GASIFICATION CHARACTERISTIC OF SEWAGE SLUDGE IN SUPERCRITICAL WATER

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The gasification characteristics of sewage sludge were determined under supercritical water conditions using continuous flow reactor. Sewage sludge was gasified at temperatures ranging from 375 to 450 °C and a pressure of 25 MPa with the residence time of 5–30 s. The gaseous products were analyzed and quantified by gas chromatography, and the total organic carbon in the liquid phase was also determined. Formation of gaseous products was intensively affected by temperature. The higher temperature and longer residence time favored production of H_2, CO_2, and CH_4. The carbon gasification efficiency increased with temperature and residence time.

Keywords: continuous reactor, gasification, sewage sludge, supercritical water

INTRODUCTION

Due to the increasing price and decreasing amount of fossil fuels, energy obtained from has received much attention in recent years. Especially, waste wet biomass such as sewage sludge attracts attention due to its negative cost. However, a large amount of energy is consumed when the biomass dried. To avoid this drying process, supercritical water gasification (SCWG) is a good option to produce hydrogen and methane [1]. Supercritical water (Tc = 374ºC, Pc = 22.1 MPa) has special physical and chemical properties [2] that allow rapid and complete gasification.

Thus, gasification characteristics of sewage sludge in supercritical water is wanted. Gasification of sewage sludge in supercritical water has been investigated by some researchers [3–6], but the finding is still limited. Especially, kinetic analysis using continuous reactors is wanted, but all of previous studies were carried out in batch reactors. The purpose of this study is to elucidate gasification characteristics of sewage sludge in supercritical water.

EXPERIMENTAL

Materials

Sewage sludge as the feedstock for SCWG was collected from wastewater treatment plant in Higashi-Hiroshima, Japan. The sewage sludge was filtered by using a suction filter and filter paper (Whatman Grade 5 Qualitative). The sludge was then dried (80 °C, until constant weight), pulverized in a ball mill, and then sieved to a particle size of 40 μm. This sludge particle was suspended in deionized water (< 1 μS/cm) obtained from a water deionizer (Organo, BB-5A).

Experimental setup and procedures

The experiment was carried out in a continuous reactor. Briefly, an SS316 steel tube with a length of 12 m and the inner diameter of 2.17 mm was used as the reactor. The reaction temperature was varied from 375 to 450 °C and reaction pressure was fixed at 25 MPa. The residence time was varied in the range of 5– 30 s by controlling water density, flow rate, and reactor length. To ensure steady state conditions, the reactor was operated for 1 h prior to sample collection.

Analysis methods

The gaseous product was analyzed by using a gas chromatograph (GC) equipped with a thermal conductivity detector (TCD) and a flame ionization detector (FID). H_2 was detected by GC-TCD with N_2 as the carrier gas; CO_2 and CO was detected by GC-TCD with He as the carrier gas, and CH_4, C_2H_4, and C_2H_6 were detected by GC-FID with He as the carrier gas. The solid product particles trapped in the inline filter was removed, placed in a porcelain crucible, dried overnight in an oven, placed in a desiccator for 30 min, and then weighed until a constant weight was reached.

The carbon gasification efficiency (CGE) for each experimental run was calculated based on the carbon content in the feedstock, as indicated in Eq. (1):

$$\mathrm{CGE}[-] = \frac{n_{\mathrm{gas}} + n_{\mathrm{IC}}}{n_{\mathrm{feedstock}}} \quad (1)$$

Where n_{gas} is the total amount of carbon present in the gaseous products [mol], n_{IC} is the total amount of inorganic carbon present in the liquid effluent [mol], and $n_{\mathrm{feedstock}}$ is the total amount of carbon present in the initial feedstock [mol]. All measurements were conducted duplicate, and the average was taken.

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RESULTS AND DISCUSSION

Effect of reaction temperature on carbon gasification efficiency

Carbon gasification efficiency (CGE) is shown in **Fig. 1.** CGE increased wi th reaction temperature. That is characteristic for supercritical water gasification. This is in a good agreement with a previous work by Xu et al. [7] in which CGE increased significantly with temperature, as was observed for glucose. The increase in the CGE with time and temperature is also in good agreement with other previous studies [8], [9].

Effect of reaction temperature on the product gas composition

Temperature can significantly affect SCWG of sewage sludge. **Figure 2** displays the effect of temperature on the product gas composition. The gas product was mainly composed of CO_2, H_2, CH_4 and small quantities of light C_2 and C_3 compounds, such as ethylene (C_2H_4), ethane (C_2H_6). No CO was found during SCWG of sewage sludge under these experimental conditions (375– 450 °C). The decrease of CO formation with increasing temperature implies that the water-gas shift reaction occurs and increased water-gas shift activity may be a cause for the increase in H_2 production. Gong et al. [10] reported that no CO was found during SCWG of humic acid as a model compound of sewage sludge.

Effect of reaction temperature and time on product yield of gaseous.

Figure 3 shows the CGE. It increased with temperature and time. The carbon yield of the gas product was around 0.8.

CONCLUSION

The gasification characteristics of sewage sludge during SCWG were studied using continuous reactor. CGE increased with temperature and reaction time. The gaseous products were mainly composed of CO_2, H_2, CH_4 and small quantities of light C2 and C3 compounds, such as ethylene (C_2H_4), ethane (C_2H_6).

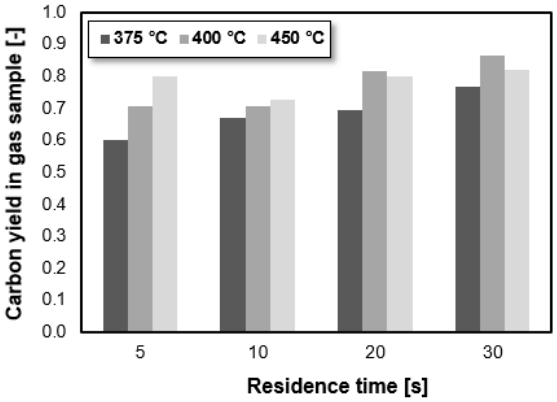

Fig. 1. Carbon gasification efficiency

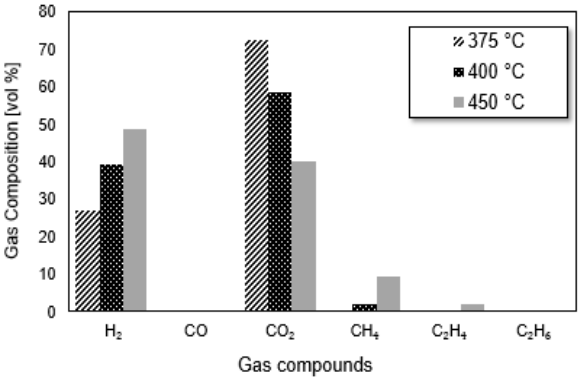

Fig. 2. Effect of temperature on product gas composition

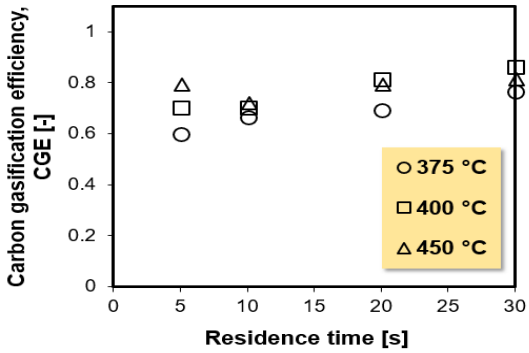

Fig. 3. Carbon yield of gaseous products

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