Application of Radio-frequency Thermal Plasmas to Treatment of Fly Ash

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ABSTRACT: RF thermal plasma systems for treatment of fly ash have been proposed in order to recover the useful metals and materials from fly ash discharged from melting furnace. The fundamental investigation for recovering the detoxified and useful materials from fly ash by means of RF thermal plasma process is performed. The possibility of separation of heavy metal components is discussed and verified in terms of the numerical analysis and the experimental results.

I. INTRODUCTION

Radio-frequency (RF) induction thermal plasmas have many advantages, such as, clean ambiance due to electrode-less in reaction region, high selectivity of reactive gases, easy generation of high temperature and high chemical reactivity, compact and simple design of apparatus, and so on. For these reasons, RF thermal plasmas are developed in a number of industrial applications, such as synthesis of ultrafine powders, plasma spraying, chemical vapor deposition and destruction of hazardous and waste materials. Especially, for the latter application, for example, the treatments of freon[1],[2], and fly ash[3] have been widely noticed.

In the previous papers [4],[5], we have pointed out that the choice of induction frequency is important in determining the optimum diameter of plasma torch to generate larger and more stable RF plasmas at atmospheric pressure for the above-mentioned applications.

Incineration of municipal waste discharges bottom ash and fly ash. Treatment of fly ash by melting furnace has been adopted to reduce its volume and to prevent contamination by heavy metals contained in the ash.

Treatment of fly ash from melting furnace, the secondary emission from melting process, is an urgent matter because of the hazard of the heavy metals condensed highly in fly ash from melting furnace. RF thermal plasma systems for treatment of fly ash from melting furnace have been proposed in order to recover the useful metals and materials[3].

In this work, the fundamental investigations for the behavior of fly ash during RF thermal plasma process and for condensation mechanism of the components generated from thermal plasma are performed in terms of the numerical analysis and the experimental results. And the possibility of recovery from fly ash of the useful materials free from heavy metal compounds is discussed.

II. EXPERIMENTAL SET-UP

The configuration of the basic installation is shown in Fig.1. The experimental installation consists of an RF plasma torch with an RF generator, a powder feeder for fly ash, a plasma gas supply, a thermostatic oven and a bag filler. The RF plasma torch composed of the quartz tube and the induction coil has an injection tube along the center axis for feeding fly ash into thermal plasma region and is operated with 50kW plate power and at the oscillation frequency of 2MHz. The flow rates of the sheath Ar gas and the carrier Ar gas are 20 and 10 liters/min, respectively. H_2 gas is added for the sheath gas to investigate the effect for separation of heavy metal components. The flow rate of additional H_2 gas is 3 liters/min.

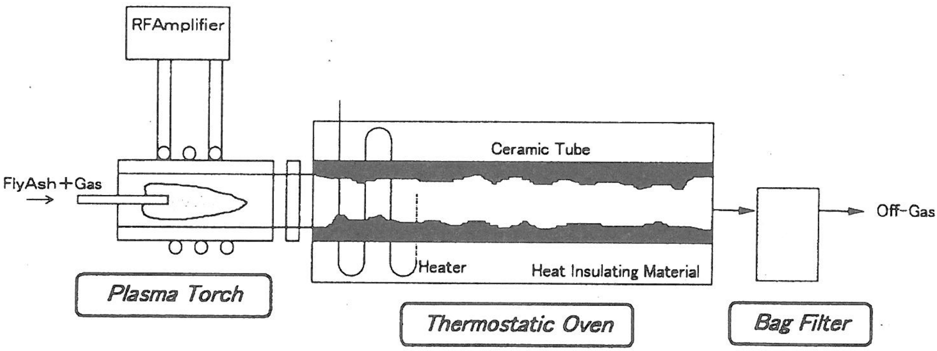


Fig.1 Schematic of the experimental installation

The fly ash which has the maximum particle size distribution at 10 micron and contains 3.1 wt.% of zinc and 1.6 wt.% of lead as heavy metals was supplied into the plasma at the feed rate of 5g/min with the carrier Ar gas.

In order to identify the kinds of atomic, molecular and ionic species included in the RF plasma region, emission spectra from the plasma region are observed by using an optical fiber and a spectrometer with a multi-channel-plate (MCP) detector.

The thermostatic oven is connected with the plasma torch directly and has the isothermal region of 500mm length and the diameter of 80mm. The operating temperature of the oven can be controlled with any temperature region up to 1600℃ in order to examine the difference of the compositions of materials captured inside the oven controlled at several temperatures.

Ⅲ. RESULTS AND DISCUSSIONS

1.Behavior of Fly Ash in Thermal Plasma

The compositions of fly ash are given in Table 1. The compositions in thermodynamic equilibrium state from 100 to 5000℃ are calculated under

CaO	48wt%
Al_2O_3	2wt%
SiO_2	2wt%
NaCl	17wt%
KCl	14wt%
ZnO	4wt%
PbO	2wt%
Others	11wt%

Table 1 Compositions of fly ash

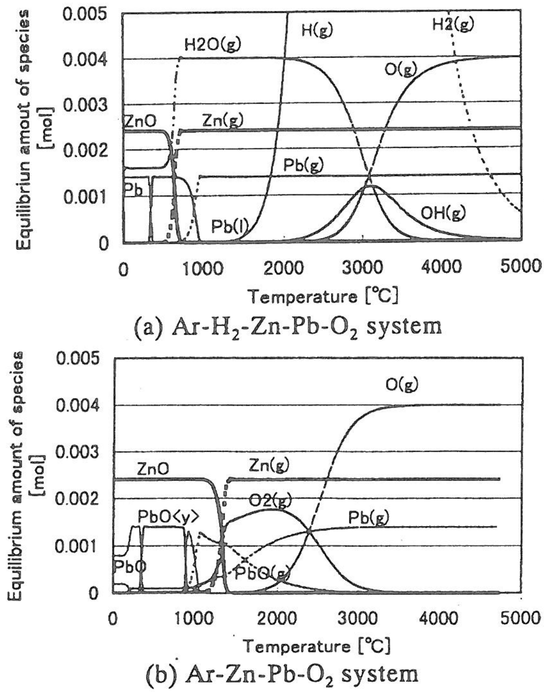


Fig.2 Equilibrium compositions

atmospheric pressure. Figure2(a) is one example of the calculated results of Ar-H_2-Zn-Pb-O_2 system, and Fig.2(b) is another result of Ar-Zn-Pb-O_2 system. In both cases of with H_2 and without H_2, zinc and lead compounds are completely decomposed into zinc gas and lead gas, respectively, over 2500℃ region.

The observed emission lines from the plasma region during injection of fly ash into the plasma are assigned as variable metal atoms and ions, such as zinc, lead, calcium, sodium and so on. This result means that the thermal plasma reduces the fly ash to the variable metal atoms and ions.

These results suggest that the metallic compounds are possibly decomposed into atoms in the high temperature region of the thermal plasma.

2. Separation of Heavy Metal Species after Thermal Plasma Treatment

The condensation rates of the components generated from thermal plasma process have to be controlled in order to separate heavy metals and other species. In Fig.3, the temperature dependence of the super-saturation ratio S is indicated, for each component whose existence is predicted after thermal plasma treatment. In this case, the super-saturation ratio S is defined by the ratio of vapor pressure to saturated vapor pressure of each component, neglecting of the influence of other species and reduction of vapor pressure by nucleation. As the nucleation is accelerated abruptly at $S>1$, it is possible that CaO and Al_2O_3 condense at higher temperature region over 2000℃ and

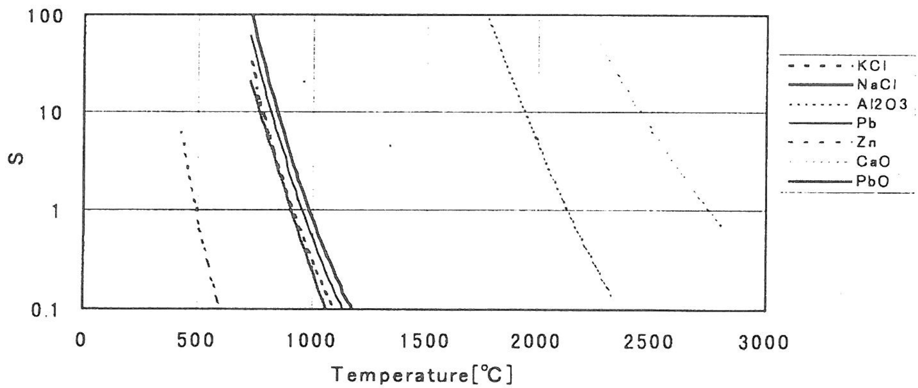
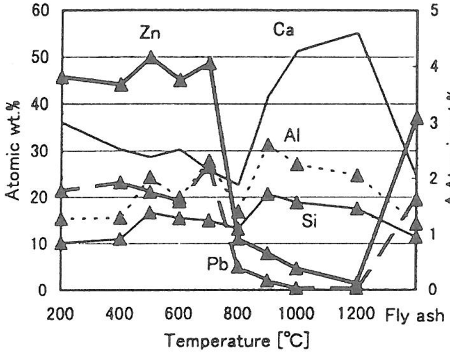


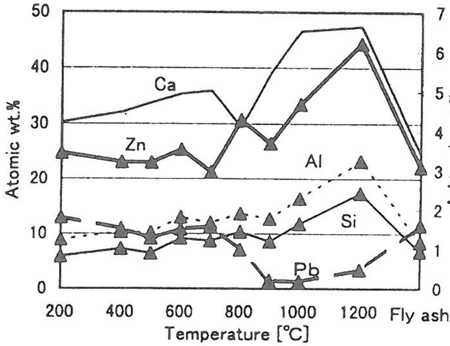
Fig.3 Temperature dependence of the super-saturation ratio S of each component

Zn, PbO, Pb, NaCl and KCl condense at lower temperature region below 1000℃.

The experimental results to examine the difference of the compositions of materials captured inside the thermostatic oven controlled at several temperature conditions are shown in Figs.4(a),(b). The results of after Ar/ H_2 plasma treatment and after Ar plasma are given in Fig. 4(a) and (b), respectively.



(a) After Ar/ H_2 plasma treatment



(b) After Ar plasma treatment

Fig.4 The compositions of materials captured inside the thermostatic oven

After Ar/H_2 plasma treatment, the fractions of the elements of Zn, Pb included in the recovered materials in the thermostatic oven increase under the temperature condition of below 800℃. The materials recovered at higher temperature include extremely less heavy metal components. On the other hand, in the case of Ar plasma, the temperature has a very weak influence to the fraction of Zn under this operating condition. The materials recovered at any temperature regions include the same or more fraction of Zn.

Thermodynamic equilibrium calculations in Fig.2 (a) and (b) can explain this difference of Zn fractions between with H_2 and without H_2. In Fig.2(a), solid state of ZnO appears near 700℃ in the case of existence of H_2. Meanwhile, without H_2, gas phase of Zn changes into solid state of ZnO at higher temperature near 1300℃. Namely, it is obvious that the existence of H_2 influences the condensation temperature of ZnO.

The recovered materials in the oven with higher temperature over 1000℃ include less heavy metal components than in initial fly ash, due to Ar/H_2 plasma treatment. It means that the materials recovered at higher temperature region are detoxfied due to drastic decrease of heavy metal components.

IV. CONCLUSIONS

The fundamental investigation for recovering the detoxified and useful materials from fly ash by means of RF thermal plasma process is performed.

(1) Fly ash fed into the RF thermal plasma is vaporized and decomposed during RF thermal plasma process.

(2) After thermal plasma treatment of fly ash, it is possible that the components are recovered separately owing to the difference of each condensation temperature.

(3) The existence of H_2 strongly influences the difference of each condensation temperature, especially Zn compounds.

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