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Gas production from polyethylene terephthalate using rotating arc plasma

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ABSTRACT

Polyethylene terephthalate (PET) is one of the most widely used macromolecule materials, but the treatment of waste PET has been a great challenge to environment safety. In this article, we report for the first time an effective method to produce gaseous products containing acetylene, ethylene and carbon monoxide from PET particles using a rotating direct current arc plasma reactor. Thermodynamic simulation was performed, and the effect of input power, PET feed rate and working gas flow rate on PET pyrolysis was experimentally investigated. An almost complete carbon conversion could be achieved by this method with a product gas containing 42% acetylene, 53% carbon monoxide and 4% ethylene, while the specific energy consumption of product gas was below 20 kWh/kg. These results show that rotating arc plasma is a promising method of improving the conversion of waste PET to valuable hydrocarbons and syngas.

1. Introduction

Polyethylene terephthalate (PET) is produced by poly-condensation reaction from benzene hydroxyethyl terephthalate (BHET), which usually comes from esterification between terephthalic acid and ethylene glycol or transesterification of dimethyl terephthalate and ethylene glycol. Dupont Company at USA first established industrial PET production device after the pilot test completed in 1949 by British ICI Company. PET shows excellent mechanical properties in a wide temperature range (up to 120 °C), such as outstanding fatigue resistance, abrasion resistance and dimensional stability, and also have good insulating properties. Most solvents, except for a few kinds of strong acids, strong bases and water vapor, have little corrosive effects on PET. PET has been used as engineering plastic and has shown considerable advantages in many fields such as automobile industry, construction, medical and health care since 1980s, and accounts for more than 90% of the polyester market [1–3].

However, due to its high chemical stability, PET wastes can hardly be degraded by microorganisms in the air and soil under conventional conditions, and they occupy a huge space for landfill because of their low density [4]. PET wastes are now recycled by physical methods (mostly mechanical recovery and melting method by cutting, crushing, heating and melting), chemical methods (depolymerization with high temperature or catalyst into monomers or intermediate raw materials) and the combination of them [5–8]. Physical recovery is lower in cost, but the products obtained contain more impurities and have poor mechanical properties. Chemical recovery has some problems such as large amount of solvent used and long reaction time of depolymerization. There are some new technologies used to assist chemical recovery such as supercritical and microwave technologies, but not ready for industrial application [9].

Thermal plasma has attracted great interest during recent years due to its high temperature, high enthalpy and rich active particles, especially in the conversion of coal/hydrocarbons/biomass to petrochemicals as well as the utilization of polymer wastes [10–14]. Guddeti et al. pyrolyzed polypropylene and polyethylene with an induction-coupled radio frequency plasma heated reactor into propylene, ethylene and other light hydrocarbons [15,16]. Chang et al. used waste tires as raw materials to obtain synthesis gas (containing ethylene, acetylene, methane, carbon monoxide and hydrogen, heating value 4–7 MJ/m^3) with argon plasma [17]. Tang et al. tried to get flammable product gas and carbon black from used tires and polypropylene with argon plasma [18]. We carried out some research on the utilization of biomass (crude glycerol, grease) and polyethylene, respectively obtained syngas (56% hydrogen and 38% carbon monoxide) and hydrocarbon product gas (> 80% acetylene) [19–21]. However, no report on PET pyrolysis with thermal plasma has been available.

This paper reports, for the first time, a method of decomposing PET into important light gases including acetylene and syngas with hydrogen plasma, and the effect of input power, feed rate and gas flow rate on carbon conversion, product gas composition, product gas selectivity and product gas specific energy consumption were systematically investigated. The experiments were carried out in a self-designed rotating DC arc plasma reactor. A field coil was designed around

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Nomenclature

m_i	Flow rate of component i (g/min)
C_i%	Mass fraction of C in component i (%)
m_{fs}	Feed rate (g/min)
C_{fs}%	Mass fraction of C in feedstock (%)
U	Arc voltage (V)
I	Arc current (A)
X	Carbon conversion (%)
S_e	Selectivity of acetylene (%)
Y	Yield of acetylene (%)
SEC	Specific energy consumption of acetylene (%)
$m_{product}$	Total mass of carbon in product gas (kg s^{-1})
m_{feed}	The mass of carbon in feedstock (kg s^{-1})

the copper anode. The field coil could generate a magnetic field, which would make the arc rotate with a high speed. The rotating arc could not only be beneficial to form a uniform and stable jet with high temperature (> 3000 K), but also can contribute to the mixing of feedstock and working gas [10,11,19–22]. The results demonstrate thermal plasma pyrolysis to be a promising method to the resource utilization of PET waste.

2. Materials and methods

2.1. Materials

The PET, used as raw materials in thermodynamic simulation and experiments in this paper, was engineering plastic (with an average molecular weight of 300,000) and bought from Youngling-tech. The particle size distribution of PET powder was illustrated in Fig. 1, most particles have a diameter from 20–60 μm, while some particles' diameter is above 200 μm. The carrier gas (Ar) and working gas (H_2), with purities higher than 99.99%), were purchased from Jingong Gas Company.

2.2. Thermodynamic simulation

The thermodynamic simulation of the PET pyrolysis in hydrogen plasma was carried out in the program Chemkin 4.1. An equilibrium model was used to calculate the thermal equilibrium composition, which contains species including H_2, O_2, H_2O(g), C(g), C(s), CH_4, CO, CO_2, CH_2O, CH_3OH, C_2H_2, C_2H_4, C_2H_6, C_3H_6 and C_3H_8, with equilibrium temperature varied from 1000 K to 5000 K. Equilibrium composition in both single-phase model and multi-phase model are calculated.

2.3. Reactor set-up

A schematic diagram of the self-designed rotating DC arc plasma system, consisting of a plasma torch, a powder feeder, a quenching unit and a sampling and detection device, is illustrated in Fig. 2. The torch, with an inner diameter of 25 mm, consists of a tube shaped copper anode (with a field coil around, which would generate a magnetic field to make the arc rotate at extreme high speed) and a rod shaped tungsten cathode, both water-cooled. The rotating arc would not only form a uniform and stable jet at extremely high temperature (> 3000 K), but also contributes to the mixing of feedstock and working gas.

2.4. Gas analysis

The product gas was analyzed by a gas chromatograph (KEXIAO, GC-1690) with a thermal conductivity detector (TCD), and PLOT 5A molecular sieve packed column followed by PLOT Q capillary column.

2.5. Evaluation of pyrolysis

The carbon conversion (*X*, %), selectivity of acetylene and carbon monoxide ($S_{C_2H_2}$ and S_{CO}, %), and the specific energy consumption of

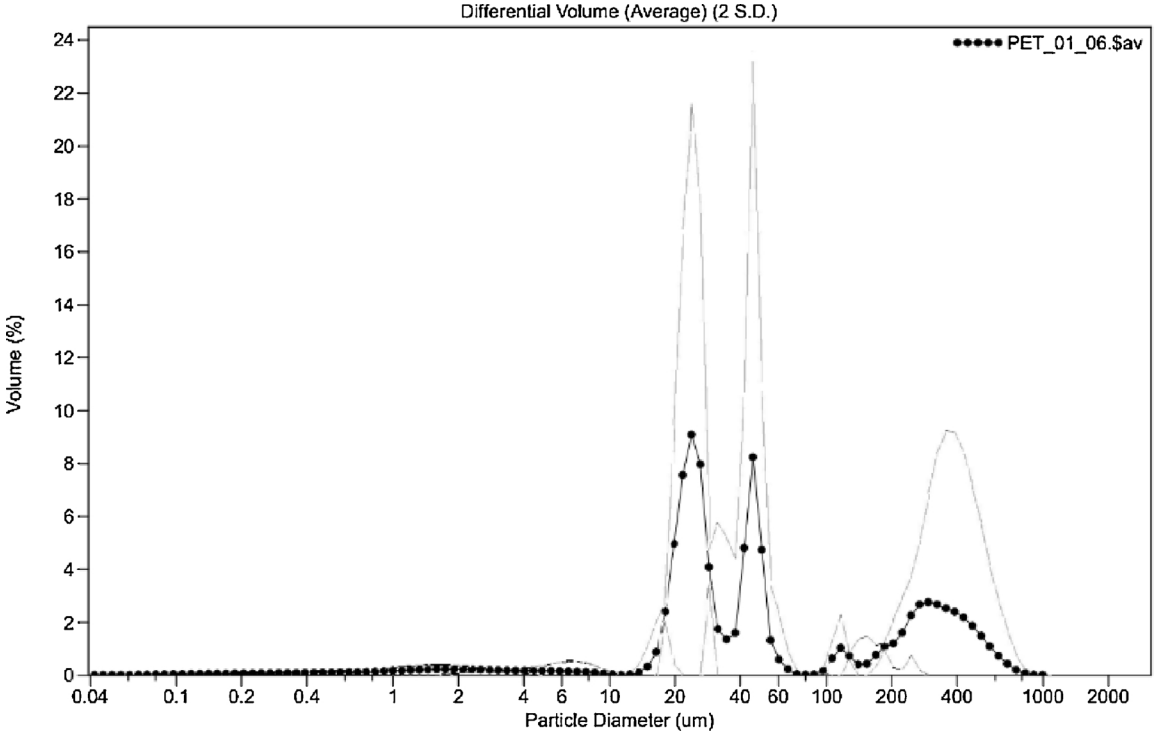

Fig. 1. Particle size distribution of PET.