PRODUCTION OF CLEAN PRODUCER GAS WITH HIGH HEATING FROM BIOMASS BY AIR GASIFICATION USING TWO-STAGE GASIFIER

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Abstract: A great interest in environment-friendly alternative energy resources that can reduce dependency on fossil fuels has been growing. In particular, among a number of alternative energy resources, biomass is seen to play an important role both as chemical feedstock and as an alternative to fossil fuels. The conversion of biomass to chemicals usually takes place via thermo-chemical and bio-chemical technologies. Among thermo-chemical conversion, gasification converts biomass into combustible gases, such as H_2, CO, CH_4 that can be used in boilers and in internal combustion engine or turbine to produce electricity generation [1]. During gasification of biomass, however, a large amount of tar is also formed. An average of 5,000 tons/day of woody wastes has been generated in Korea recently, and majority of them have been simply treated through incineration. Sewage sludge, usually disposed via ocean dumping in Korea, also as a biomass resource can be energetically utilized through gasification. The production of sewage sludge in Korea is continually increasing every year, amounting to 2.7 million ton/yr in 2006.

This paper reports experimental results on the air gasification of biomass in a newly developed two-stage gasifier (Fig.1). In the experiments activated carbon was applied to reduce tar components in producer gas. In experiments, the total amount of tar in producer gas was reduced sixfold when activated carbon was used in the upper reactor of the gasifier. The producer gases (inclusive of N_2) that were obtained with the application of activated carbon had high hydrogen contents (24 vol%), and their lower heating values (LHVs) amounted to 11.6 MJ/Nm^3.

1. Introduction

The conversion of biomass to chemicals usually takes place via thermo‐chemical and bio-chemical technologies. Among thermo‐chemical conversion, gasification converts biomass into combustible gases, such as H2, CO and CH4 that can be used in boilers and in internal combustion engine or turbine to produce electricity generation [1]. During gasification, however, tar formation is one of the major problems to deal with because of

blocking and fouling process equipments such as pipes and valves in gas engine and turbines [2] [3]. Tar can be defined in various ways. In the EU/IEA/US - DOS meeting on tar measurement protocol held in Brussels in the year 1998, it was agreed by a number of experts to define tar as all organic contaminants with a molecular weight larger than benzene [4]. Tar removal technologies can be divided mainly into two methods; primary methods and secondary methods. Primary methods are treatments inside the gasifier. These are proper selection of operation parameters, use of bed additive or catalyst and gasifier modifications. Secondary methods are a measure downstream of the gasifier. These are tar - cracking either thermally or catalytically and mechanical methods such as use of cyclone, ceramic filter, electrostatic precipitator and scrubber. Secondary methods have been well studied, but till now these seem to be not effective enough and too expensive. An average of 5,000 tons/day of woody wastes has been generated in Korea recently, and majority of them have been simply treated through incineration. In this study, a fraction of woody waste supplied by a wood pellet production facility was gasified in a newly developed two - stage gasifier. The aim of the research was to reduce tar content directly in the gasifier and to produce a producer gas with a high caloric value. For the purpose, activated carbon was applied in the upper reactor of the gasifier. In accordance with purpose, the paper reports the development of producer gas composition according to reaction conditions, such as reactor temperature and equivalence ratio, and LHV, etc.

2. Experiments

2.1 Feed material

A fraction of woody waste was supplied by a wood pellet production facility. The fraction was grinded, and was sieved by 20~30 mesh. Fine particles (600~850 μm) of them were used as feed material. The specification of the feed material is listed in the Tab. 1.

Tab. 1 Specifications of feed material

Proximate analysis	wt%	Element analysis[a]	wt%
Moisture	7.1	C	48.0
Volatile matter	92.3	H	6.4
Fixed carbon	0.2	N	0.1
Ash	0.4	O	42.3
Lower Heating Value (MJ/kg)	16.3	S	-

2.2 Gasifier and experimental procedure

Air gasification experiments were carried out in a two‐stage fluidized bed. A schematic diagram of the plant is given in Fig. 1.

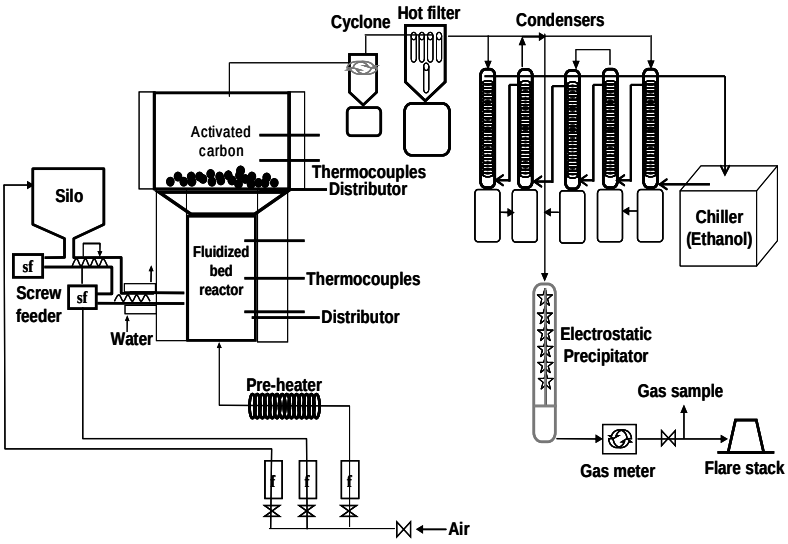

Fig. 1 Schematic diagram of the gasification plant

The plant has two reactors in series, which were heated indirectly with electricity and were made of STS‐316. The bottom reactor has a height of 380 mm and an inner diameter of 110 mm. It has three thermocouples for checking fluidization stability in the reactor and was filled with silica sand. The upper reactor has a height of 340 mm and an inner diameter of 160 mm. It was filled with activated carbon for tar‐cracking. The two reactors were separated by a distributor. Air, a fluidizing medium, was heated by a pre‐heater to reduce heat loss of bottom reactor and then entered in the bottom reactor. Immediately after the gasification, producer gas passes through a char separation system consisting of a cyclone and a hot filter. After the char separation system, liquid was collected in a series of glass condensers that were cooled up to a temperature of 10 ˚C using water as a cooling solvent. Finally, electrostatic precipitator (EP) captured particles and aerosols in producer gas. The remaining producer gas was either burned in flare stack or was sampled using teflon gas bags at 3 min. intervals to analyze their composition using a GC-TCD and GC-FID.

2.3 Reaction Conditions

Experiments were carried out to investigate the influence of the main reaction conditions, such as bottom reactor temperature, upper reactor temperature, and equivalence ratio. The influence of activated carbon on the development of producer gas and tar reduction was also estimated, while experiments without activated carbon in the upper reactor were performed. Tab.2 shows the reaction conditions in the experiments.

Tab.2. Reaction conditions

Parameter	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8
Upper reactor (˚C)	799	794	805	675	732	796	796	796
Bottom reactor (˚C)	763	820	873	823	818	829	829	816
Feed rate (g/min)	12	13	13	13	14	17	10	14
Equivalence ratio	0.37	0.34	0.34	0.33	0.31	0.25	0.46	0.32
Activated carbon	O	O	O	O	O	O	O	X

Run1 to Run3 were conducted to find out the effect of bottom reactor temperature on the producer gas composition. Run2, Run4 and Run5 have similar bottom reactor temperatures, but different upper reactor temperatures. Experiments Run2, Run6 and Run7 were carried out to investigate the effect of equivalence ratio. Run8 was conducted without activated carbon to find out the effect of activated carbon on tar reduction and producer gas composition. The results can be compared with the results of Run2. In each experiment, the flow rate of air was approximately 20.2 ℓ/min. 2.5 kg of silica sand (SiO_2 99.9 wt%), the average particle size of which was 325 μm, was used as the bed material.

3. Results and Discussions

The composition of producer gases according to upper reactor temperature and equivalence ratio is shown in Fig. 2.

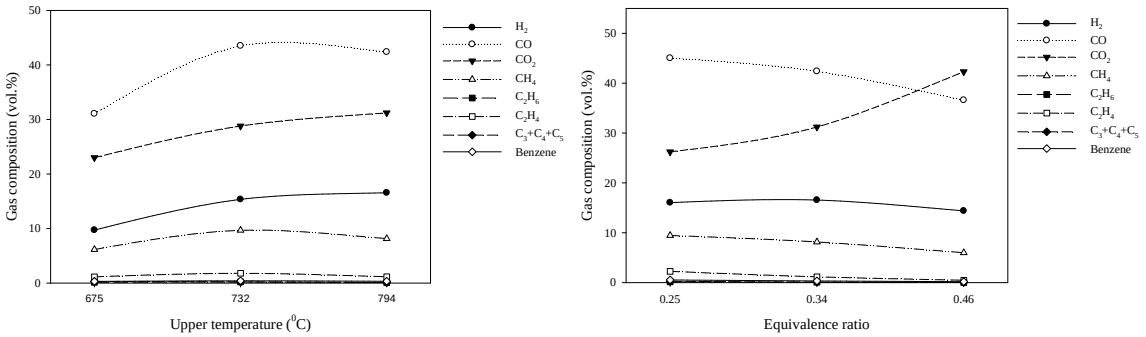

Fig. 2 Gas development with upper reactor temperature and equivalence ratio

It can be seen in Fig. 2 that H_2 and CO_2 increased with temperature. The maximum value of H_2 reached up to 16.6 vol.% in Run2. The higher amount of H_2 at elevated temperatures can be explained on one hand by the enhanced tar-cracking at these temperatures. In the experiments with equivalence ratio (ER), the increase in the concentration of CO_2 with ER was observed. On the other hand, CO, H_2, CH_4 and hydrocarbons decreased with ER.

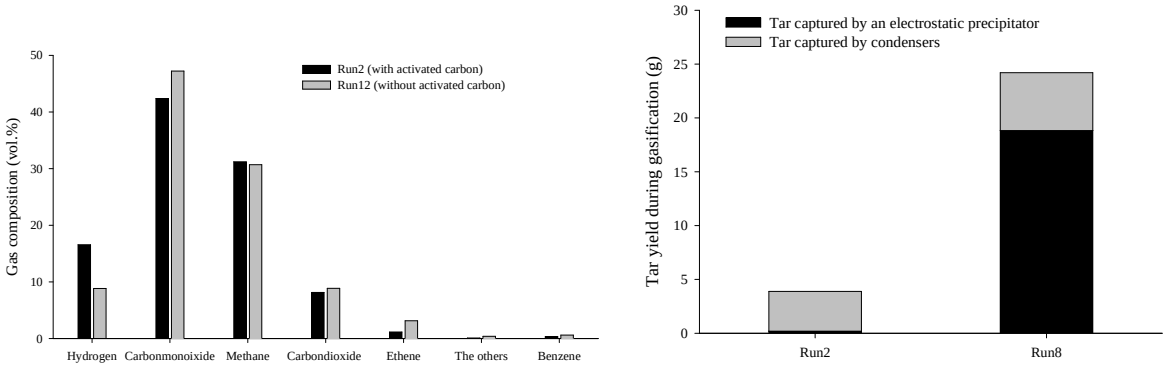

Fig. 3 Producer gas composition and tar yield with and without activated carbon

Fig. 3 shows the comparison of producer gas composition and tar yield obtained with and without activated carbon. The producer gas with activated carbon contains higher H_2 and less other hydrocarbons including methane than without activated carbon. During gasification, total collected tar with activated carbon was much less than that without activated carbon. The strong tar reduction with activated carbon may result from tar adsorption itself by activated carbon, and from the enhanced possibility of tar cracking with the help of adsorption of tar on the surface of activated carbon.

4. Conclusions

The gasification of waste woody biomass was performed in a newly developed two - stage fluidized bed reactor equipped with a char separation system. The producer gas was mainly composed of CO_2, H_2, CO, CH_4 and C_2H_4 as in typical gasification. At first, the influence on the upper reaction temperature, on the hydrogen production was significant. As the reactor temperature increased, H2 concentration strongly increased up to 16.6 vol.%. With respect to the influence on equivalence ratio, it was found that increase in equivalence ratio led to the higher production of CO_2, whereas the concentration of H_2, CH_4 and hydrocarbons decreased. Therefore at higher equivalence ratio, a producer gas with a low heating value was obtained. In an experiment that was carried out at an ER of 0.25, a producer gas with LHV around 9.5 MJ/Nm3 was obtained. This value was much higher than the typical LHV values (4~6 MJ/Nm3) obtained in general air biomass gasification.

Activated carbon played a significant role in tar - cracking and H_2 production. Total tar content consisting of tar on apparatus and in condensate liquid reduced from 24 g to 4 g, when activated carbon is used. As a result, a producer gas with a high caloric value and low amount of tar could be obtained by applying activated carbon in the upper reactor in the two - stage fluidized bed gasifier. The producer gas obtained in the experiments seemed to be appropriate for fuel gas in internal combustion engines.

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