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Tar removal from biomass pyrolysis gas in two-step function of decomposition and adsorption

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ABSTRACT

Tar content in syngas pyrolysis is a serious problem for fuel gas utilization in downstream applications. This paper investigated tar removal, by the two-step function of decomposition and adsorption, from the pyrolysis gas. The temperature of the tar decomposition process was fixed at 800 °C both with and without steam, with air as the reforming agent. Both steam and air had a strong influence on the tar decomposition reaction. The reduction of the gravimetric tar mass was 78% in the case of the thermal cracking, whereas, it was in the range of 77–92% in the case of the steam and air forming. Under conditions of tar decomposition, the gravimetric tar mass reduced, while the yield of the combustible gaseous components in the syngas increased. Synchronously, the amount of light tars increased. This should be eliminated later by fixed-bed adsorption. Three adsorbents (activated carbon, wood chip, and synthetic porous cordierite) were selected to evaluate the adsorption performance of light tars, especially of condensable tar. Activated carbon showed the best adsorption performance among all light tars, in view of the adsorption capacity and breakthrough time. On the other hand, activated carbon decreased the efficiency of the system due to its high adsorption performance with non-condensable tar, which is a combustible substance in syngas. Synthetic porous cordierite showed very low adsorption performance with almost all light tars, whereas, wood chip showed a high adsorption performance with condensable tar and low adsorption performance with non-condensable tar. When compared with other adsorbents, wood chip showed a prominent adsorption selectivity that was suitable for practical use, by minimizing the condensable tar without decreasing the efficiency of the system.

1. Introduction

Pyrolysis is one of the thermal conversion technologies for liquid fuel production and gas fuel production. Despite a low efficiency of gas fuel production, pyrolysis has the significant advantage of a higher heating value for the producer gas when compared to the gasification process. The pyrolysis process requires lesser carrier gas quantity, a small capacity of downstream gas cleaning. Moreover, controlling of the pyrolysis process is not complicated. For pyrolysis gas application, the liquid production as well as the tar should be converted to gas, or minimized, in order to prevent the damage of downstream applications and improve the gas production efficiency. Tar is an undesirable material typically described as a complex mixture of condensable hydrocarbons, which include single-ring to multiple-ring aromatic compounds along with other oxygen-containing hydrocarbons that easily condense in ambient conditions [1,2]. The condensable tar deposits on the gas pass-way may cause blockage and corrosion of the downstream equipment. This problem necessitates frequent maintenance of the downstream equipment, resulting in lower plant reliability. Without the appropriate gas cleaning processes, higher investment is required for the duplicate installation of some downstream equipment, in order to operate the plant continuously [3]. There are five classes of tar: (1) undetectable, (2) heterocyclic, (3) light aromatic hydrocarbons, (4) light polyaromatic hydrocarbons, and (5) heavy polyaromatic hydrocarbons [3,4]. Excluding the light aromatic hydrocarbons, the others are considered as problematic, as they condense at an ambient temperature.

Thermal decomposition is one conventional method used to convert tar to gas with high temperature and long residence time. Besides this effect, the tar is also converted into refractory tar [5]. In other words, thermal decomposition is able to minimize tar quantity and increase the yield of producer gas. In order to elucidate tar decomposition during the thermal tar decomposition process, many researchers have utilized one or numerous aromatics as model biomass tar compounds, to investigate the decomposition behavior [1,6–10]. Yet, those studies are based on aromatic combinations modeled as biomass tar compounds, and therefore, cannot be practically applied to the real process. Some papers have

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reported on the effect of thermal cracking and reforming by using real biomass, but the qualitative and quantitative information of each refractory tar compound is rare. In this paper, we studied the real biomass and investigated the change not only in the gravimetric tar mass (total mass of tar) [11], but also in the concentration of major tar compounds, especially for class 3 and class 4 of tar. Although higher temperature and increasing reforming agents are able to meet the tar concentration requirement, the heating value and the cold gas efficiency will significantly decrease [12]. To optimize the system with maximum cold gas efficiency the remaining tar must be removed with the help of an additional approach. Thus, we have contributed fixed-bed adsorption as an additional equipment, in order to prevent downstream equipment damage from the remaining tar.

Fixed-bed adsorption, using three kinds of adsorbents, that is, activated carbon, wood chip, and synthetic porous cordierite, has been conducted to study the adsorption characteristics of real biomass tar. Activated carbon is the most widely utilized adsorbent selected for adsorption of volatile organic compounds (VOCs), which are components of biomass tar, due to its high adsorption capacity. Wood chip is selected because they are low cost adsorbents, and synthetic porous cordierite is selected because it is a re-usable (regenerable) adsorbent. Their adsorption characteristics have been compared with those of activated carbon with real biomass tar. Although many researchers have demonstrated the adsorption performance of many kinds of activated carbon by using tar model compounds [13–16], the information on using real biomass tar is rare. Moreover, the literature carried out on the model tar compound, arranged in class 3 of tar (non-condensable tar) [14], and consequently, it cannot be practically applied to the real process due to a decrease in the efficiency of the system.

This paper aims to improve pyrolysis production by converting pyrolysis tar to fuel gases and minimizing condensable tar by using the two-step function of decomposition and adsorption, for the purpose of fuel gas application. Quantitative information on the major tar components on account of the first step of thermal decomposition during the process is acquired. As the second step, fixed-bed adsorption is installed to remove the refractory tar in the system in order to capture the remaining tar. Finally, the performances of the three adsorbents, which are activated carbon, wood chip, and synthetic porous cordierite, are compared by their adsorption in a wide range of tar compounds from the real biomass tar.

2. Material and methods

2.1. Biomass pyrolysis

A schematic representation of the experimental setup is shown in Fig. 1. The feedstock was prepared from Japanese cedar, crushed and sieved with a mesh size of 0.71–1.00 mm. The feedstock was dried at a temperature of 105 °C overnight in an oven, before it was packed in the feeder, to remove moisture. The proximate and ultimate analysis results of the feedstock are summarized in Table 1. The feedstock was introduced into the pyrolyzer by a controlled screw feeder with a continuous feed rate of 0.6 g/min. The pyrolyzer reactor was made of stainless steel with an inner diameter of 30 mm and a length of 280 mm, and was surrounded by an electric heater. In each experiment, the pyrolyzer was heated up to a temperature of 600 °C and kept at this temperature for 30 min before starting the feeder, in order to ensure that pyrolysis tar production should be done under a steady-state operation. When the feedstock was introduced into the pyrolyzer, the feedstock released its volatiles in the form of syngas and tar aerosols, which were carried out of the pyrolyzer by nitrogen, used as a carrier gas, and entered the gas cleaning equipment with the flow rate of 1.5 l/min. The product of the pyrolysis process was sampled at the exit of the reformer, which was kept at 400 °C, in order to avoid tar decomposition or condensation.

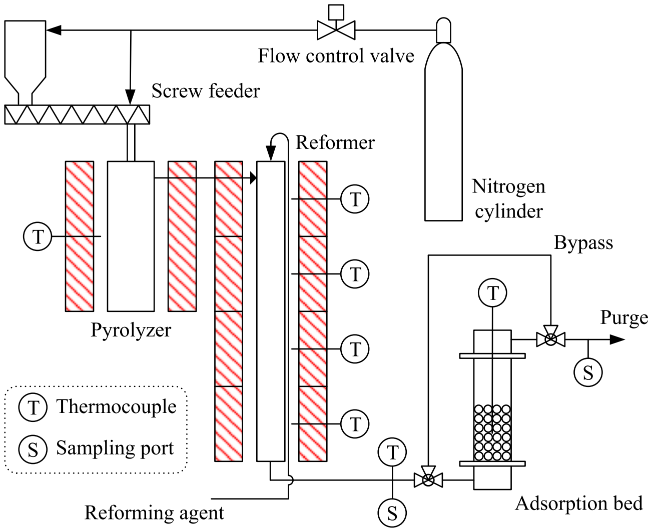

Fig. 1. Schematic diagram of the experimental equipments.

2.2. Tar decomposition

Pyrolysis tar decomposition experiments under different reforming agents were carried out in an externally heated reactor. The reactor, called as the reformer, was made of stainless steel with an inner diameter of 25 mm and a length of 1300 mm. The entire pyrolysis product in the form of gas was supplied directly into the reformer. In the tar decomposition experiment, the effect of each reforming condition was investigated on the basis of the change in gravimetric tar mass and concentration of tar compounds, and their changes were compared with the result of the pyrolysis condition. All experimental conditions of tar decomposition are summarized in Table 2. In the studies of steam and air reforming, water and fresh air were heated up to the temperature of reforming, before being supplied into the reformer for supporting the tar decomposition reaction. The parameters of steam and air reforming used to observe the effect on tar decomposition are given by the steam to biomass (S/B) ratio and the equivalent ratio (ER), respectively, where the S/B ratio is defined as the steam mass flow rate divided by the feedstock mass flow rate on the dry basis, while the ER is defined as the actual amount of air supplied to the reformer divided by the stoichiometric amount of air for complete combustion of the feedstock.

Table 1
The proximate and ultimate analysis of wood chip.

	Japanese cedar
Proximate analysis (wt.% dry basis)	
Volatile matter	80.8
Fixed carbon	18.9
Ash	0.3
High heating value (MJ/kg)	19.3
Ultimate analysis (wt.% dry-ash free basis)	
C	49.7
H	6.4
N	0.1
O	43.8
S	<0.1
Cl	<0.1