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Study of Hydrogen Production from Banana Waste Using In-Liquid Plasma Method

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Abstract. Banana waste is agricultural residues that can be utilized as biomass sources due to its lignocellulosic content. The In-liquid plasma method was applied is to investigate the possibility of hydrogen production from banana pseudo-stem, banana true stem and banana peel. In this study, cellulose was decomposed from banana waste using radio frequency (RF) as a power source. When applying plasma in banana waste powder, all main gas and by-product were observed using gas chromatograph. At the initial concentration of 0.5 wt%, higher hydrogen production rate and hydrogen percentage 0.30 mL/s and 70.03% respectively was obtained when using banana true stem.

Introduction

Banana (Musaceae) is one of the herbaceous plants of the genus Musa that grown in every tropical and subtropical region. It is breed mainly for its fruits for application in food industry. Some researchers have reported that Banana tree cultivation is the fourths largest food crop of the worlds (Kv, Sarvamangala, Kandisa, Gopinadh, & King, 2013). In 2015, approximately 9.5 million tons of bananas were produced in Indonesia (Of & Chemical, 2010).

About ten until 12 months needed from banana planting until harvesting time. However, it only breeds fruits once in a lifetime. After harvesting time, banana tree will be cut and leaving the base piece of stem and rhizome untouched. Banana produced waste such as rotten fruits, fruit bunch, stem, leaves, pseudo-stem, and rhizome. The previous study has reported that for every ton of banana picked, 100 kg of fruit is eliminated, and about 4 tons of wastes are produced. It is implied, that for each cycle of production four times of waste are produced (Abdullah, Sulaiman, Miskam, & Taib, 2014).

Overall, most of banana by-products are undervalued commodity with a limited application and even considered as an agricultural waste. To provide some of the nutrients in the soil, the pseudo-stem and leaves are left to rot in farms. While pseudo-stem piths, inflorescence, and young shoots, in spite of consumed as vegetables by a peculiar community in parts of Southeast Asia region, they may not be able to compete with the common leafy vegetables due to its undesirable taste. On a small case, banana waste was utilized as an animal feed to minimize cost production. However, since its higher water content that may reduce its nutritional density, additional processing is required in this application. In some places where "open fire burning" is still practiced, the burning of banana wastes may contribute to serious environmental issues. Almost 80% of the total plant mass was produced from waste that a single banana produced. It is estimated that 220 tons of by-products are produced per hectare annually indeed requires an innovative idea to turn these readily available resources into a value-added products (Padam, Tin, & Chye, 2012).

Banana pseudo stem by product generated in banana which is planted on a large scale contains an average amount of cellulose 47 %, hemicellulose 13 %, holocellulose 55 %, lignin 13.0 %, ash 8.2 % and extractives 3.05 % (Idrees et al., 2013; Li et al., 2015). The green banana peel presents cellulose content of 7.5% (Tibolla, Pelissari, Rodrigues, & Menegalli, 2017). Banana by-products are an abundant and cheap resource of lignocellulosic biomass that can be found throughout the world especially in Asia and Europe.

Cellulose, the major structure component of plants, is a glucose polymer bounded in the β-1, 4 linkage configuration. The β-1, 4 linkage allows the cellulose polymer to crystallize in a linear configuration, with a high degree of intermolecular hydrogen bonding, which gives it substantial shear and tensile strength (Singanusong, Riantong Tochampa, Worasit Kongbangkerd, Teeraporn Sodchit, 2014).

Development of in-liquid plasma application has been applied with great success in various fields such as nanoparticle production (Amaliyah, Mukasa, Nomura, & Toyota, 2015; Hattori, Mukasa, Toyota, Inoue, & Nomura, 2011), decomposition of clathrate hydrates (Shinfuku Nomura et al., 2011) methane hydrate (Rahim, Nomura, Mukasa, & Toyota, 2015a) (Rahim, Nomura, Mukasa, & Toyota, 2014), and hydrogen production from glucose (Syahrial, Nomura, & Mukasa, 2015) due to the high temperature and high electron density it provides either at atmospheric and higher pressure (Hattori et al., 2013). Plasma is generated inside bubbles produced by the evaporation of surrounding liquid heated by plasma (S Nomura et al., 2011)

Hydrogen production from cellulose has been extensively investigated. From pyrolysis catalytic reforming of cellulose, the lifetime test showed that hydrogen production was about 28 mmol g^{-1} of cellulose (Zou et al., 2016). High temperature (~650 °C) and high catalyst loading (~100%) are favorable for hydrogen production from lignin, cellulose and waste biomass via supercritical water gasification (Kang, Azargohar, Dalai, & Wang, 2016). The effect of biochemical composition and temperature was found to be a key to sustainable bio-hydrogen production of cellulose (Gadow, Li, & Liu, 2012)(Tian, Li, He, & Tan, 2017)

In-Liquid plasma method has been applied to produce hydrogen from glucose solution and cellulose suspension by 27.12 MHz RF with and without ultrasonic irradiation (Syahrial, Mukasa, Toyota, Okamoto, & Nomura, 2014), using batch-type breakdown device and funnel shape device (Rahim, Nomura, Mukasa, & Toyota, 2015b) and using various types of reagents such as H_2SO_4 and

NaOH (Tange, Nomura, Mukasa, Toyota, & Syahrial, 2016). Since cellulose is nonvolatile, it cannot enter the bubble containing plasma, so the cellulose is not directly decomposed by plasma, but rather is decomposed indirectly by the active radicals created by plasma. Another research in the decomposition of cellulose has been conducted using hydrothermal decomposition (Jewena, Miyanomae, Sasaki, & Mashimo, 2017) and thermal decomposition (Shen & Gu, 2009). Most of cellulose decompositions are using chemical cellulose powder.

In this study, cellulose is directly decomposes from biomass source from a banana using radio frequency (RF) In-Liquid plasma. Three types of biomass source from banana such as banana pseudo stem, true stem and banana peel powder were used to compare gas production rate and gas percentage produce from the decomposition of cellulose content in that biomass.

Methodology

Banana pseudo stem, banana true stem and banana peels were cut into small pieces and air dried for approximately a week in the sun and then pulverized into a mesh size of about 50 μm.

The experimental apparatus is schematically shown in figure 1. Radio-frequency (RF) in-liquid plasma was generated at the tip of the electrode. An electrode composed of a copper rod 3 mm in diameter enveloped by a glass pipe with an outer diameter of 6 mm and an inner diameter of 4 mm as a dielectric substance was inserted at the bottom of a polycarbonate reactor vessel. The inner and outer diameters of the reactor vessel were 55 mm and 60 mm, respectively. In order to generate plasma in liquid, the impedance and input power were adjusted together by a matching box and 27.12 MHz RF generator.

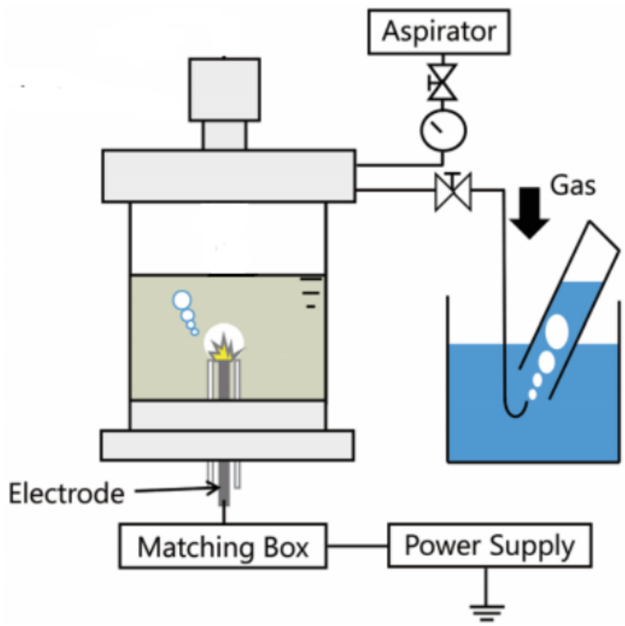

Figure 1. Schematic diagram of experimental apparatus

The initial concentrations of banana powder solution were prepared at 0.5 wt%. 80 mL of pure water and banana waste powder were poured into the reactor vessel. The pressure of the reactor vessel was reduced to 0.02 MPa using an aspirator to expel the air. In-liquid plasma was generated at an RF input power of 200 W at atmospheric pressure. The power values were calculated by subtraction of the reflected power from the forward power. The reflected power, which can be determined from the monitor of the RF generator, was maintained constant at the lowest value possible. The gas produced was collected from the top of the reactor vessel using water displacement method after the pressure reaches the atmospheric pressure. Gas collected then transferred to a gas-tight glass syringe and the concentration of the produced gas was determined with a gas chromatograph (GC-14A Shimadzu). Argon gas was used as the carrier gas with a flow rate of 0.5 mL/s and the head pressure was 152 kPa.

Result and Discussion

The experiment for hydrogen production from banana waste was carried out at atmospheric pressure in-liquid plasma generated by an RF generator. Three types of banana waste were used in order to analyze the hydrogen production rate. The incident power of RF was 200 W.

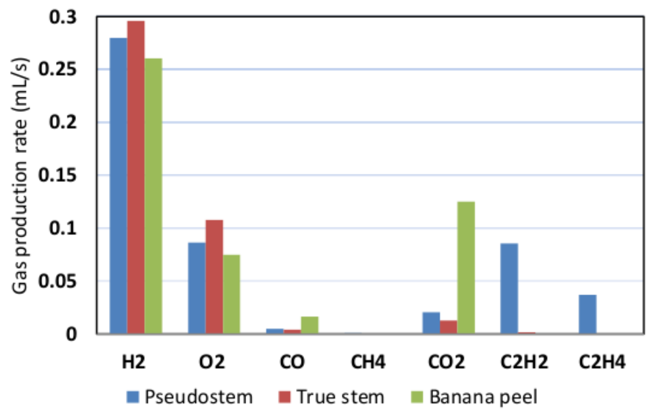

Figure 2. Decomposition of banana waste: Main gas production rates at initial concentration 0.5 wt%

Figure 2 shows the production rates of the main gasses produced from the decomposition of cellulose as a function of kind of banana waste at initial concentration 0.5 wt%. The volume of gas produced was 200 mL after exposure to RF in-liquid plasma for 10 minutes. The gas production rate is calculated from the average of the percentage of each gas produced, the total volume and the time exposed. The higher production rate was obtained when using banana true stem powder, and the lowest in banana peel powder. As can be seen in Figure 3, the hydrogen gas increased when using banana true stem due to methane and ethylene were not observed by gas chromatograph result. When applying plasma in banana pseudo stem powder, all main gas and by-product were observed using gas chromatograph, while in banana peel powder, acetylene and ethylene were not detected.

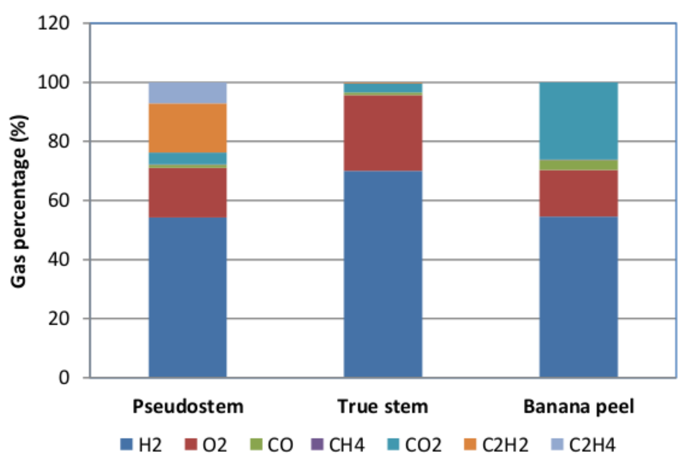

Figure 3. Gas produced from decomposition of banana waste powder in pure water at initial concentration 0.5 wt%

The decomposition of cellulose will not occur directly by the plasma, because cellulose is nonvolatile and remains in the liquid water in spite of evaporation of water. The evaporated water is fed into the plasma, and decomposed by the plasma. Cellulose content in true stem was higher than other and if the concentration of cellulose increases more, the decomposition of cellulose will occur by hydroxyl radicals which are produced by the decomposition of water. This is because the hydroxyl radicals reach the surface of the bubble more easily without colliding with the water molecules in the bubble (Syahrial et al., 2014).

Though the hydrogen production rate is still low in RF in liquid plasma using banana biomass powder, this process can be applied directly on biomass source without using any catalyst for hydrogen production making it possible to be considered as a promising technique in the future.

Conclusion

Hydrogen gas including any main gas and by-product is decomposed from cellulose content in banana pseudo-stem, banana true stem, and banana peel using in-liquid plasma method in this early finding. This method induced the formation of OH and H radicals that are essential for decomposition of cellulose. The production rate and gas percentage were higher when applying plasma in banana true stem. This result raises the prospect of investigating the influence of concentration and pretreatment on banana waste for future research.

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