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EFFECT OF ELECTRON INJECTED AIR ON THE THERMAL DECOMPOSITION OF SOLID WASTES (PART 1: EXPERIMENTAL INVESTIGATION)

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ABSTRACT

In this research, thermal decomposition characteristics of cellulose with electron injected air were investigated in a laboratory scale reactor based on the principle of the groundbreaking organic substance reduction device ERCM (Earth-Resource-Ceramic-Machine), which was developed by a Japanese venture company. A 12 V voltage electron generator as the key part, was adopted to inject electrons into the air for accelerating the thermal decomposition of carbonaceous materials during the ERCM process.

A modified fixed bed reactor was adopted to investigate the effects of different parameters including the on/off of electron injection into the air and the thermal decomposition temperatures (350-500^{O}C) on the decomposition degree (volume reduction rate) and the syngas generation of pure cellulose.

It was found that the thermal decomposition reaction was more accelerated with the electron-ON case than that with the electron-OFF case. In addition, it was shown that the volume reduction rate of cellulose in the electron-ON case was higher by 4.4% to 18.3% than that in the electron-OFF case.

These results suggest that electron injected air may accelerate the thermal decomposition of solid wastes.

Keywords: thermal decomposition, solid waste, cellulose, electron injected air

1. INTRODUCTION

In recent years, the issue of solid waste has expanded all over the world. How to deal with these solid wastes in an efficient and environmentally friendly way has been getting more and more attention in both developed and developing countries. More efficient waste disposal and recycling technologies are urgently needed worldwide.

There are several studies on the electric field-induced in the flame for combustion control [1, 2]. Experimental investigations of the DC electric field effect on the flame formation and combustion of volatiles have shown that flame species in the zone direction allows controlling the process of products' recirculation, with direct impact on the combustion characteristics [2]. If an electric field is applied to the pyrolysis zone of biomass, it results in processes related to biomass dipole polarization [3], causing different effects, such as constant-current electro-osmotic dewatering [4], dielectric RF biomass heating [8], and adhesion forces improvement. The organic substance reduction device ERCM (Earth-Resource-Ceramic-Machine) developed by a Japanese venture company is a very revolutionary volume reduction device. ERCM mainly has the following features:

1: Running cost is very low because there is no need for auxiliary fuels.

2: The solid residue is a powdery inorganic substance, and its carbon content is less than 1%. The organic compositions were decomposed to a great extent. The volume reduction rate of ERCM system can be more than 10 times than that of conventional incineration facilities.

3: There are almost no pollutant emissions such as dioxins, NOx, hydrogen chloride and dust during the ERCM process.

A major principle of the ERCM process is that the electron injected air is supplied from the bottom and walls of the reactor, and this type of electron injected air can accelerate the decomposition degree of solid waste.

So far, quantitative data have not yet been well obtained for the ERCM system. Therefore, the mechanism of how the electron injected air works during the ERCM process is still unknown. Here, fundamental researches were carried out to investigate the effects of electron injected air on the thermal decomposition of cellulose.

2. LAB-SCALE EXPERIMENTAL FACILITY AND PROCEDURE

2.1 Lab-scale experimental facility

In this research, the main purpose is to investigate how electron injected air affects the thermal decomposition of solid wastes. A lab-scale experimental facility was set up according to the principle of the ERCM process as shown in Fig.1. The scheme of this experimental device is described below:

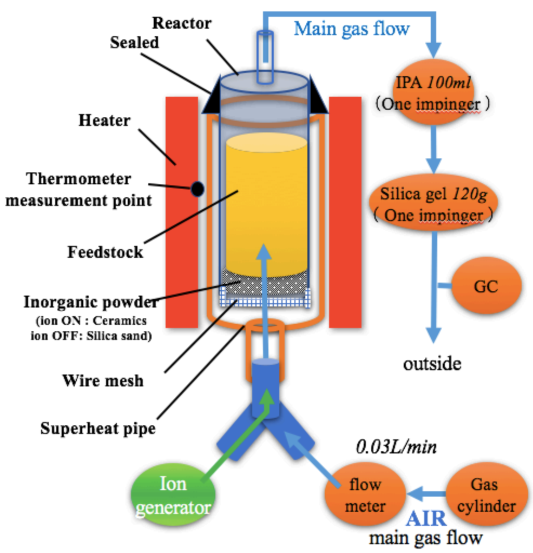


Fig 1. Experimental setup

The electrical heater was installed surrounding the outer metal pipe. Another inner reactor pipe with the cellulose samples was inserted in the outer metal pipe for experiments. A metal mesh was fixed to the lower end of the inner metal pipe with aluminum tape for holding the samples. A Y-shaped branch pipe was set at the bottom of the inner pipe, and one branch was used for air injection, and another was used for injecting electrons into air.

The electron generator manufactured by Andes Electric Co. was adopted in this research. For the commercial plant, the same electron generators are used. The photo of the electron generator is shown in Fig. 2; whose electrical consumption is only 0.4W. It is noted that the terminal of the electron generator was inserted into the intersection of the Y-shaped branch so that electrons could be carried by the air flow. Thereby, electron injected air can be supplied from the lower end of the inner pipe. After the reaction, the syngas came out from the upper part of the inner pipe and then went through IPA solution (100 mL) and silica gel (120 g) for capturing tar and moisture in the syngas. Finally, the syngas was continuously analyzed using a micro-GC with an interval of 110 seconds.

Fig 2. The electron generator for electron injection into the air

2.2 Electron injected air

As described above, experiments were conducted under the conditions of air with electron injection on or off cases. Hereinafter, these conditions are called "electron-OFF" (in the case of air only) and "electron-ON" (in the case of air + electron).

The air flow rate was determined according to the parameters from the pilot-scale ERCM operation conditions, and it was 0.03L/min. In the experimental system of this study, only one electron generator was installed. The electron injected amount is calculated from the standard specifications of the ERCM reactor, and the number of electrons (0.5 million) for 1cc of air can be obtained sufficiently by installing one electron generator for the size of the reactor of this research.

2.3 Feedstock

Firstly, 0.7g of the inorganic residue obtained from an ERCM reactor (in the case of electron-ON) or silica sand (in the case of electron-OFF) was stalled at the bottom of the inner reactor pipe as the supporter of the sample.

Secondly, 7.5g of pure cellulose was supplied into the inner metal pipe, and then the inner metal pipe was well sealed, as shown in Fig. 3. The thickness of each zone was determined according to the depth of the pipe as follows. The thickness of the inorganic powder is about 5mm-10mm (about 0.7 g). The thickness of the feedstock is about 150mm (about 7.5 g). The inorganic residue used for the case of electron-ON was the solid residue discharged from the pilot-scale ERCM facility, and it is known that this residue has a property of emitting electrons. Furthermore, it is also known that heating of this residue emits more electrons [5].

The feedstock cellulose was powder-like solid with an average particle size of 38μm, which was purchased from FUJIFILM Wako Pure Chemical Corporation.

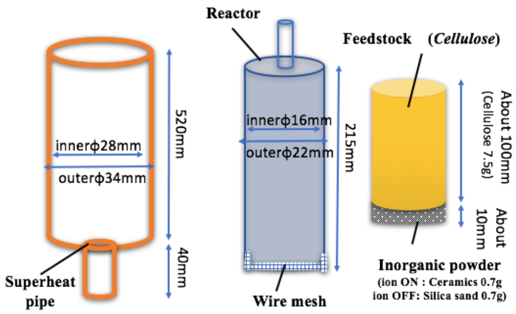


Fig 3. The structure of the heating pipe and inner pipe

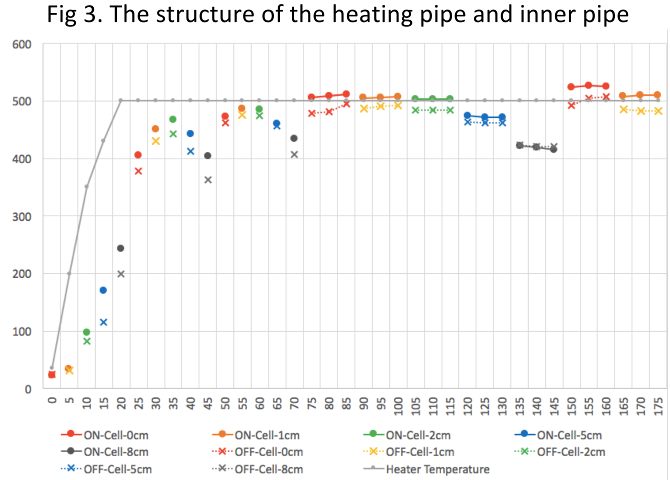


Fig.4 Reactor temperature change

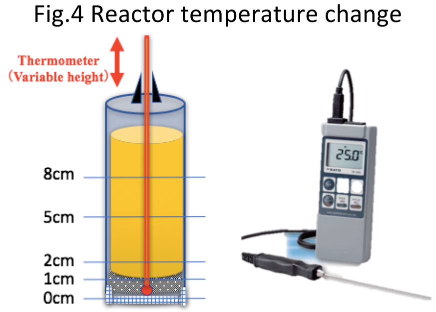


Fig.5 Temperature measurement positions and equipment

2.4 Heater temperature and experimental time

Since cellulose is used as a feedstock, experiments were conducted at four temperatures (350°C, 400°C, 450°C and 500°C). Moreover, the total running time of 220 min for one batch was chosen to evaluate the effects of electron injected air on the decomposition degree of cellulose. Fig.4 shows the time change of the temperature of the external heater and the temperature of the feedstock in the reactor.

This figure shows the temperatures in the reactor for both electron on/off cases. The actual temperature of the feedstock was measured at five heights (0, 1, 2, 5, 8 cm from the bottom of the reactor) by inserting a long thermocouple (SK-S102K(0-800 ℃ ,ϕ4.8mm,L500mm)) from the top of the reactor, as shown in Fig.5. We can see that the feedstock temperature was little bit higher in the electron ON case than in the electron OFF case.

3 RESULTS AND DISCUSSION

Figs.6 (a)-(d) show the time change of the concentrations of the main gas compositions (H_2, CO, CO_2, CH_4) in the syngas measured by the micro GC when the heater temperature reached to the target temperature.

H_2, CO and CH_4 were significantly released at the beginning stage of the reaction. However, CO_2 gradually increased to some extent from the middle stage of the reaction. From these results, it can be concluded that the pyrolysis reaction occurred mainly at the beginning stage, and the combustion reaction occurred after the middle stage. From the release behavior of H_2 and CH_4, we can say that the electron injection may not affect the pyrolysis process significantly. Moreover, from the release behavior of CO and CO_2, it is noted that the electron injection would affect the char combustion process significantly.

In addition, it is considered that the slight ON / OFF difference seen from the hydrogen concentration etc. is due to the higher feedstock temperature resulted from the acceleration of the combustion by injecting electrons. Table 1 shows the results for the solid residue in the reactor after 220 minutes at each reaction temperature. Furthermore, the results of electron-ON/OFF cases at the same temperature are compared. It can be seen that the weight reduction ratio is higher in the case of the electron-ON at any temperature. The difference in the weight reduction ratio between electron-ON and OFF cases can reach 4.4-18.3%.

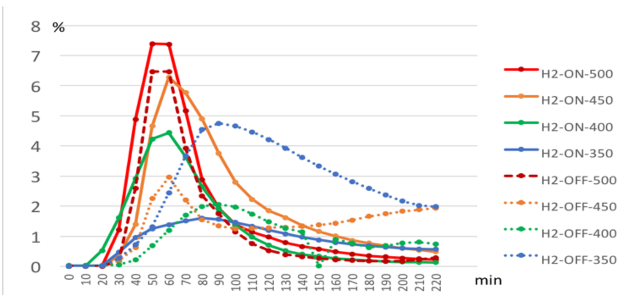
These results suggest that the number of electrons injected into the air may be a new parameter of the reaction rate formula (Arrhenius formula) for char combustion by including this parameter into the activation energy.

4 SUMMARY AND FUTURE DEVELOPMENT

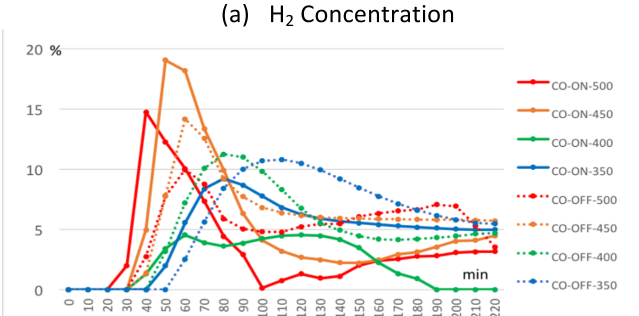
In this study, in order to investigate the principle of ERCM, we conducted lab-scale experiments to investigate the effects of electron injected air on the thermal decomposition of cellulose.

Table 1 Summary of the results of the residue

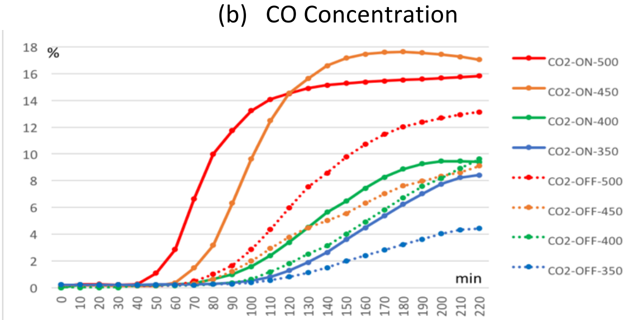
Temperature (℃)	Electron	Residue	Reduction rate(%)	ON / OFF difference	
		After (g)		OFF - ON= (g)	Rate (%)
500	ON	3.80	46.3	+0.36	+4.4
	OFF	4.16	50.7		
450	ON	4.58	55.9	+0.97	+11.8
	OFF	5.55	67.7		
400	ON	4.55	55.5	+1.5	+18.3
	OFF	6.05	73.8		
350	ON	5.10	62.2	+0.5	+6.1
	OFF	5.60	68.3		



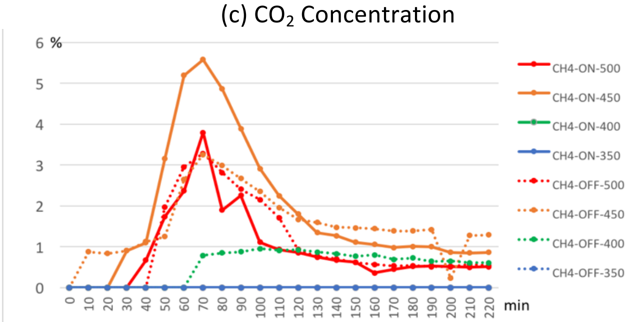
(a) H_2 Concentration



(b) CO Concentration



(c) CO_2 Concentration



(d) CH_4 Concentration

Fig.6 Experimental results for different temperatures with electron ON/OFF.

The experiment was divided into the case of adding electrons to the air entering the reactor and the case of not adding electrons, and the gas concentrations and the weight reduction rate were measured. In addition, the effect of the temperature in the reactor was investigated at 350°C, 400°C, 450°C and 500°C.

As a result, it can be seen that the electron injected air reacts more actively at almost any temperature than normal air. From the behavior of H_2 and CH_4, we can say that the electron injection does not affect the pyrolysis process significantly. From the behavior of CO and CO_2, we can say that the electron injection affects the char combustion process significantly.

In addition, it was found that the weight reduction rate of the electron-ON case was higher by 4.4% to 18.3% than that of the electron-OFF case. These results suggest that the number of electrons in the air may become a new parameter of the reaction rate formula (Arrhenius formula) for char combustion.

In the future, we would like to repeat the experiment under the same conditions to confirm the reproducibility and show the results of increasing the number of data. Also, we would like to look at the reproducibility by replacing the feedstock from cellulose to other material such as plastic, and investigate whether electrons mainly contribute to the combustion reaction as in the cellulose experiment. Then, we are planning to increase the size of the reactor from lab-scale to $1m^3$ and $20m^3$ to investigate the effect of the reactor scale.

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