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Gasification of Food Waste with Steam in Fluidized Bed

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Abstract−Biomass has became an important renewable alternative energy resource. Million tons of food sludge, which is difficult to handle because of its rank smell and water content, is generated in Korea. Thermochemical conversion is one way to convert biomass to energy; it can be divided into carbonization, liquefaction, and gasification. Carbonization of food waste was carried out in a conventional stainless steel autoclave of 2 L capacity at different temperatures. Since gasification produces hydrogen-rich synthesis gas, which can be used for methanol synthesis, gasification of carbonized solid was studied in the fluidized-bed gasifier. The reaction parameters in the gasification of carbonized solids were investigated.

Key words: Biomass, Food Waste, Gasification, Fluidized Bed

INTRODUCTION

Biomass, such as wood, bark mill residue, agricultural and food wastes, manure, and ocean plants etc., has been an important renewable alternative energy resource. Million tons of food sludge, which is about 30 percent of waste from homes, is generated in Korea and various methods to treat this waste have been developed [Fung and Kim, 1990; Kim et al., 1996; Yoon, 1998]. Landfilling poses a problem of ground water pollution and difficulty of recalamation. Alternative methods to treat the problem are conversion to alcohol, and organic fertilizer by biotreatment, but these methods have limitations for large amounts of waste and more effective methods need to be developed.

Thermochemical conversion, which is one of the methods to convert biomass to energy, can be divided into carbonization, liquefaction and gasification [Dote, 1993; Garg et al., 1988; Mallya and Helt, 1988; Maniatis and Buckens, 1988; Lee et al., 2000]. Gasification has the merit of producing hydrogen-rich synthesis gas, which can be used as feedstock for intermediate of fine chemicals [Chen, 1994; Ganesh et al., 1992; Garcia et al., 1998; Lee et al., 1999].

The aim of this work was the development of a new gasification system from food waste. First, this study was intended to develop a thermal method to treat waste obtained from mess halls to carbonized solid. Second, synthetic gas was prepared by gasification of carbonized solid in a fluidized-bed. The effects of various factors on carbonized solids and formation of synthesis gas were investigated.

EXPERIMENTAL

The schematic diagram of the experimental apparatus is shown in Fig. 1. It consisted of an autoclave (Parr model 4532) with a magnetic drive system, and the pressure control circuit mainly consisted of a cooler, a back pressure regulator (Tescom model 261725) and a gas reservoir. Food wastes for the thermal degradation to carbonized solid were introduced into the autoclave.

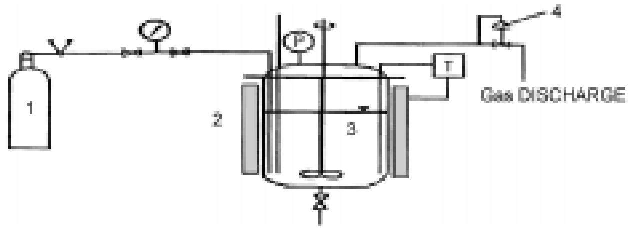

Fig. 1. Experimental scheme for the carbonization of food waste.
1. Nitrogen cylinder
2. Electric heater
3. Autoclave
4. Back pressure regulator

Reaction conditions were as follows: reaction temperature of 200 °C, 30 min holding time and 200 psi nitrogen. Reaction mixture in the autoclave was separated by filtration. Dark brown heavy oil and solvent-soluble material were obtained from the filtrate. The amount of formed gas was measured with a gas meter and the compositions of evolved gases were determined by gas chromatography with TCD (silica gel column of 60/80 meshes).

After the autoclave was deaerated, the temperature was raised by heating the autoclave with an electrical heater. With increase of the temperature between 50 and 300 °C, the working pressure between 10 and 100 kg/cm^2 was increased gradually and was maintained at a constant value by releasing the excess pressure through the back pressure regulator to the gas reservoir.

After the mixture was allowed to stand for several hours and the raffinate was filtered. Then, The carbonized solid residue was obtained by drying the cake on the filter glass at 105 °C for 5 hrs. Then filtrate was intensively extracted with dichloromethane (Junsei Chemical Co.,). Dichloromethane was was recovered by using a rotary evaporator (Buchi RE 111). The heavy oil eas obtained as a dark

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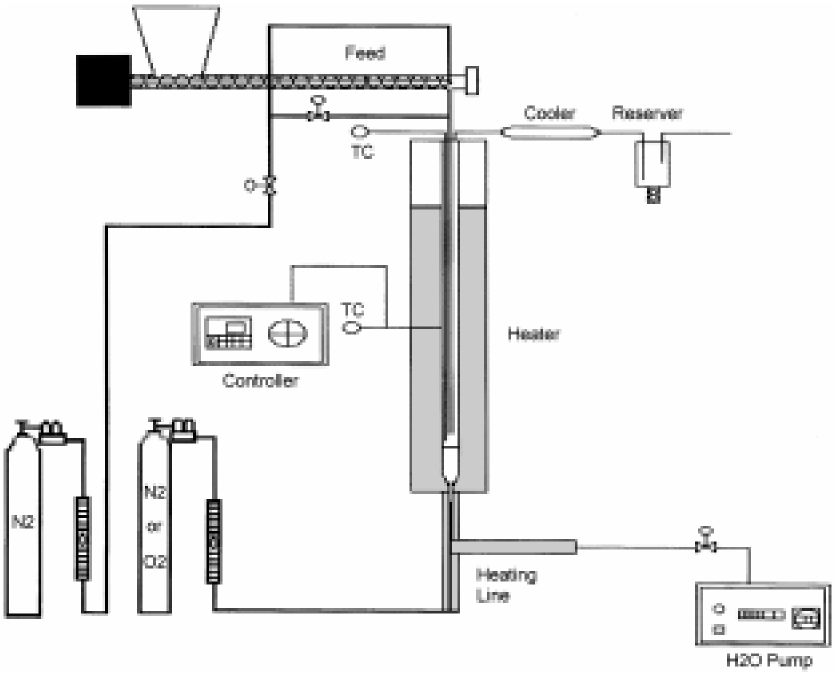

Fig. 2. Experimental scheme for fluidized-bed gasification of carbonized solid.

brown viscous oil.

These carbonized solids were gasified in the gasifying system showed in Fig. 2. The system consisted of a fluidized-bed gasifier (50 mm ID and 1.5 m height) with continuous biomass feeding system, steam supply system with heating line and liquid metering pump, a cooling system, a gas reservoir, a gas meter, a temperature controller, and gas analyzer. The reactor was kept at the operating temperature by means of electric furnaces located along the fluidized column. The temperature of the reactor ranged between 400 and 1,000 °C. The preheated nitrogen/oxygen fluidized the biomass through a distributor. The biomass between 80 and 120 mesh size was fed continuously inside the fluidized bed by means of a screw feeder at a fixed rate of 1.3 g/min. The fluidizing medium was nitrogen/oxygen, the flow rate of 1.0 liter/min (0.82 m/s). After the dust removal section, samples for the gas composition were taken. H_2, CO, CO_2, and CH_4 was measured with a gas chromatograph [Donam DS 6200].

The conversion was defined as follows:

* Thermal degradation of Food waste

$$\text{Conversion} = \frac{\text{Weight of materials obtained in each phase}}{\text{Weight of volatile materials in food waste}} * 100(\%)$$

* Fludized gasification of carbonized solid

$$\text{Conversion} = \frac{\text{Weight of gas product}}{\text{Weight of carbonized solid}} * 100(\%)$$

RESULTS AND DISCUSSION

1. Thermochemical Degradation of Food Waste

Thermal degradation of food waste was conducted in the reaction system as in Fig. 3. The operating pressure was maintained at the saturated water vapor pressure at required temperature. Yokoyama et al. [1984] reported that the reaction temperature 300 °C showed the most excellent results for the thermal liquefaction of the sewage sludge as feed stock. Korean food sludge contains large amounts of radishs. Thus, the radish is selected as a standard feed material to obtain the optimum condition in this study. These results showed the different aspects from those obtained by Yokoyama from the sewage sludge. Although Yokoyama et al. [1984] obtained the crude oil as a major product, our result showed the carbonized solid as shown in Fig. 3.

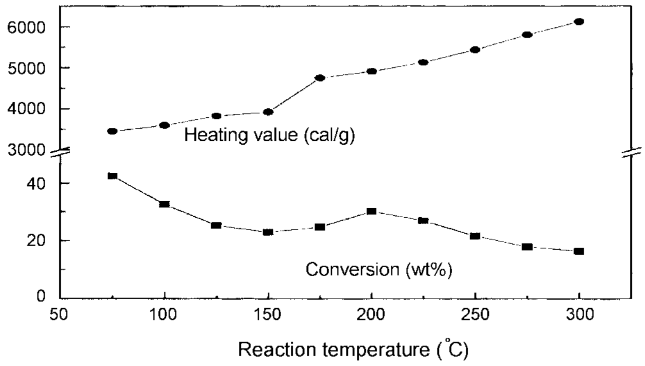

Fig. 3. Effect of reaction temperature on the thermal degradation of radish.

The yield of carbonized solid was between 26 and 43%. Also, the heating values were increased with increasing reaction temperatures and showed low values below 150 °C. The infrared spectroscopic method and elemental analysis were examined to understand these phenomena. As shown in Table 1, elemental analysis showed an increase in amounts of carbon with increasing the reaction temperature.

Also, Fig. 4. of the infrared analysis shows a decrease of $\delta_{C\text{-}H}$ band at 1,384 cm^{-1} and $\delta_{O\text{-}H}$ band at 1,054 cm^{-1} with increasing the reaction temperature. Conversion to carbonized solid showed a maxi-

Table 1. Elemental analysis of carbonized solid obtained from various temperatures in thermal degradation of radish

Rx. temp (°C)	Elements (%)			
	Carbon	Hydrogen	Nitrogen	Oxygen
200	59.21	5.09	3.23	32.47
250	62.67	4.61	3.85	28.87
300	69.32	4.85	4.86	20.97

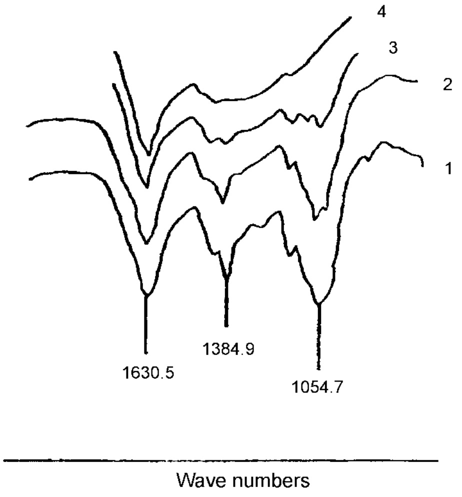

Fig. 4. IR spectra of solids obtained at various reaction temperatures (KBr disk).
(1. 150 °C, 2. 200 °C, 3. 250 °C, 4. 300 °C)

mum value at 200 °C.

Thermal degradation of food waste obtained from a mess hall was studied at the reaction temperature of 200 °C. The composition of waste food sludge shown in Table 2 was used in the reaction.

Radish and food sludge were compared in this reaction system. As shown in Table 3, in the case of food waste, amounts of carbonized solid, oil and gas were increased significantly. This difference was caused by amounts of water contained in the feed.

Table 2. Composition of food sludge obtained from a mess hall

Testing item (%)	Weight percent (%)
Water content	80.1
Carbonized solid	20.9
Composition of carbonized solid (wt,%)	
Fat	12.7
Protein	20.2
Fiber	19.1
Carbohydrate	46.9
Ash	1.1

Table 3. Products obtained in the thermal degradation of food waste

Products	Radish	Food sludge
Solid (gr)	9.0	30.1
Oil (gr)	0.55	1.1
Gas (ml)	925	3700
Total energy (cal)	44226	177630

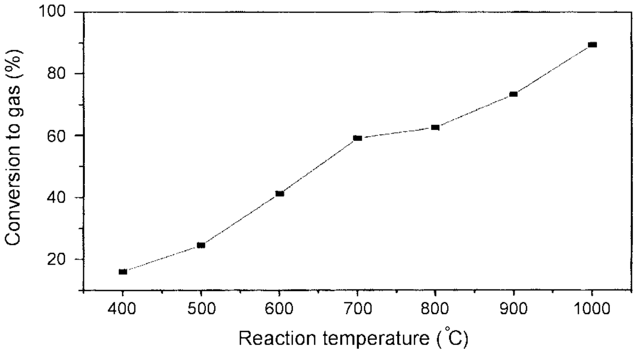

Fig. 5. Conversion of gas obtained at different reaction temperatures. Rx. Condition: Carbonized solid (1.318 g/min), Water (0.5 ml/min), N_2 (1,500 ml/min).

2. Fluidized Gasification of Carbonized Solid

Gasification using carbonized solid (carbon: 59%, hydrogen: 5%, nitrogen: 3%, oxygen: 33%) obtained from food waste was carried out in a fluidized gasification system. The main parameters in the gasification of carbonized solid, which is investigated, were reaction temperature, amount of steam and oxygen.

The reaction temperature largely affected the conversion of carbonized solid into gas product and the composition of formed gas. As shown in Fig. 5 conversion to gas was sharply increased with reaction temperature.

Amount of water not only enhances the reactivity of gasification by increasing by steam reforming reaction, but also diminishing amounts of carbon monoxide by water gas shift reaction. The results obtained are represented in Fig. 6. It shows the effect of the amount of steam on the reaction at carbonized solid feeding rate 1.3 g/min and 800 °C, and also the maximum gas composition of hydrogen and carbon monoxide at the 0.5 ratio of steam per carbonized solid. From this evidence, the ratio of 0.5, water-to-carbon, may be an equilibrium range for the three gases, H_2, CO and CO_2, at a given condition.

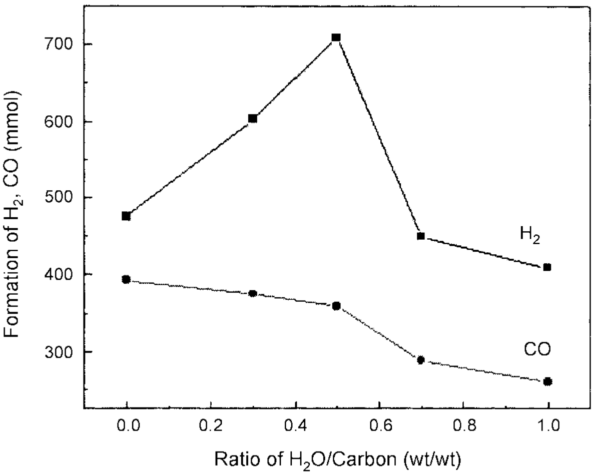

Fig. 6. Effect of amounts of water on gasification of carbonized solid.

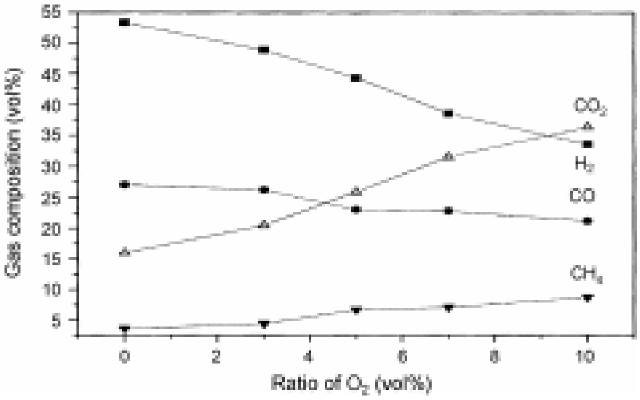

Fig. 7. Effects of ratio of oxygen on the gasification of carbonized solid.

Also, this high temperature gasification system has a high energy requirement to operate above 800 °C. Thus, effect of oxygen was examined to use exothermic heat produced from formation of CO and CO_2.

$$2C+O_2 \rightarrow 2CO \qquad \Delta H_R=-58\ \text{kcal/mole}$$
$$C+O_2 \rightarrow CO_2 \qquad \Delta H_R=-97\ \text{kcal/mole}$$

The effect of oxygen on the gasification of carbonized solid at the fixed ratio of steam-to-carbon(0.5) is presented in Fig. 7. As expected, the formation of carbon dioxide was increased and the formation of hydrogen, carbon monoxide was decreased with increase of oxygen. But methane showed a large increase with increase of oxygen. This result is caused from cracking of carbon chain at partial oxidation using low concentration of oxygen.

CONCLUSIONS

In this study, optimal temperature for thermal degradation of food waste was at 200 °C and the main product obtained from thermal degradation of waste food was carbonized solid. The conversion to carbonized solid was about 25-32% at 200 °C.

Also, gasification of carbonized solid was carried out in the fludized-bed reactor. Various reaction parameters on the gasification of carbonized solids were investigated. The reaction temperature largely affected the conversion of carbonized solid into gas product and the composition of formed gas. Conversion to gas was sharply increased with reaction temperature.

Gas composition of hydrogen and carbon monoxide formation showed the maximum at the 0.5 ratio of steam per carbonized solid. The effect of amounts of oxygen was studied and the formation of hydrogen and carbon monoxide decreased with increase of oxygen. But methane was slightly increased with increase of oxygen.

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