

Development of Food Waste Disposal Technology Using Sodium Hydroxide

M. Nakayasu and T. Wajima

Abstract—In this research, we focused on the recycling of food waste using sodium hydroxide (NaOH). Pyrolysis of rice, one of the major elements of food waste in Japan, was carried out to obtain carbon material with adsorption ability, together with fuel gases (H₂, CH₄). As a result, it was possible to convert rice into carbon material while generating fuel gas. With increasing the NaOH addition and temperature, the contents of CO and CO₂ decreases, those of H₂ and CH₄ increased in the generated gas, and the mass of the residue after pyrolysis with NaOH decreases to one-tenth weight of raw rice. The residue after pyrolysis is a carbonaceous material with approximately 80% carbon content, and the residue after pyrolysis with NaOH (rice sample : NaOH = 1 : 1) has smooth porous surface with higher specific surface area (901 m²/g) than that after pyrolysis without NaOH (72 m²/g).

Index Terms—Food waste, sodium hydroxide, fuel gas, pyrolysis, porous carbon material.

I. INTRODUCTION

Global food production amounted to 4.33 billion tons, and 1.3 billion tons were abandoned (FAO, 2011), which is about 12.4% of the global solid waste (11 billion tons per year) [1]-[3]. In Japan, the amount of the food waste was estimated in 2015 to be 28.42 million tons per year, which 1.12 million tons are incinerated or landfilled [4]. The food waste is degradable at the landfill sites, resulting in environmental impacts such as infectious diseases, vermin, polluted water, bad smell [5]-[7]. From this situation, Food Waste Recycling Law was enforced in December 2007 in Japan, and the rate of reuse and recycling for total food waste was 71 % in 2015 [8]-[12].

Food waste contains a large amount of water (80 %) organic substances (16.7 %) and inorganic matters (3.3 %) [13]. Therefore, as a recycling method of food waste, there are various technologies that have been explored for food-waste-to-energy conversion including biological (e.g. feed, fertilizer and methane fermentation), thermal and thermochemical technologies (e.g. incineration, pyrolysis and gasification) [14]-[18].

In 2015, the recycling rate of the food waste is 74 % for fertilizer, 17 % for feed, 4% for methane fermentation, and 2 % for heat recovery [19]. Feed and fertilizer can be done with small emission of greenhouse gases using small initial investment. However, there are problems that the odor was generated during the production process, and it is necessary to avoid contamination for agricultural uses [20]. Methane fermentation requires specific conditions for decompose of

organic matter using microorganisms for long time [21], and the produced gases by methane fermentation are methane gas, carbon dioxide and hydrogen sulfide to be removed for fuel gas. Therefore, fermenters require a large site area for various process and long reaction time [22].

Pyrolysis treatment is one of thermochemical techniques to produce gases from organic matters, such as agricultural crops and their by-products, municipal solid waste, and waste from food processing, using high temperature via an external heat source in an inert atmosphere [23]. The waste is carbonized to reduce the volume using the compact apparatus. However, conversion of food waste with high moisture content into useful gases and carbonaceous materials needs high energy.

The previous study showed that use of the sodium hydroxide promoted pyrolysis of waste plastics and enables efficient pyrolysis and gasification. However, there are no examples pyrolysis using sodium hydroxide for food waste at all.

In our previous studies, pyrolysis of waste can be promoted by sodium hydroxide to obtain the oil, gas and carbon residue [24], [25]. However, little information can be available on pyrolysis using sodium hydroxide for food waste [26].

In this research, we attempted to convert rice, which is one of the main contents in food waste in Japan, into flammable gases to be used as fuel and carbonaceous material with high specific surface area to be used as adsorbent using pyrolysis with sodium hydroxide.

II. EXPERIMENT

A. Materials

The rice sample used in this study was commercial rice pack which was produced from Niigata Prefecture, Japan. Before the experiment, the pack was heated, and then cools to room temperature for use. Industrial and elemental analysis of the rice sample is shown in Table I, which was analyzed using JIS M 8812.

TABLE I: PROPERTIES OF RICE SAMPLE

	Content
Proximate (wt. % . d.b.)	
Ash	0.1
V. M.	36.7
Moisture	53.9
F. C.	9.3
Ultimate (wt. % . d.a.f.)	
Hydrogen	5.0
Carbon	23.0
Nitrogen	0.6

V.M. : Volatile Matter, F.C. : Fixed Carbon,
d.b. : dry base , d.a.f. : dry ash free basis

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Masami Nakayasu and Takaaki Wajima are with Department of Urban Environment Systems, Graduate School of Engineering, Chiba University, Japan (e-mail: mamihimu@gmail.com).

Granular sodium hydroxide was purchased from Hayashi Pure Chemical Industries Co., Ltd, Special grade reagent, Japan.

B. Experimental Apparatus and Procedures

The experimental apparatus used in this study is presented in Fig. 1. A mixed sample of rice (20 g) and sodium hydroxide (0 - 20 g) was placed in the reactor, and nitrogen gas was injected into the reactor for 60 min at 50 mL/min to remove oxygen from the reactor. After nitrogen substitution, the nitrogen gas was stopped, and the reactor was heated to the setting temperature, 600 °C or 700 °C, at heating rate of 10 °C/min using the tubular furnace. After heating for 60 min or 70 min, the reactor was cooled to room temperature. The residue after pyrolysis was washed with distilled water, filtrated and dried in a drying oven overnight to obtain the product. The weight of the product was measured to calculate reduction ratio to raw rice. The non-condensable gases produced during pyrolysis were recovered in a gas pack after passing through an aqueous alkaline solution. The total amount of the generated gases collected in the gas pack was assumed to be generated by the pyrolysis.

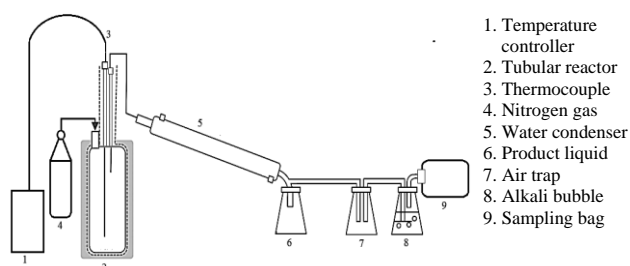


Fig. 1. Experimental apparatus.

C. Analysis

The generated gas was qualitatively and quantitatively analyzed using gas chromatography (Shimadzu, GC 2014). The morphologies of the product surface before and after pyrolysis was observed by a scanning electron microscope (Joel Ltd, SM-6510LA), and chemical analysis of the product surface with an energy dispersive X-rays analyzer (BRUKER, Quntax70) that attached to a tabletop electron microscope (Hitachi High Technologies Co., Miniscope, TM3000). The specific surface area of the product was measured using a Macsorb HM model-1210, Manufactured by MOUNTECH Co., Ltd..

III. RESULTS AND DISCUSSION

Table II and III show the gas generation amount and composition from the gas generated in the experiment at 600 °C and 700 °C, respectively.

Fig. 2 shows the amount of total volume for generated gas by pyrolysis. In comparison with rice without sodium hydroxide, the amount of total gas generated increased approximately 4 fold at 600 °C, 15 fold at 700 °C when an equal mass of sodium hydroxide was added.

Fig. 3 shows the amount of hydrogen gas generated by pyrolysis. Almost the same amount of hydrogen gas is

generated at 600 °C and 700 °C. When an equal mass of sodium hydroxide was added, the amount of hydrogen gas generated increased about 42 fold at 600 °C, and 115 fold at 700 °C as compared with the case of only rice.

TABLE II: GENERATED GASES DURING PYROLYSIS OF RICE AT 600 °C WITH SODIUM HYDROXIDE

Amount of sodium hydroxide addition (g)	0	2	5	10	20
The total amount of gas generated (mL)	293	2097	2381	2746	4614
H ₂ (wt. %)	7	20	46	62	72
CH ₄ (wt. %)	3	3	4	5	6
CO (wt. %)	10	16	11	5	3
CO ₂ (wt. %)	15	14	6	1	0
other (wt. %)	65	47	33	27	19

TABLE III: GENERATED GASES DURING PYROLYSIS OF RICE AT 700 °C WITH SODIUM HYDROXIDE

Amount of sodium hydroxide addition (g)	0	2	5	10	20
The total amount of gas generated (mL)	978	1550	2348	3362	4387
H ₂ (wt. %)	7	23	45	71	72
CH ₄ (wt. %)	5	9	8	9	19
CO (wt. %)	11	23	13	6	2
CO ₂ (wt. %)	12	23	10	0	0
other (wt. %)	65	22	24	14	7

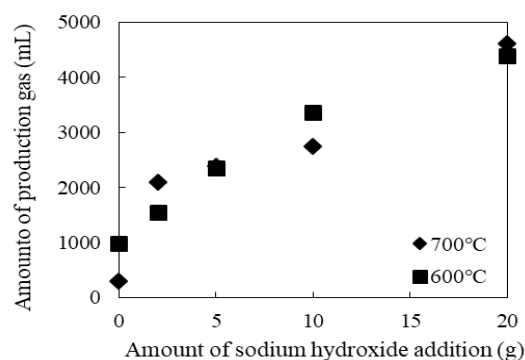


Fig. 2. Total volume of generated gas.

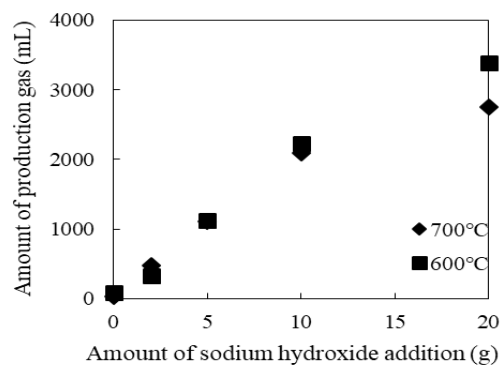


Fig. 3. Volume of H₂ in generated gas.

Fig. 4 shows the amount of methane gas generated by the pyrolysis. Increase for the addition of sodium hydroxide increased the amount of methane gas generated by the pyrolysis of rice. With increasing sodium hydroxide, the amount of methane gradually increases, and methane generated at 700 °C is higher than that at 600 °C. The amount of methane gas generated approximately 8 fold at 600 °C and 27 fold at 700 °C when an equal mass of sodium hydroxide was added.

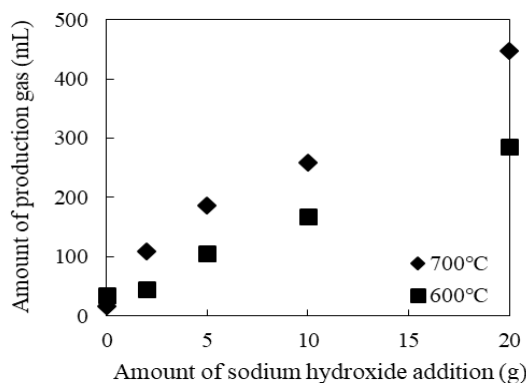


Fig. 4. Volume of CH₄ in generated gas.

Fig. 5 and 6 show the amount of carbon monoxide and carbon dioxide in the generated gas. Addition of sodium hydroxide affected the production of carbon monoxide and carbon dioxide. When the amount of sodium hydroxide increases, the amounts of carbon monoxide and carbon dioxide gradually decrease.

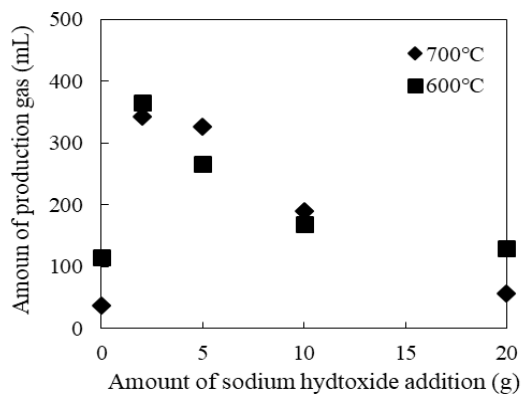


Fig. 5. Volume of CO in generated gas.

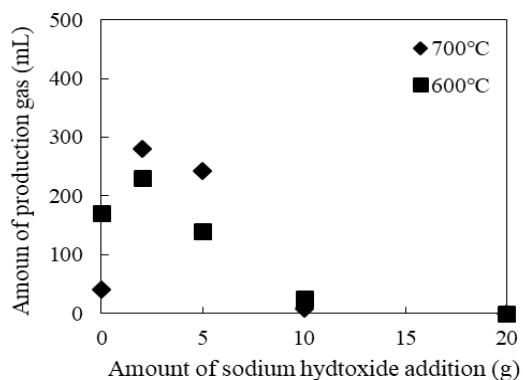


Fig. 6. Volume of CO₂ in generated gas.

Fig. 7 and Fig. 8 shown the yield of the gas generated from rice with addition of sodium hydroxide at 600 °C and 700 °C,

respectively. When sodium hydroxide was not added, the gas composition was the same at 600 °C and 700 °C, but as the added amount was increased, the composition ratio of carbon monoxide and carbon dioxide decrease and those of hydrogen and methane gas increased. The composition ratio of combustible gas composed of hydrogen and methane gas showed higher composition ratio at 700 °C than at 600 °C.

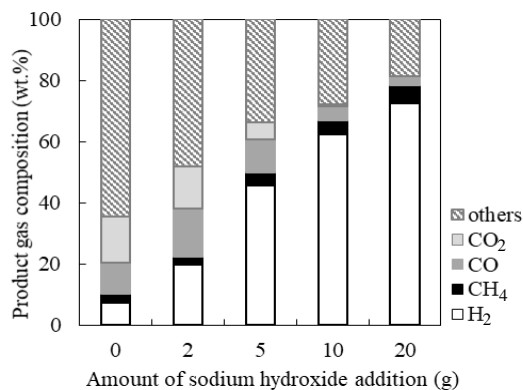


Fig. 7. The production rate of gas generated at 600 °C.

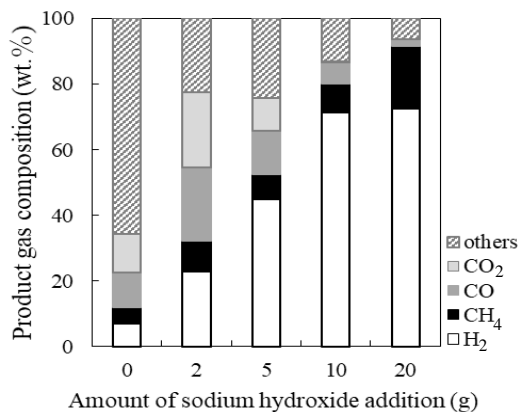


Fig. 8. The production rate of gas generated at 700 °C.

Fig. 9 shows the mass of residue after thermal decomposition without and with sodium hydroxide in 700 °C. The residue obtained after pyrolysis decreased to 99 wt % carbon.

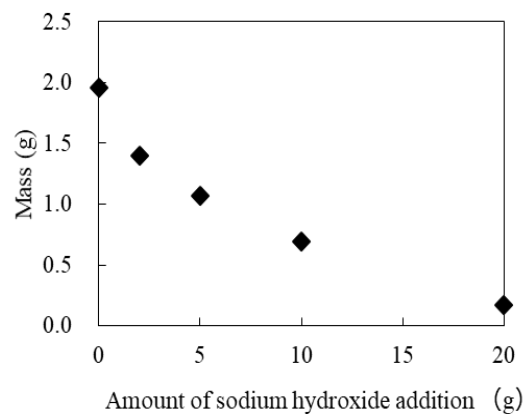


Fig. 9. Mass of residue after pyrolysis.

Fig. 10 shows the carbon content of residues without and with sodium hydroxide in 700 °C. This residue mainly consists of carbon (approximately 80%), regardless of sodium hydroxide addition.

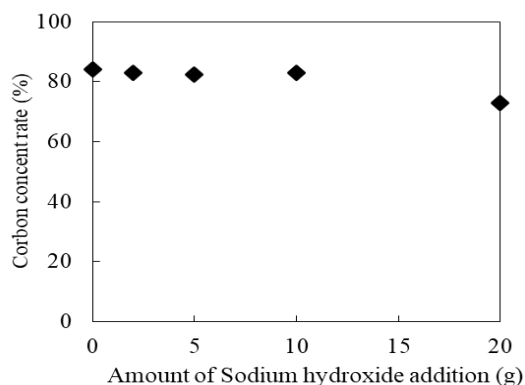


Fig. 10. Carbon content of residues.

Fig. 11 shows the scanning electronic microscope images of residues without (a) and with (b) equivalent amount addition of sodium hydroxide. The residue with addition of sodium hydroxide had a porous structure while that without sodium hydroxide indicates no porous structure.

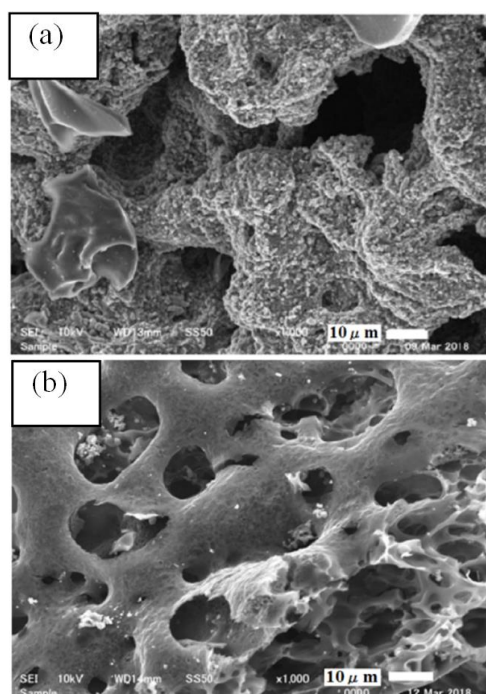


Fig. 11. Residues (a) with out and (b) with addition of sodium hydroxide.

Table IV shows specific surface area of residue without and with addition sodium hydroxide in comparison with commercially available activated carbons (Junsei Chemical Co., Ltd., Activated carbon). As the amount of sodium hydroxide is increased, the specific area increased from $72 \text{ m}^2 / \text{g}$ to $901 \text{ m}^2 / \text{g}$, which was almost same as specific surface area of the activated carbon ($966 \text{ m}^2 / \text{g}$).

TABLE IV: SPECIFIC SURFACE AREA OF RESIDUES

Amount of sodium hydroxide addition (g)	0	2	20	commercially available activated carbon
Specific surface area (m^2/g)	72	245	901	966

IV. CONCLUSION

In this study, rice, one of the main contents in general

waste, was converted into flammable gas and carbonaceous adsorbent by pyrolysis with sodium hydroxide. Raw rice can be converted into flammable gas, mainly including hydrogen, methane, carbon monoxides and carbon dioxide gases. With increasing the addition of sodium hydroxide or heating temperature, the flammable gas including higher content of hydrogen and methane can be obtained. The weight of the residue after pyrolysis with equivalent amount addition of sodium hydroxide at 700°C is 1 % of raw rice sample, and the residue had a porous structure with high specific surface area, which is equivalent to commercially available activated carbon.

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Masami Nakayasu was born on May 6, 1976 in Ibaraki Prefecture, Japan. She studied chemical and environmental engineering at Chuo University Faculty of Science and Technology and graduated in 1999. She is now studying at the Department of Urban Environment System at Chiba University, Japan.