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Enhancement of synthesis gas production using gasification-plasma hybrid system

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ABSTRACT

The gasification of a high density polyethylene (HDPE) was conducted by a hybrid gasification system which is divided into a gasification reactor and a plasma reactor. HDPE pellets were injected into the gasification reactor at the feeding rate of 22 g/min. In the gasification reactor, HDPE were converted into gas phase with the help of oxygen and steam additives. Nitrogen thermal plasma was operated at 3 kW in the plasma reactor to enhance syngas production by gas reforming and thermal cracking. Produced gases from each reactor were analyzed to examine chemical reactions in each stage. A high yield of syngas was achieved in virtue of enhanced gasification reactions in the thermal plasma reactor, while the gasification reactor was operated at the durable condition of atmospheric pressure and low temperature of about 900 K. In the gasification, CH_4 was produced from the decomposition of raw material and methanation reaction. In the plasma reactor, however, the amount of CH_4 was decreased obviously due to the oxidation, reforming and decomposition of hydrocarbon. Therefore, the yield of syngas was improved from 17.66 g/min to 28.46 g/min in HDPE gasification with oxygen additive and from 17.89 g/min to 25.80 g/min with oxygen and steam additives, respectively.

Introduction

The disposal of waste has been a significant issue on both environmental problem and energy crisis in all over the world [1–3]. Among various wastes, solid organic waste is the most serious one because its treatment has brought about pollutions of soil, water, and air. Although landfill method has been used for the treatment of solid waste, incineration and recycling methods are essentially required due to limited landfill area [4]. However, the incineration method generates NO_x, SO_2, and hazardous gases such as dioxin and furan. Therefore, recycling methods have been widely researched nowadays. Especially, the gasification method has received considerable attention due to its unique advantages including the production of synthesis gas for chemical feedstock and power generation and easy to control air pollutants [5–9].

Researches of gasification process using a waste plastic which is a major component of industrial waste have been carried out, because waste plastics are composed of volatile

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matter and high contents of C and H atoms. The major waste plastics are polyolefins and polyaromatics [10]. Polyolefins which include high density polyethylene (HDPE), low density polyethylene (LDPE), and polypropylene (PP) are considered as promising materials for gasification application compared to polyaromatics. It is because required energies for the decomposition of C–C and C–H bonds are 348 kJ/mol and 413 kJ/mol, while it for the decomposition of benzene ring is 656 kJ/mol. Among polyolefins, HDPE has been chosen as a raw material for gasification in many researches, because the decomposition behavior of other polyolefins is similar to that of HDPE due to the basic chemical structure of polyolefin [11–13]. The gasification process using the waste plastic as a raw material has great potential as an environmentally friendly process, because it can produce energy instead of disposing them at an expense. A conventional gasification process is operated at a high temperature of about 1200 K and at a high pressure of 20~25 bar [14–19]. A fluidized bed reactor where reactor temperature can be uniformly distributed to facilitate the gasification reaction and to restrain the generation of by-product such as hydrocarbon and tar has been used as a typical gasification reactor [20]. However, it is difficult to operate the fluidized bed reactor system for a long time due to high temperature and high pressure. Therefore, many researchers have studied the gasification of solid waste in a relatively low reactor temperature with a catalyst or plasma for the cracking of tar which is one of major by-products [21–24].

In this work, the gasification of the waste plastic was demonstrated by using a hybrid reactor operated in low temperature and a low pressure compared with a conventional gasification reactor. The hybrid system is composed of a gasification reactor and a thermal plasma reactor, because thermal plasma has advantages of easy to start up and high energy density in atmospheric pressure. Thermal plasma provides high temperature region for the acceleration of gasification reactions including oxidation, cracking, and reforming without a catalyst and an additional fuel source. Accordingly, the enhancement of syngas production is achieved by low power thermal plasma. In addition, a durability of the gasification system was secured due to the low temperature and atmospheric pressure operation of the gasification reactor.

The gasification reactor oxidizes or partially oxidizes solid plastics and the plasma reactor reforms and cracks produced gas from the gasification reactor. In the gasification reactor, solid plastics are oxidized and vaporized by oxygen or steam which is supplied from the bottom of the reactor. As a result, solid plastics are converted into the gas phase including CO, CO_2, H_2 and hydrocarbon by exothermal reactions in the gasification reactor. Produced gases from the gasification reactor are moved to the plasma reactor and they react rapidly in a high temperature region of thermal plasma. In the plasma reactor, hydrocarbon gas is reformed and the generation of syngas is enhanced. In the present work, the gasification-plasma hybrid system was operated for the gasification of a high density polyethylene (HDPE). In order to determine an appropriate operating condition and to confirm an economic feasibility of the newly developed gasification-plasma hybrid system, gas composition and cold-gas efficiency were measured according to the ratio of oxygen source and reactants of O_2 and steam.

Experimental

Raw material

Spherical HDPE pellets (HANWHA HDPE 7600, Hanwha Chemical, Korea) were used as raw material which has the mean diameter of 5 mm. HDPE was composed of volatile matter and ash, and major components of HDPE are carbon and hydrogen as shown in Table 1. The chemical bond of HDPE which is one of thermosoftening plastics has little branching structure. In addition, the dissociation energy of chemical bond in thermosoftening plastics such as HDPE, polypropylene (PP), poly ethylene terephthalate (PET) and polyvinyl chloride (PVC) is relatively low compared with thermosetting plastics. It is because thermosetting plastics have networks of heavily crosslinked chains compared with thermosoftening plastics. Therefore, it can be expected that HDPE is easily oxidized and pyrolyzed at a relatively low energy consumption compared with other plastics. The lower heating value of HDPE was calculated by following equation using proximate and ultimate analysis results from Table 1.

$$LHV = 81C + 341\left(H - \frac{O}{8}\right) + 22S - 5.84\left(w + 9H\right) \quad (1)$$

where, C (%), H (%), O (%), S (%) and w (%) are mass fraction of carbon, hydrogen, oxygen, sulfur and moisture in raw material.

Gasification-plasma hybrid system

Fig. 1 presents the schematic diagram of the gasification-plasma hybrid system which is composed of the supply part of plastic pellets and oxygen sources, two gasification reactors, a gas cooling fan, a gas furnace, and gas analysis part. Oxygen and steam were injected as reactants to provide oxygen sources in gasification reaction. Oxygen was injected into the bottom of the gasification reactor and its flow rate was controlled from 5 L/min to 35 L/min by using a mass flow controller (TSC-220, Korea Instrument T&S, Korea). In addition, steam was also injected into the gasification reactor by using a steam generator (CRES-SG, 2 kW, Infinity fluids, USA) which is composed of a water evaporator and a steam heater to increase steam temperature up to

Table 1 – Properties of high density polyethylene (HDPE).

[Proximate analysis (%)]	
Volatile matter	98.4
Ash	1.6
[Ultimate analysis (%)]	
C	85.3
H	13.4
N	0.3
O	0.5
S	0.5
Particle density (g/cm^3)	0.96
LHV (MJ/kg)	45.04