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CATALYTIC AND THERMAL DEGRADATION OF KOREAN FOOD SLUDGE

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Abstract – Korean food waste sludge was degraded by using a new thermal degradation method. In this system, radish contained waste food sludge as main portion was selected as a standard material. Products of thermal degradation were mainly composed of carbonized solid, small amounts of oil and methane. Total energy production was dependent on the reaction temperature. About 25-32% of solid in the radish was converted to carbonized solid in the thermal degradation of radish at 200°C. The heating values of the carbonized solid and the liquefied heavy oil were 4000-6000 cal/g and about 8000 cal/g respectively. Various catalysts were also examined to improve the carbonized solid used as energy source. Acid clay and Montmorillonite KSF catalysts showed the best results among the catalysts tested. From the energy balance, this thermal degradation process operated at 200°C was a net energy producer.

Key words: Catalyst, Thermal Degradation, Food Sludge, Treatment of Food Sludge

INTRODUCTION

More than 4 million tons of food sludge are generated annually in Korea. Various methods were developed to treat this food sludge. Landfilling poses a serious problem because of ground water pollution and difficulty of reclamating the place. Although, incineration is very effective for treating the putrescible organic materials, this method is expensive because of its high energy consumption. Pyrolysis and direct thermochemical degradation of sewage sludge to produce fuel materials has been known for almost 50 years. Processes for converting sewage to heavy oil using the pyrolytic method have been reported by various researchers [Garg, 1988; Mallya, 1988; Maniatis, 1989; Scott, 1985; Yokoyama, 1984].

Recently, biomass such as wood, alcohol fermentation stillage and sewage sludge was liquefied in an alkaline solution under pressurized inert gas at 300°C [Yokoyama, 1984; Suzuki, 1990; Dote, 1993].

Thus, we developed the new technology to treat the waste food sludge that caused many environmental problems. We studied the thermal treatment of food sludge obtained from mess hall. Radish based on waste food sludge was selected as a standard material. The effects of the various factors on carbonized solids were examined in the optimum condition. Also, energy yield of the different composition of food sludge was compared in the optimum conditions. The result shows the feasibility of the setting up an industrial scale plant for the direct thermochemical degradation of food sludge.

EXPERIMENTAL

1. Experimental Apparatus and Procedures

The schematic diagram of the experimental apparatus is shown in Fig. 1. It compromised an autoclave (Parr model 4532) with a total volume of 2L. The autoclave had a stirrer with a magnetic drive system and the pressure control circuit mainly consisted of a cooler, a back pressure regulator (Tescom model 26-1725), and a gas reservoir. Food sludge and a catalyst for the thermal degradation were introduced into the autoclave.

After the autoclave was deaerated, the temperature was raised by heating the autoclave with an electric heater. With increase of the temperature, the working pressure was increased gradually and was maintained at a constant value by releasing the excess pressure through the back pressure regulator to the gas reservoir.

Regarding the separation procedure, the reaction mixtures were intensivly extracted with dichrolomethane (Junsei chemical Co., CP grade) as a solvent. After the mixtures were allowed to stand for several hours, both the extract and the raffinate were filtered. Then, the solid residue was obtained by drying the cake on the filter glass at 105°C for 5 hrs. The dichloromethane was evaporated from the filtrate of the extract using a rotary evaporator (Buchi RE 111). The heavy oil, the solvent soluble material, was obtained as a dark brown viscous oil in

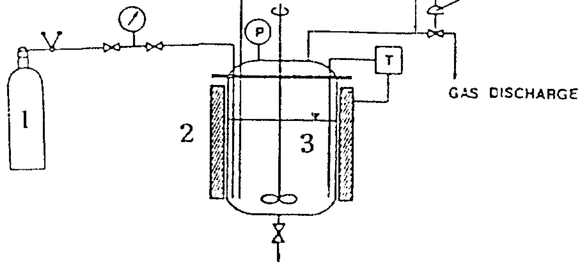

Fig. 1. Experimental apparatus.
1. Nitrogen cylinder
2. Electric heater
3. Autoclave
4. Back pressure regulator

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this manner. The solid residue defined as the material insoluble in both water and the solvent phases.

The conversion and energy yields are defined as follows.

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

$$\text{Energy yield} = \frac{\text{Energy obtained from each reaction product}}{\text{Energy consumed for food sludge}} \times 100\ (\%)$$

RESULTS AND DISCUSSION

1. Thermal Degradation of Radish at Various Reaction Temperature

The operating pressure was maintained at the saturated vapor pressure of water at the required temperature. Yokoyama et al. [1984] reported that the reaction temperature of 300°C showed the most excellent results for the thermal liquefaction of the sewage sludge as feed stock. Korean food sludge contains lots of radish [Ku, 1992]. Thus, 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 Table 1.

The conversion to solid was between 26 and 43%. Also, the heating values were increased with increasing reaction temperatures and showed low values below 150°C (Fig. 2). The infrared spectroscopic method and elementary analysis were examined to understand the these phenomena. As shown in Table 2, elementary analysis showed an increase in amounts of carbon with increasing the reaction temperature. Also, Fig. 3 of infrared analysis showed decrease of δ_{C-H} band at 1384 cm^{-1} and δ_{O-H} band at 1054 cm^{-1} with increasing the reaction temperature. Total heating value on reaction temperature showed a maximum value at 200°C and a minimum value at 150°C as Fig. 4. These maximum and minimum points resulted from the formation of carbonized solid, oil and gas as shown in Fig. 5. This graph points to three important meanings.

i) below 150°C, uncarbonized solid was mainly obtained

ii) at 150°C, oil dissolved in aqueous layer was increased

iii) above 200°C, gas formation rapidly increased from carbonized solid

Table 1. Effect of reaction temperature in the thermal degradation of radish

Rx. temp. (°C)	Conversion (wt%) Solid	Solid heating value (cal/g)	Energy conversion (%)
75	42.5	3445	43
100	32.5	3596	34
125	25.2	3822	28
150	22.8	3922	26
175	24.6	4754	34
200	30.1	4914	43
225	26.8	5134	40
250	21.5	5440	34
275	17.8	5797	30
300	16.3	6120	29

*Reaction condition

Reaction Time: 1 hr, Radish: 600gr, Water content: 95%

Table 2. Elemental analysis of solid obtained from various temperatures in thermal degradation of radish

Rx. temp (°C)	Elements (%)			
	C	H	N	O
225	59.21	5.09	3.23	32.41
250	62.67	4.61	3.85	28.27
300	69.32	4.85	4.86	20.91

2. Effect of Types of Food Sludge

Korean food sludge contains carbage, bean sprouts and boiled rice in addition to radish. Thus, the study on energy yields

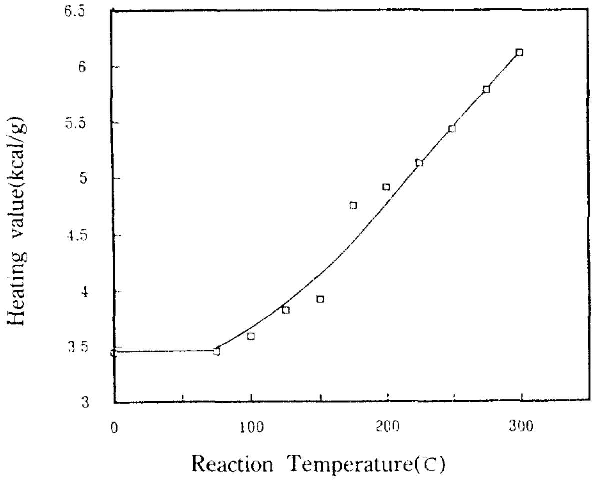

Fig. 2. Heating values of solids obtained at different reaction temperatures.

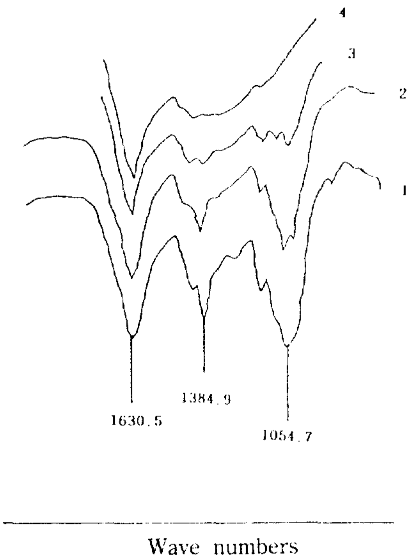

Fig. 3. IR spectra of solids obtained at various reaction temperatures (KBr disk).
(1: 150°C, 2: 200°C, 3: 250°C, 4: 300°C)

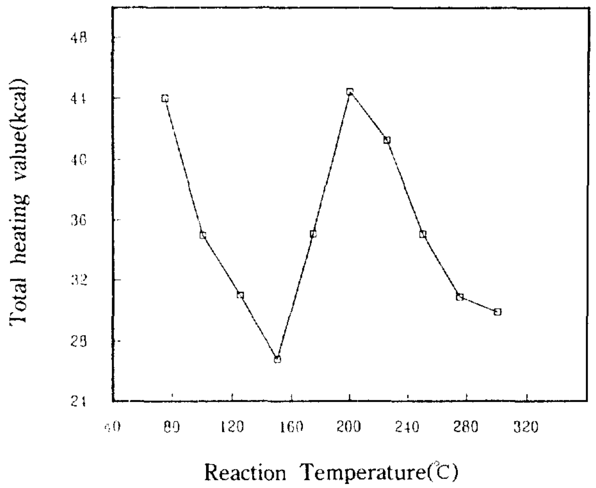

Fig. 4. Total heating values of products obtained in various reaction temperature.

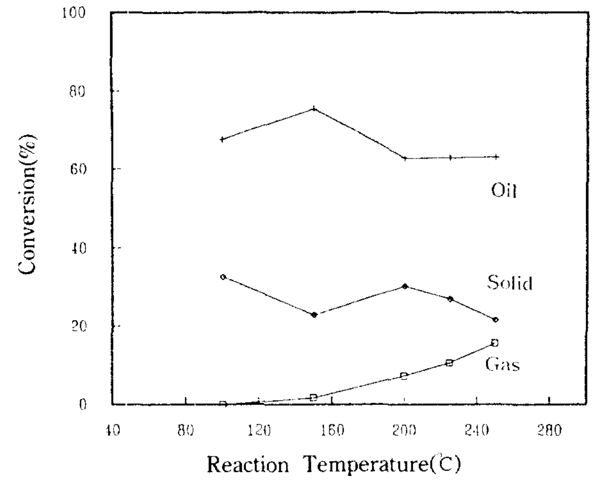

Fig. 5. Conversion to carbonized solid, oil and gas at various reaction temperatures.

was extended to other components. The energy yields may be attributed to the ratio of the quantities of carbohydrate, fat and protein contained in waste food. This study is examined with the optimum condition which obtained from radish and boiled rice gave best results on the obtaining total energy conversion as shown in Table 3.

3. Effect of Various Catalysts

Effects of various catalysts were studied to select the most effective one. As shown in previous results, obtained solid was usable as energy source. Thus, various catalysts were used to increase the energy yield. Yokoyama [1984] showed that basic catalyst as sodium carbonate was a good catalyst in the liquefaction of sewage sludge. The effects of various catalysts including sodium carbonate and bentonite were studied in thermal degradation of radish. As shown in Table 4, layer catalysts like bentonite showed good results. This result indicates that the hydroxyl group which contributes to the strong acid site may be responsible for thermal degradation. Also, bentonite as heterogeneous catalyst showed that would be easily separated from reaction mixture.

Thus, various layered catalysts were examined in this system. As shown in Table 5, acid clay and Montmorillonite KSF catalysts represented excellent results in total heating energy.

4. Thermal Degradation of Waste Food Sludge

Thermal degradation of waste food sludge was studied at the same reaction condition that was used for radish as feed material.

The composition of waste food sludge shown in Table 6 was used in this reaction. As shown in Table 7, amounts of car-

Table 3. Effects of various feed stocks in the thermal degradation

Reactant	Water content (%)	Conversion (wt%)		Heating value
		Solid	Oil	
Radish	95	30.1	2.9	4914
Carbage	95	30.0	2.1	5448
Bean sprouts	80	18.3	1.2	5990
Boiled rice	60	48.3	0.3	5926

*Six hundred grams of each material was reacted at 200°C for 1 hr.

Table 4. Effects of various catalysts in the catalytic degradation of radish

Catalyst	Conversion (wt%) Solid	Heating value of solid (cal/g)
Without	30.1	4914
Sodium carbonate	34.1	4431
Bentonite	35.7	5227
ZSM-5	32.3	3572
NaOH	26.7	4332

*Reaction was proceeded at 200°C for 1 hr using 600gr of feed material.

Table 5. Effects of various layered catalysts in the catalytic degradation of radish

Catalyst	Conversion (wt%) Solid	Heating value of solid (cal/g)
Without	30.1	4914
Acid clay	42.5	5049
Bentonite	35.7	5227
Activated clay	40.5	5165
Montmorillonite KSF	38.8	5495
Montmorillonite K10	35.8	4915
Kaoline	38.8	4884

*Reaction was proceed at 200°C for 1 hr using 600gr of feed material under 5 wt% catalyst on volatile solid

Table 6. Composition of food sludge obtained from a mess hall

Testing item (%)	Results (%)
Water content	80.1
Volatile component	98.9
Fat	12.7
Protein	20.2
Fiber	19.1
Carbohydrate	46.9
Ash	1.1

Table 7. Products obtained in the thermal degradation of food wastes

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

*Feed material: 600 gr, Reaction temperature: 200°C, Reaction time: 1 hr

bonized solid, oil and gas increased significantly compared with radish as feed.

This result was probably caused by water contents contained in feed material. Solid obtained from reaction can also be used as the energy source for the reaction.

CONCLUSION

1. Optimal temperature for thermal degradation of waste food sludge was at 200°C.
2. The main product obtained from thermal degradation of waste food sludge was carbonized solid.
3. Total energy generation was dependent on the reaction temperature and the conversion to carbonized solid was about 25-32 wt% at 200°C.
4. The heating value of the carbonized solid was 4000-6000 cal/g and that of liquefied heavy oil was about 8000 cal/g.
5. Acid clay and Montmorillonite KSF catalysts showed the best result among the various catalysts studied.
6. This process showed a possibility that the obtained carbonized solid could be used as the net energy producer from the energy balance.

REFERENCES

Dote, Y., Yokoyama, S., Minowa, T. and Masuta, T., "Thermochemical Liquefaction of Dewatered Sewage Sludge", *Biomass and Bioenergy,* **4**, 243 (1993).

Garg, M., Piskorz, J., Scott, D. S. and Radlein, D., "The Hydrogasification of Wood", *Ind. Eng. Chem. Res.,* **27**, 256 (1988).

Ku, C. G., "Study on Conversion of Biodegradable Waste Sludge", KIST, Report of Basic Research, **13** (1992).

Mallya, N. and Helt, J. E., "Effect of Feedstock Components on Municipal Solid Waste Pyrolysis", *Research in Thermochemical Biomass Conversion,* 111 (1988).

Maniatis, K. and Buckens, A., "Fast Pyrolysis of Biomass", *Research in Thermochemical Biomass Conversion,* 179 (1988).

Scott, D. S., Piskorz, J. and Radleign, D., "Liquid Products from the Continuous Flash Pyrolysis of Biomass", *Ind., Eng., Chem., Res.,* **24**, 581 (1986).

Suzuki, A., Nakamura, T. and Yokoyama, S., "Effect of Operating Parameters on Thermochemical Liquefaction of Sewage Sludge", *J. of Chem. Eng. of Japan,* **23**(1), 6 (1990).

Yokoyama, S., Ogi, T., Koguchi, K. and Nakamura, T., "Direct Liquefaction of Wood by Catalyst and Water", *Liquid Fuels Technol.,* **2**(2), 155 (1984).