. Phuphuakrat et al. [17] investigated the tar removal performance of specific oily materials, and the performance resulted in a vegetable oil > engine oil > water > diesel fuel. Since tar is a non-polar material, like oil, more tar can be absorbed by an oily absorbent than by water, and an oil scrubber showed higher tar removal performance. Paethanom et al. [18] compared the tar removal performance of a waste-cooking oil scrubber to that of a vegetable oil scrubber to explore the possibility of cost reduction. As a result, the waste-cooking oil and the vegetable oil could remove 81.4% and 89.8% of tar in the producer gas, respectively. Balas et al. [19] reported that a scrubber with biodiesel oil showed more than 95% tar removal rate. However, they also mentioned that the tar concentrations in the gas should be minimized before the scrubber is applied, in order to maintain the scrubber efficiency, because the performance degrades easily. Ozturl and Yilmaz [20] investigated the relationship between the operation time and the removal efficiency of some oily scrubbers for benzene and toluene. A vegetable oil scrubber and a lubricant scrubber removed 80–90% of the tar at the beginning of the operation. However, the removal performance decreased by half after 300–500 min because the tar concentration in the absorbent increased. In order to reduce the absorbent consumption, OLGA tar removal technology was applied to remove the tar with an oil scrubber and reuse the absorbent by regenerating it with a stripper [21]. The absorbent was circulated between the scrubber and the stripper, and was maintained at a constant level with respect to the tar concentration.

In our previous research, we investigated the possibility of using bio-oil produced from the biomass gasification process as a scrubbing medium for tar removal [22]. The scrubber with 500 mL bio-oil showed 56.8% tar removal efficiency with a mixing ratio of 1000 rpm by a magnetic stirrer machine in a lab-scale experiment. The performance increased with the scrubber temperature, which was controlled with an electronic heater; the highest tar removal rate was 73.3% at 50 °C. Using the bio-oil scrubber eliminates the purchasing and transportation costs for a scrubbing medium because the bio-oil is produced on site in the gasification plant. In order to investigate the commercialization feasibility of the bio-oil scrubber, this research aims to evaluate its tar removal performance in the pilot-scale gasification facility.

Another method is using the dry system, which removes tar in vapor or mist phases. The centrifugal separation is effective not only for the removal of water and soot but also tar. Although the high efficiency of the centrifugal separation for tar removal of coal gasification was reported, there are almost no data on using centrifugal separation for biomass gasification [14]. One of the originalities of the present study is the use of centrifugal separation for tar removal. In addition, regarding adsorption technologies, it was demonstrated that activated carbon has high tar removal ability, because it behaves as a tar absorbent due to its high porosity [23–25]. At the same time, however, the limited lifetime and the high operational cost make it difficult to put this into practical use. The biomass char was also investigated as a tar adsorbent/catalyst since biomass char has a high porosity and a high-specific surface area. Some studies reported that char has removal ability for model tar components, such as benzene and naphthalene as catalysts [26,27]. It was reported that using char and sand together, more than 80% of model tar compounds were removed. Liu et al. [28] investigated the adsorption capacity of chars generated from rice husk and corncob pyrolysis. They found that the retention time in a pyrolysis reactor in the char generation process affects the tar removal performance. Paethanom et al. [18,29] investigated the tar adsorbent ability of the char bed filter of the rice husk for pyrolysis gas, by changing the generation temperature of the char bed, in a bench-scale facility. The rice husk char showed a tar removal rate greater than 80%, and the highest removal rate, 87.5%, was observed at 800 °C generation temperature. They concluded that the combination of an oil scrubber and a char adsorbent is effective for tar removal, since most of the heavy tar can be removed with the oil scrubber and the rest of the heavy tar as well as light tar can be removed by the char adsorbent, which increases the lifetime of the char adsorbent. In order to overcome the disadvantage of the activated carbon/char adsorbent, which has a limited lifetime, a technology was developed to regenerate activated carbon saturated with benzene and toluene [29]. By keeping tar-saturated activated carbon in successive cycles in an oxidant atmosphere (i.e., with an oxygen composition similar to that in air), it can be regenerated at about 300 °C. Investigating the lifetime of the char filter will be fundamental for its application.

In the present study, the tar removal performance of the combination of some secondary removal methods such as a bio-oil scrubber, a char bed filter, a cooler, and a centrifuge is investigated in a pilot-scale gasification plant. In particular, we evaluate (1) the tar removal performance of the bio-oil scrubber and the char bed filter, (2) the time-dependent change in the tar removal performance of the bio-oil scrubber and the char bed filter, and (3) the tar removal performance of a combination of secondary tar removal methods.

2. Material and methods

2.1. Gasification facility

The pilot-scale gasification plant we investigated in this research belongs to Maywa Co., Ltd. in Ishikawa Prefecture, Japan. The process scheme of the experimental setup is shown in Fig. 1. The gasification reactor is an updraft gasifier with an internal diameter of 800 mm and a height of 1250 mm. Air was supplied from the bottom of the reactor as a gasifying agent at the rate of 23 m^3/h. The cedar feedstock was prepared by crushing with a mesh size smaller than several centimeters. The screw feeder was used for maintaining a continuous feed rate of 60 kg/h. The cedar ultimate and proximate analysis is shown in Table 1. When the feedstock was supplied into the reactor, the volatiles of the feedstock were released as syngas, called producer gas. The producer gas was first cleaned by the tar removal system because it contains considerable tar and soot. Therefore, we prepared two coolers, two centrifuges, two bio-oil scrubbers, and two char bed filters, in order to record the performance of the secondary tar removal methods, as shown in Fig. 2. Basically, the method was designed to remove water and heavy tar from the producer gas by the 1st cooler with decreasing of the gas temperature to around 50 °C. Middleweight tar was collected by the bio-oil scrubber, and finally, light tar was adsorbed by the char bed filter. The nine

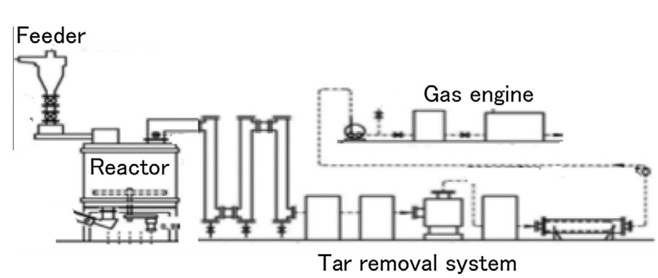

Fig. 1. Scheme of the gasification plant.