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Improvement in hydrogen production with plasma reformer system

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Abstract

In our previous studies of a plasma reformer system, the effects of temperature of the reactants and input voltage have not been considered. In the present investigation, the plasma reformer system has been modified to study the influence of the reactants' temperature and input voltage on hydrogen production experimentally. The plasma reformer system includes a supersonic atomizer, a plasma generator, and a controlling device. In the experiment, the operating parameters include the temperature of the reactants and the input voltage. The temperature of the reactants varies from 25 °C to 50 °C, and the input voltage ranges from 12.5 V to 14.5 V. Results show that the increase in temperature of the reactants and input voltage will improve the production of hydrogen. In addition, the improvement of heating on the reactants shows significant influence on hydrogen production.

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1. Introduction

Hydrogen and fuel cells are considered as the most promising energy systems in the 21st century for transport, distributed heat and power generation, and energy storage systems because they are highly efficient and environmentally compatible [1, 2]. Hydrogen is particularly suitable for use in high-efficiency power generation systems, including fuel cells, for both vehicular transportation and distributed electricity generation. Spark ignition (SI) and diesel engines, widely used to power various types of vehicles, have been shown to be a major source of air pollution in cities [3]. The addition of hydrogen for combustion helps reduce pollutant emissions [4], and the use of fossil fuels. However, pure hydrogen feeding is relatively difficult for practical applications and can result in safety issues and storage problems.

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Combining energy conversion devices with methanol reformer can overcome the high risk of carrying a large quantity of hydrogen.

The extensive literature devoted to the plate methanol steam micro-reformer has been reviewed on several occasions [5-8]. As the steam reforming reaction is an endothermic reaction, several researchers have used an electrical heater to supply heat flux to the plate methanol steam micro-reformers using micro-channels patterned on the plates. Generally, there is a trade-off, wherein the higher conversion ratio is obtained with higher CO concentrations, however, CO is a poisonous material for catalyst of a fuel cell electrode. On the other hand, non-thermal plasma can afford promising reactive media for the generation of H₂ from hydrocarbons, alcohols, and water in flow reaction systems since high electron energies are acquired at short residence times [9].

To use a reformer for hydrogen production, it is necessary to consider the following criteria: fuel type and the content of hydrogen in syngas. Chao et al. [10] used methane as fuel in a reformer due to its low carbon content and cost. Henriques et al. [11] employed methane as fuel for a reformer in order to produce syngas with enriched hydrogen. Then hydrogen from syngas was purified using a catalyst and transferred to the fuel cell. Moreover, methanol has a relative mass that is close to pure water. It can easily dissolve in water and exhibits no stratification. It was reported that a mixture of 16.7 mass% pure water and 83.3 mass% methanol not only improved methanol conversion to hydrogen production, but also increased the reaction rate of a reformer [12]. In addition, methanol can be converted from biomass leading to zero CO₂ emission in a short life cycle period. However, the operating temperature can ramp up to 240 °C [13] using methanol or methane as fuel.

A typical reformer utilized steam as the heating element to fog up the fuel and to dissociate fuel into H₂ during the process. Hence, large amounts of energy or electricity are required, which in turns results in a high operating temperature. Inside a reformer, there are two chemical pathways to generate H₂ gas: electrolysis of water and fuel dissociation. Focusing on fuel dissociation, plasma dissociation generally consumes much less power than catalytic dissociation. Recently, Huang and his colleagues [14, 15] have successfully developed a plasma reformer system with a supersonic atomizer for hydrogen production. Their plasma reformer system can reduce power consumption and be operated in a low operating temperature.

In this paper, the same plasma reformer system from our previous study using methanol as fuel has been built for hydrogen production. The supplied voltage and plasma frequency have been increased in order to investigate the effect on hydrogen production. In addition, a heater for heating the reactant air has been equipped to the plasma system for the study of improvement in hydrogen production.

2. Experimental setup

In the reforming system, methanol water solution was used for hydrogen production. There were three parts for the system: a supersonic atomizer, a plasma generator, and a controlling device. The setup of the plasma reformer system used in the present study is shown in Figure 1. In Fig. 1, a supersonic oscillator with excitation frequency of 1.6 MHz to 1.7 MHz and approximated power consumption of 5 W was placed under the liquid mixture of 83.3 mass% methanol and 16.7 mass% distilled water. In the present study, the plasma generator system consisted of two spark plugs with two ground electrodes. Each spark plug was equipped with an ignition coil, a high-voltage wire, and a high-voltage capacitor. The model of the spark plugs used was NGK-BP8ES. This ignition coil was a commercial product with the primary coil of 12 V/0.2 Ω and secondary coil of 12 V/0.65 kΩ, such that the secondary voltage can be as high as 8 kV to produce plasma on the spark plug. The high-voltage capacitor was parallel connected to the spark plug with specification of 40 kV-500 pF. The distance between the two spark plugs was 50 mm. The spark plugs with the capacitors and ground electrodes were placed at an angle of 180° on the pipe wall. The power consumption of the plasma generator system ranged from 25 (12.5 V) to 42 (14.5 V) W. A heater was placed outside of the chamber to study the influence of temperature of the mixtures on hydrogen

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