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Gasification of corn cob using non-thermal arc plasma

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ABSTRACT

With high quality syngas consisting almost completely of H_2 and CO, and solid carbon residues with high quality, the plasma treatment technology of biomass has been widely studied with the purpose of generating hydrogen. In this paper, the plasma gasification process of corn cob using non-thermal arc plasma was investigated after comparing various components of biomass, combining the physical truth of agricultural waste. The gas yield can reach 79.0% of the biomass feed without drying conditions at a discharge power of 25.2 W when using nitrogen as carrier gas with energy cost from the decomposition of corn cob is 5328 kJ/kg_{H2}. Meanwhile, carbon conversion rate of 82.9%, CO selectivity of 39.9% and a ratio of H_2/CO greater than 1.5 are obtained. It is found that different carrier gases have different impacts upon the reforming performance, and air is more beneficial for higher gas yield and CO selectivity. Besides, the presence of moisture is conducive to improve the gas yield, especially the production of hydrogen, carbon conversion rate and the molar ratio of H_2/CO. Also, the varying tendencies of the gas products over the time at different experiment parameters are also discussed. Finally, the results of residual solid products were analyzed.

Introduction

With the development of economic globalization and the growing demand for energy, the fossil fuels (oil, gas and coal) have become increasingly scarce. At the same time, the environmental problems produced due to fossil fuels usage are becoming more and more serious, which manifests as atmospheric pollution, ozone depletion and greenhouse effect, etc. The issues of the environment and energy have motivated researchers to develop an efficient and clean energy technology to substitute fossil fuels as well as reduce greenhouse gas emission [1–3] and more attention has been paid to low carbon economy which is characterized by low energy cost, reduced emission, and zero pollution [4]. In the light of this finding, renewable energy sources such as ethanol and biomass and clean energy hydrogen have gradually attracted people's attention. At present, there have been many researches on hydrogen production from ethanol reforming [5–9], while researches on biomass are still rare.

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Biomass is the collective term of substances derived from plant or animal organism. Available biomass resources can be divided into five classes, i.e. crops, forest crops, aquatic algae photosynthetic microbes and other types (mainly referring to waste biomass including agricultural waste, forestry waste, and urban waste).

Biomass energy belongs to renewable resources, which meets the requirements of maximum energy and resource utilization and minimum environmental impact. China is a country requires large quantities of crude oil import, but is also an agricultural country quite rich in agricultural biomass. The output of crop straw alone is about 700 million tons per year in China. Therefore, if biomass is developed and utilized effectively, there will be positive significance in reducing the reliance of our country on fossil fuels, environmental purification or sustainable economic development [10,11].

The main ingredient of available biomass like crop, forest crops and its derivative waste is lignocellulose, which is mostly composed of cellulose, hemicellulose and lignin. Ayhan [12] considers that the order of priority decomposition of the three components in lignocellulose is hemicellulose > cellulose > lignin. Lignin is the most difficult to break down because of its network of heavily crosslink chains structure. Hemicellulose tends to generate more light gas and less coke compared with cellulose. Cellulose and hemicellulose tends to generate volatile relative to the lignin, while lignin mainly produces coke.

At present, there are four major methods of biomass utilization at home and abroad, namely combined combustion, biochemical fermentation, pyrolysis liquefaction and gasification. The pyrolysis and gasification is one of the efficient ways to use biomass among them [13–16]. Although pyrolysis liquefaction technology has the advantage of the easy temperature management and short residence time, and the maximum bio-oil yield can reach 80% in the optimal conditions, there are some problems like high water content, strong volatility, unstable viscosity, aging, severe corrosion, combustion defects and so on. Thus, the gasification technology becomes another focus of biomass utilization, which includes conventional gasification and plasma gasification technology. And plasma gasification is a promising method of hydrogen production [21]. There are some problem occurred in conventional gasification process, such as low gas productivity and the generation of heavy tar compounds. Compared with the conventional gasification, plasma gasification technology is more effective and with less harmful to the environment. Another advantage of plasma usage is the possibility to maintain high temperature, which leads to the intensification of tar cracking [17,18]. Thus, the plasma gasification method has received considerable attention due to its unique advantages including the production of high quality synthesis gas for basic chemical raw materials and power generation and relatively easy to control air pollutants [19–23].

Plasma is a mixture of ions, electrons and neutral particles and is often called the "fourth state of matter" [24]. Plasma can be categorized as high temperature plasma and low temperature plasma. High temperature plasma is thermodynamic equilibrium plasma, while low temperature plasma can be subdivided into the local thermal equilibrium plasma (thermal plasma) and the thermodynamic non-equilibrium plasma (non-thermal plasma) [21,25,26].

A mixture of hydrogen and carbon monoxide produced by plasma pyrolysis biomass can be used for power production, which is called syngas. If the hydrogen yield is high enough, it can be separated out independently. Biomass gasification is an evolution of pyrolysis technology, where the biomass material is partial oxidized into H_2, CH_4, CO and other gases by add lower than stoichiometric amount of oxygen into the plasma reactor. In addition to gaseous products, the main solid product is coke, and it also has potential application in chemical industry. In recent years, many researches have focused on plasma processing of biomass. By the reason of pyrolysis of biomass to produce syngas offers an alternative supply of energy other than fossil fuels. However, most of them are about thermal plasma, owing to the high temperature, high intensity, non-ionizing radiation and high energy density of thermal plasma, while researches on non-thermal plasma processing of biomass are relatively rare [27,28]. For example, Zhao et al. [29] investigated argon-hydrogen plasma pyrolysis of sawdust and chaff biomass with a mixture of argon and hydrogen as the carrier gas, observing that the dominant gaseous products were H_2, CO. HLINA et al. [30] used a plasma chemical reactor equipped with a water cooling system to treat wood chips. Tang et al. [31] investigated a high-frequency plasma technique for wood chips pyrolysis with different input powers (1.6–2.0 kW), different pressures (3.0–8.0 kPa) and different electrode structures, observing that the gas conversion rate is up to 88.40%. KEZELIS et al. [32] employed water vapor plasma torch to treat pine pieces. Tu et al. [33] used radio-frequency (RF) plasma pyrolysis of rice straw, observing that no tar product is formed via pyrolysis using RF plasma. Despite the current mostly researches of biomass focus on thermal plasma, but non-thermal plasma with the characteristics of non-equilibrium thermodynamic state also received a lot of attention. In our lab, Du et al. have conducted a number of studies on non-thermal arc plasma reactor, e.g. the decolorization of acid orange 7 solutions [34–36], destruction of toluene [37,38], degradation of phenol [39] and PCDD/PCDFs [40] and so forth. Non-thermal arc plasma reactor can be driven by a DC power supply or an AC power supply, arc discharge is characterized by a high voltage and low current, the discharge power can be as low as several tens of watts to several hundred watts [41].

The non-thermal plasma is characterized by high electron temperature, while the temperature of other particles and gas is very low. Yet the thermal plasma has high gas temperature, thus most of the heat generated by arc discharge is consumed in heating the background gas, reducing the energy conversion efficiency. This insufficiency could be excused in case of non-thermal plasma, although the non-thermal plasma has lower discharge power and gas temperature compared to thermal plasma, it also contains a lot of active particles, thus induced a series of electron impact excitation, dissociation excitation, light excitation and spontaneous radiation decay, electron impact ionization and multi-body recombination,