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Hydrogen and syngas production from glycerol through microwave plasma gasification

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ABSTRACT

Glycerol which is a byproduct of biodiesel production is considered as a potential feedstock for syngas production with the increase of biodiesel demand. In this study, the characteristics of glycerol gasification under a microwave plasma torch with varying oxygen and steam supply conditions were investigated. The experimental results demonstrated that the gasification efficiency and syngas heating value increased with the supplied microwave power while the increase of oxygen and steam led to a lower gasification performance. In order to achieve high carbon conversion and cold gas efficiency in the microwave plasma gasification of glycerol, the O_2/fuel ratio should be maintained at 0–0.4. It was revealed that the fuel droplet size and the mixing effect and retention time inside the plasma flames are critical factors that influence the product gas yield and gasification efficiency. This study verified that syngas with a high content of H_2 and CO could be effectively produced from glycerol through microwave plasma gasification.

1. Introduction

There is increasing interest in the use of new and renewable energy sources due to limited fossil fuel reserves, oil price fluctuations, and international regulations on CO_2 emissions. Studies on biomass, which is a CO_2 neutral source, are being actively conducted not only regarding its primary use of obtaining heat and electricity through combustion, but also regarding its high value-added use through conversion to transportation fuels such as biodiesel that can replace petroleum. The global production of biodiesel has increased annually by 32.5% on average from 2000 to 2010 [1]. In particular, biodiesel production has increased sharply since 2006. The production of biodiesel is expected to grow continually in the United States and the European Union in order to attain the goal of replacing 20% and 30% of petroleum-based diesel with biofuels by 2020 and 2030, respectively [2]. The method of using transesterification reaction to produce biodiesel, which is currently the primary method of biodiesel production, generates crude glycerol of approximately 10 wt% as a byproduct. As the generation of crude glycerol is also expected to grow with the increased production of biodiesel, the effective use of crude glycerol is important from both economic and environmental perspectives.

For utilization of crude glycerol, many studies are being conducted on the conversion of glycerol into valuable

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components or energy through various techniques, such as refinement, purification, pyrolysis, reforming, and gasification. Among these techniques, energy conversion through gasification has advantages in that it does not require catalyst or additional pretreatment of the crude glycerol [3]. Gasification refers to the technique of generating syngas that contains H_2 and CO through the partial oxidation of hydrocarbon fuels. As a clean fuel utilization technique, gasification is being applied to the production of electricity, hydrogen, and chemical materials using various fuels, such as coals, waste, and biomass. These days, various studies on gasification using plasma torches are in progress [4–6]. For plasma gasification, plasma flames are formed using external electric energy sources and the fuels are gasified through plasma flames with high temperatures over several thousand degrees [7]. Thus, it does not require oxygen or it requires only a small amount of oxygen, which is required in the conventional gasification process for the partial oxidation of fuels in order to maintain the reaction temperature. This decreases the burden of the installation and operation of highly expensive air separation units. Unlike the conventional gasification method that raises the temperature of the reactor through preheating, plasma gasification starts simultaneously with the activation of a high temperature plasma torch. Therefore, rapid production of syngas is possible. Furthermore, the high concentration of active species, such as ions and radicals, in the plasma state accelerates the gasification reaction [8,9]. As the reaction is activated, a quick reaction can be induced during the short retention time of fuels in the reactor, and the size of the total process can be reduced due to the decreased volume of the reactor. Most previous studies have focused on the plasma combustion [9], pyrolysis [10], and gasification [11,12] of various fuels using arc electrodes. The use of arc electrodes, however, requires periodic replacement due to the loss of electrodes and is vulnerable to the oxygen and steam that are used as gasification agents [9,13]. The use of microwaves as the energy source for plasma generation exhibits a higher power transfer efficiency than arc plasma and a high durability because electrodes are not used [14,15]. Therefore, the reforming and gasification of various hydrocarbons using microwave plasma torches are being actively investigated [16–18].

In this study, the gasification characteristics of glycerol under various conditions using a plasma torch equipped with a 2 kW microwave power generator was investigated. For the uniformity of fuels and convenient interpretation of the gasification characteristics, pure glycerol was used instead of crude glycerol. Nitrogen was used as the plasma forming gas, and the microwave power for plasma formation was adjusted to 1–2 kW. The variations of the gasification characteristics were studied with the supply amount of oxygen and steam, which were used as gasification agents. At this time, the O_2/fuel ratio and steam/fuel ratio are varied 0–1.2 and 0–2.4, respectively. Furthermore, the changes in the product gas composition and gasification efficiency were examined when the glycerol was atomized through the reactor using a spray nozzle.

2. Experimental

In this study, 99% pure glycerol (Duksan Chemical) was used as a substitute for crude glycerol without further purification. Fig. 1 presents a schematic diagram of the plasma gasification system with the 2 kW microwave generator (2.45 GHz, SM745, Richardson Electronics) that was used in this study. This system consists of a glycerol preheater and feeder, steam supplier, gasification agent and plasma forming gas feed unit, microwave generator, gasification reactor, gas purifier and analyzer, and data collection unit. The glycerol was supplied to the reactor constantly at a rate of 3 g/min through a gear pump (Cole-Parmer, 74014-75). In order to supply glycerol to the plasma reactor, two methods were used and compared:

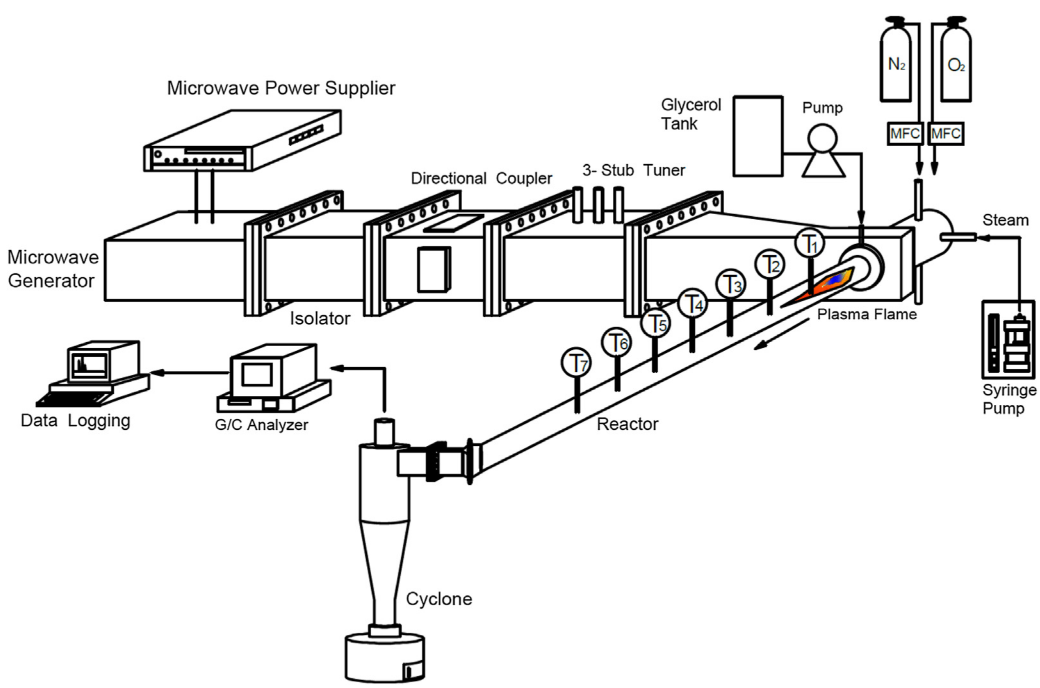

Fig. 1 – Schematic diagram of the microwave plasma glycerol gasification system.