In-Flight Melting for Waste Treatment by Multi-Phase AC Arc

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Abstract: A new type of furnace with large-volume and high-temperature arc generated by twelve-phase alternative current power supply has been developed to apply to in-flight melting of waste materials. The most important advantage of the furnace is the simple configuration, therefore it can be realized with a low cost for hazardous and waste material destruction.

Keywords: Multi-phase AC arc, Thermal plasma, Waste treatment, In-flight melting

1. Introduction

A number of processing of thermal plasmas has been applied for welding and cutting of metals. Thermal plasmas as high-temperature source with high energy -efficiency has been also tried to open new technological fields for better global environment with related new industrial markets, including hazardous and waste treatments as well as material processing.

In general, the power source for arc generation is accomplished by a direct current (DC) power supply. For inverting from AC to DC, higher cost is expected for larger capacity power source. Besides, a single-phase and a three-phase AC power supply as the alternative power sources have been proposed for arc generation [1, 2]. Arc generation systems by an AC power supply with high power have not been fully developed, since these systems have inherent characteristics of intermittent discharge.

In order to improve this defect, a multiple-phase AC power supply has been developed. To obtain a more effective arc generation by expanding this concept, we have developed a twelve-phase AC power supply [3]. The most important advantage of this system is that there are large number of discharging paths among the electrodes in comparison with the case of the single-phase and the three-phase systems. Therefore, some of the plasma paths always exist among the electrodes for the continuing smooth discharge. It seems as if this system was driven by the DC power supply instead of actual commercial AC power supply (60 Hz) [4].

Attractive thermal plasma processing have been proposed especially for waste treatments, because thermal plasmas offer distinctive advantages; these advantages include high enthalpy to enhance reaction kinetics; high chemical reactivity; oxidation and reduction atmospheres in accordance with required chemical reactions; and rapid quenching to suppress by-products formation. Moreover, engineering advantages such as smaller reactor, lower capital cost, portability allowing on-site destruction, rapid star-up and shutdown offer efficient destruction of hazardous and waste materials.

In this paper, application for melting and destruction of waste materials by a twelve-phase AC arc is discussed. A new type of the plasma furnace with a twelve-phase AC discharge has been developed to generate stable and continuous arc by the transformers for converting from three-phase AC to twelve-phase AC [5].

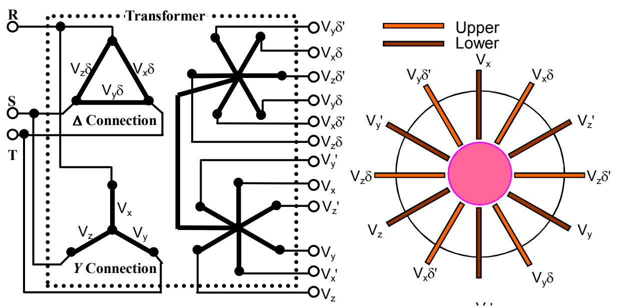


Fig. 1 Electrical circuit diagram and connection diagram of twelve-phase AC arc furnace.

2. Development of twelve-phase AC power supply

Fig. 1 shows the circuit diagram of the transformer for converting from three-phase AC to twelve-phase AC. The input of the three-phase power supply is connected to 200 V commercial power lines. The primary coils of transformers are divided into two parts: one is a Y connection, and the other is a Δ connection. The twelve-phase system can be realized by the combination of these circuits, then, each line is directly connected to the corresponding electrodes, as shown in Ref. [6].

From Y connection, the voltage components V_x, V_y, V_z, V'_x, V'_y, and V'_z of the 6-phase AC are defined by the following equations:

$$V_i = V_m \sin\left(\omega t - \frac{n}{3}\pi\right), \; (i = x,\ y,\ z;\ \mathrm{n} = 0,\ 2,\ 4) \quad (1)$$

$$V'_i = V_m \sin\left(\omega t - \frac{n}{3}\pi\right), \; (i = x,\ y,\ z;\ \mathrm{n} = 3,\ 5,\ 7) \quad (2)$$

where V_m and ω are the maximum value of the sinusoidal wave and the angular velocity, respectively. Here, $\omega = 2\pi f$, f is the frequency of AC (60 Hz).

From Δ connection, the voltage components $V_x\delta$, $V_y\delta$, $V_z\delta$, $V_x\delta'$, $V_y\delta'$, and $V_z\delta'$ of the 6-phase AC are defined as follows:

$$V_i\delta = V_m \sin\left(\omega t - \frac{n}{6}\pi\right), (i = x, y, z;\ n = 1, 3, 5) \quad (3)$$

$$V_i\delta' = V_m \sin\left(\omega t - \frac{n}{6}\pi\right), (i = x, y, z;\ n = 7, 9, 11) \quad (4)$$

To realize the power supply for the generation of a twelve-phase AC arc discharge, twelve pieces of single-phase AC arc welding transformer (DAIHEN B-250) were used as shown in **Fig. 2**. These welders are the conventional ones and have a dropping characteristic. The input voltage, the maximum non-loading output voltage, the typical loading voltage, the power, and the range of output currents are 200 V, 80 V, 32.5 V, 12.4 kW, and from 75 A to 250 A, respectively.

Fig. 2 Setup of the twelve-phase AC power supply.

Fig. 3 displays the generated twelve-phase AC arc discharge inside of the furnace without the feeding of samples. The input power was 66 kW, voltage 200 V, and current 380 A. The discharge voltage and current of each electrode were 20-23 V and 80-150 A, respectively. The diameter of the arc was about 100 mm. The voltage and current waveforms of the single-phase AC arc discharge and the twelve-phase ones are shown in **Figs. 4** and **5**, respectively. The voltage wave form shown in Fig. 4 has steep spike-edges which mean the halts of discharge when the current value is zero. Furthermore, the single-phase AC arc generates much more noise due to its spike-edges. It is obvious that the twelve-phase arc discharge is more stable and has less noise than that of single-phase one.

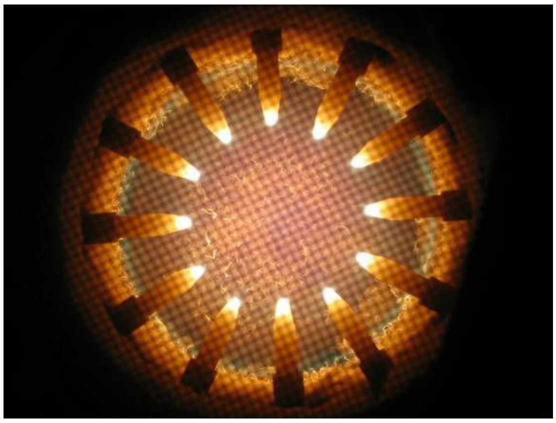


Fig. 3 Photograph of twelve-phase AC arc discharge, ND8 filter×3, diameter of arc is about 100 mm.

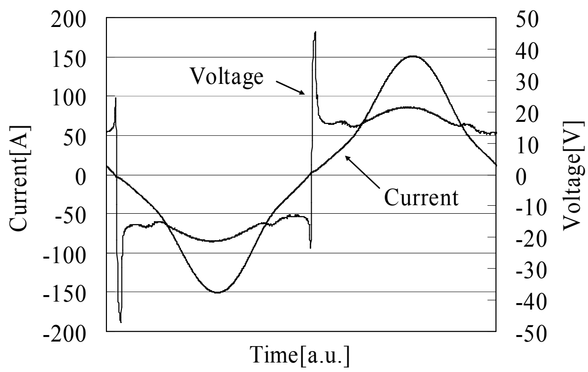


Fig. 4 Voltage and current waveforms in case of single-phase AC.

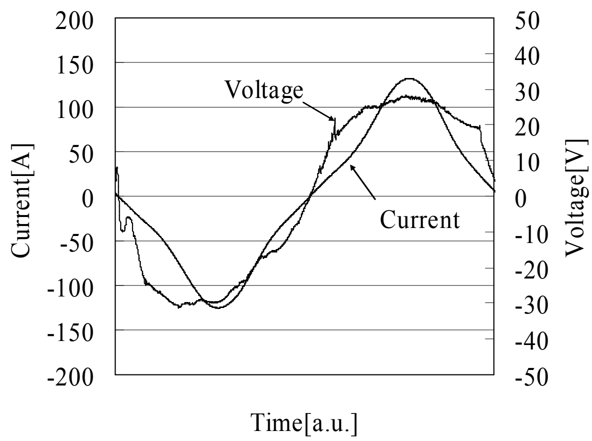


Fig. 5 Voltage and current waveforms in case of twelve-phase AC.

3. Experimental

The schematic diagram of the experimental setup is shown in **Fig. 6**. It consists of 12 electrodes, a reaction chamber, s sample feeder, an exhaust gas treatment, and an AC power supply. The 12 electrodes were symmetrically arranged by the angle of 30 deg and were divided into two layers, upper 6 electrodes and lower 6 electrodes. The distance between the two layers of the electrodes was 250 mm. The electrode in diameter of 12 mm was made of graphite. The inner part of the furnace was constructed by a cylindrical graphite of 400 mm in diameter, 1000 mm in height. Outside of the furnace was covered with refractory bricks. The height of the furnace was approximately 1800 mm. The powder feeder with electric vibration was mounted on the top of the furnace, and the outlet of the melted materials is placed at the bottom of the furnace. The waste materials treated by the twelve-phase arc were quenched on a stainless pan at a distance of 500 mm below the lower electrodes.

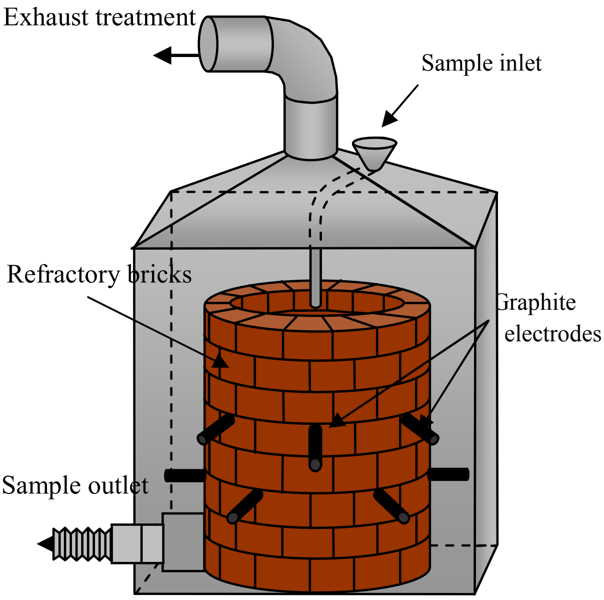
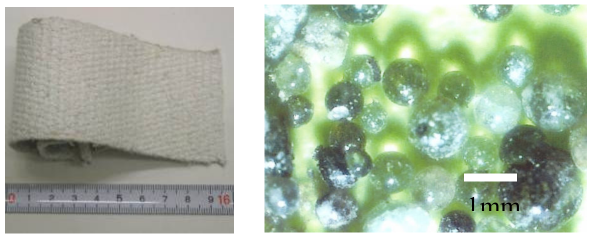


Fig. 6 Schematic diagram of twelve-phase AC arc for waste destruction.

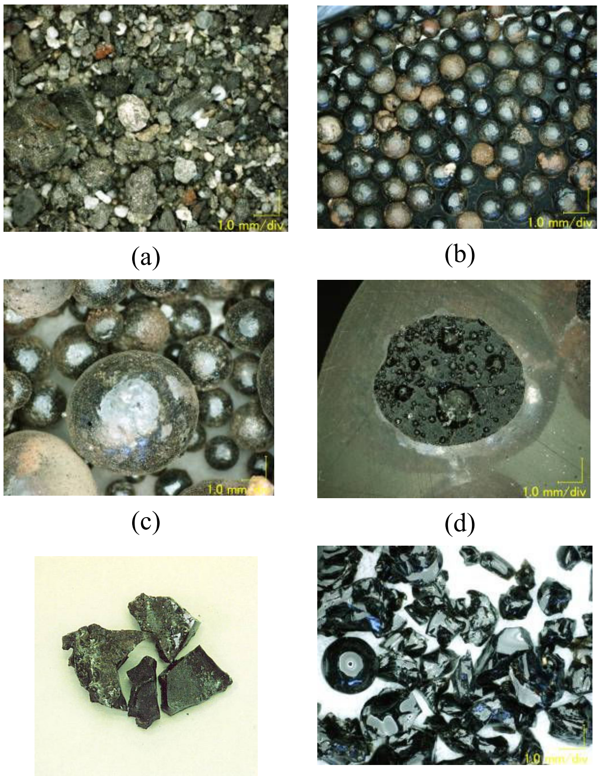
4. Results and discussion

Three kinds of waste materials were in-flight melted in the furnace heated by the twelve-phase AC arc. The morphology of the melted asbestos, the incineration ashes from municipal solid wastes (MSW), and the fly-ashes of electric power plants are shown in **Figs. 7-9**, respectively. These waste materials after the in-flight melting have smooth surface. It was further confirmed by SEM and XRD that the crystal structure contained in these waste materials was transformed into amorphous glassy structure during the in-flight treatment.



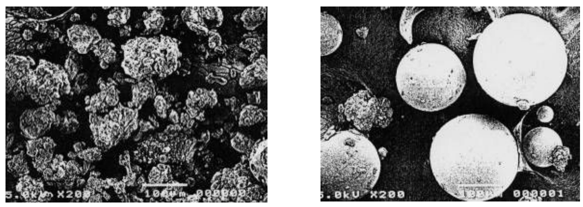
(a) (b)

Fig.7 Photographs of asbestos sheets; (a) before melting, (b) melted asbestos



(a) (b) (c) (d) (e) (f)

Fig.8 Photographs of incineration ashes; (a) before melting, (b) melted (primary treatment), (c) melted (secondary treatment), (d) cross section image, (e) cullet-like, (f) water crashed



(a) (b)

Fig.9 Photographs of fly-ashes; (a) before melting, (b) SEM image of melted ashes

Fig. 7 (a) shows the asbestos sheets which was conventionally used as insulation material. The melted asbestos shown in Fig. 7 (b) was obtained by the in-flight heat treatment after tearing the asbestos sheets into small pieces.

The incineration ashes from MSW were also treated by the twelve-phase AC arc as shown in Fig. 8. The incineration ashes before the melting are shown in Fig. 8 (a). After the in-flight treatment, the melted ashes are presented in Fig. 8 (b) and (c); Fig. 8 (b) is the photographs of the melted spherical materials of 1 mm in diameter after the primary treatment of the raw materials, and Fig. 8 (c) shows the larger spherical materials of 6 mm in diameter after the secondary treatment. Fig. 8 (d) presents the cross section of the melted materials corresponding to Fig. 8 (c). The melted materials were gathered on the carbon tray located 50 mm below the lower electrodes, and then they were quenched in water at the bottom of the furnace. The obtained materials were crashed by rapid quenching by water-cooling as shown in Fig. 8 (f).

The last example is the in-flight treatment of fly-ashes. Fig. 9 (a) shows fly-ashes generated from electric power plants. Fig. 9 (b) shows SEM image of the spherical ceramics in diameter of 200-300 μm afer the in-flight treatment.

The XRD pattern of the incineration ashes from MSW are presented in **Fig. 10**, corresponding to the raw materials shown in Fig. 8 (a) and the melted materials shown in Fig. 8 (b) and (c). The intensities of the raw material can be assigned to the peaks of SiO_2, $CaCO_3$, and Fe_2O_3. Only the strong peak of SiO_2 can be seen from the melted materials after the primary treatment. The melted materials after the secondary treatment present the weak SiO_2 peak, indicating the amorphous glassy structure.

Fig. 11 shows the size distribution of fly-ashes before and after the in-flight treatment. The original materials mainly contain the powders smaller than 150 μm in diameter. The larger spherical ceramics from 150 μm to 1 mm were obtained after the in-flight treatment.

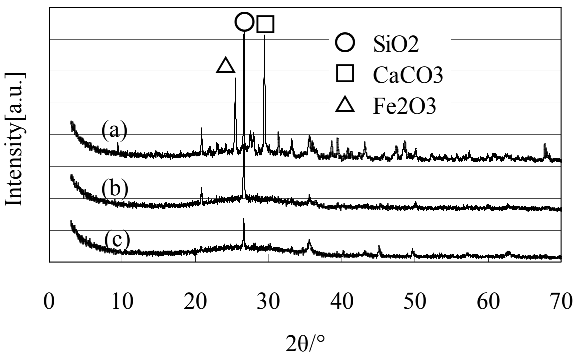


Fig.10 XRD patterns of MSW ashes;
(a) before melting, (b) primary treatment,
(c) secondary treatment.

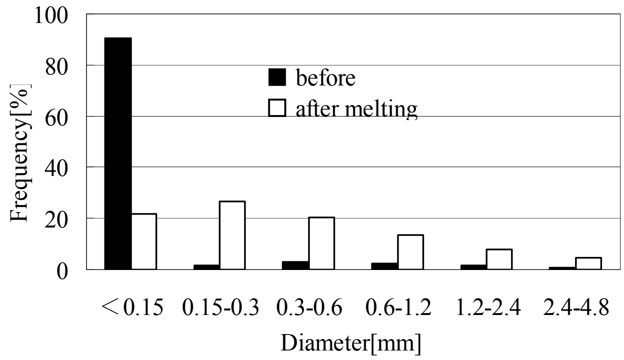


Fig.11 Size distribution of the fly-ashes before and after the in-flight melting.

Conclusion

We have developed the techniques for obtaining the new type of plasma furnace with the twelve-phase AC discharge. This configuration provides the attractive advantages of the thermal plasma in the stable and continuous arc discharge with wider high-temperature region. In-flight melting technology was successfully developed to melt asbestos, incineration ashes and fly ashes. These wastes can be vitrified by the twelve-phase AC arc with short processing time. The twelve-phase AC arc discharge is particularly useful for processing solid wastes which contain hazardous materials.

References

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