Gasification Characteristics of Sewage Sludge in Water under Subcritical Conditions

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Abstract: Gasification of sewage sludge in sub-critical water was investigated in a continuous flow reactor at temperatures of 300 and 350 °C and residence time in the range of 5–30 s under the fix pressure of 25 MPa. The effect of temperature and residence time on the composition of the product gas were investigated. The gaseous products were 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 were 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 results showed that the gaseous product mainly contained H_2 and CO_2 with less amount of CH_4 and C_2H_4, and no CO was found. Temperature did not affected carbon gas efficiency

1. Introduction

Fossil fuels are predominantly used today to fulfill the skyrocketing global demand for energy. Much of this energy demand is believed to be supplemented by biofuels produced from renewable sources. Renewable energy is a promising solution to the problem of depleting fossil fuel, global warming, and increasing energy consumption. Biomass is one of the potential renewable resources for this purpose, and hydrothermal gasification is a promising technology for biomass utilization so that it is converted to synthesis gas in an environmentally benign environment. In hydrothermal gasification, water is used both as a solvent and reaction medium with its thermophysical properties near its critical temperature (TC) and critical pressure (PC). Depending on the temperature and pressure of water, hydrothermal gasification processes employ subcritical (TC < 374 °C and PC <22.1 MPa), near-critical (TC ~ 374 °C and PC ~ 22.1 MPa) and supercritical (TC > 374 °C and PC> 22.1 MPa) water 1). It should be noted that subcritical water exists at temperatures between the boiling point of water and its critical temperature. In this process, water is in the liquid state in subcritical conditions 2).

Among various biomass feedstock, sewage sludge is the most promising wet biomass. Sewage sludge is the solid fraction of urban and industrial wastewater containing inorganic and organic substances. Various thermochemical technologies such as pyrolysis, liquefaction, torrefaction and carbonization have been employed to convert sewage sludge into beneficial secondary energy. Pyrolysis and liquefaction primarily generated bio-oil as the main liquid fuel product, whereas torrefaction and carbonization produced torrefied biomass or char as the main solid fuel 3–5). Different gasification technologies such as downdraft and updraft fixed beds, bubbling fluidized beds, double and triple stages have been also applied to gasified sewage sludge at the previous study. However, for high moisture content, these conventional gasification processes are not appropriate. Another problem of sewage sludge is the high ash content in sewage sludge. It has been pointed out an obstacle both in fluidized bed and in the fixed bed gasification.

To circumvent these problems, hydrothermal gasification should be the most appropriate to the best of our knowledge. Especially when it is operated under subcritical conditions, energy requirement for reactor operation can be minimized.

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By employing a continuous hydrothermal reactor, the pressure can be constantly controlled and the associated thermal phenomena readily levels the bed temperature avoiding ash slagging and clinkering [6]. Unfortunately, gasification of sewage sludge in a hydrothermal continuous flow reactor has not been reported so much.

Therefore, in this study, experimental gasification of sewage sludge in hydrothermal continuous reactor under subcritical condition will be presented and discussion is made on the novelties including the detail effect of temperature and residence time on gasification characteristics of sewage sludge under subcritical conditions.

2. Experimental

The gasification of sewage sludge was carried out in a continuous flow reactor. The reactor was made of SS316 steel tubing (i.d., 2.17 mm; o.d., 3.18 mm and lengths 12 m). Initially, water was fed into the reactor. Subsequently, the pressure was increased to 25 MPa using a back-pressure regulator. After achieving a constant pressure of 25 MPa, the reactor temperature was set at desired temperature. The feedstock was then fed using the feeding system. The feedstock was fed into the system for 1 h prior to sample collection after steady-state. Gas samples were collected in vials and their compositions were determined. The gaseous product was characterized and quantified using gas chromatography (GC). Carbon dioxide and carbon monoxide were detected by GC with a thermal conductivity detector (GC-TCD) using helium as the carrier gas. Methane, ethene, and ethane were detected using GC with a flame ionization detector (GC-FID) using helium as the carrier gas. Hydrogen was detected by GC-TCD with nitrogen as the carrier gas. The liquid product was analyzed for the amounts of carbon in the liquid product (non-purgeable organic carbon, NPOC) and the dissolved carbon gas product (inorganic carbon, IC) by a total organic carbon (TOC) analyzer.

The experiment was conducted for sewage sludge concentration of 0.1 wt% under 300–350 °C, varies residence time (5–30 s), and fix pressure of 25 MPa.

Carbon gasification efficiency was defined as the ratio of the total carbon in the gas product to that in the feedstock solution.

3. Results and Discussion

The effect of reaction temperature and residence time on gasification efficiency is shown in **Fig. 1.** The carbon gasification efficiency of sewage sludge slightly increased with temperature and residence time employed here. Similar trend was observed by Dianningrum et al.[7], who worked on gasification of glycerol in hot compressed water with residence time ranging 15–120 min.

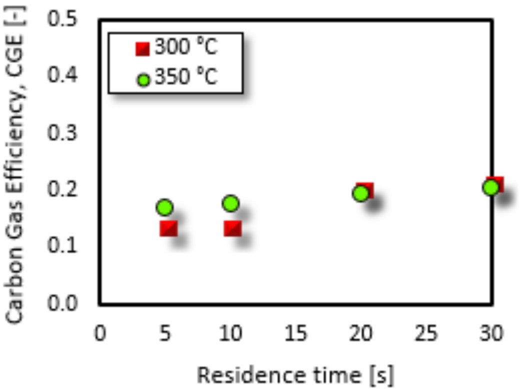

Fig.1. Effect of temperature and residence time on gasification efficiency.

The gaseous products were rarely found under subcritical conditions (300 and 350 °C). This is in good agreement with the results of Paksung and Matsumura[8], who showed that the gaseous product in case of xylose were rarely found under subcritical conditions. The gaseous products mainly contained H_2 and CO_2 with less amount of CH_4 and C_2H_4, and no CO was found. This in line with previous study of Seif et al. [9]. They obtained the gas products mainly containing H2 and CO2 with less amounts of CH4 and CO. Prolonging the reaction time at 300 °C resulted in slight reduction of hydrogen mole fraction on gas product. This is likely due to the fact that hydrogen is consumed through methanation reactions to produced methane.

4. Conclusion

Gasification of sewage sludge was conducted using a continuous flow reactor at 300 and 350 °C and the residence time in the range of 5–30 s under 25 MPa. The carbon gasification efficiency slightly increased when the temperature was increased from 300 to 350 °C. However, variation in reaction time did not have considerable effect on gas composition. The gaseous products mainly contained H2 and CO2 with less amount of CH4 and C2H4, and no CO was found.

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