Pure & Appl. Chem., Vol. 66, No. 6, pp. 1295–1300, 1994.
Printed in Great Britain.

High power plasma arc melting process for incinerated ash contraction

Katsuo Kinoshita*, Akihiko Hayashi*
Kohzo Akahide* and Taketoshi Yamazaki**

* Kawasaki Steel Corporation, 351, Naganuma-cho, Inageku, Chiba, 263, Japan
** Tokyo Electric Power Company, 1-3 Uchisaiwaicho, 1-chome, Chiyodaku, Tokyo 100 Japan

A new process to reduce the volume of the incinerated ash and to make the ash harmless and recyclable has been developed using a high power plasma arc system.
The experiments have been done in the Structure Research Laboratories of Kawasaki Steel Corporation in Chiba City using the pilot plant of which the melting efficiency of ash is 200kg/h and the maximum power of plasma is 240KW. The energy and material balances of this process were made clear by the experiments. Melting process metamorphoses ash to granulated slag which is reduced to one-third in its volume with no toxic problems. The slag is available for construction materials. A new operation method in a reducing atmosphere has been also developed to depress the NO_x content in exhaust gas which is evolved in the plasma gas. The reduction of collimator diameter of plasma torch to prevent the erosion of copper electrode achieves remarkable prolongment of its lifetime.

1. Introduction

In Japan, approximately 50 million-tons of municipal waste have been disposed every year and about 70% of them has been incinerated. About 15wt% of the waste incinerated remains as ash and has been utilized as a sanitary landfill material. Many municipalities, however, are troubled with the disposition of the ash because of the limited space for the landfill.

A new process to reduce the volume of the incinerated ash and to make the ash harmless and recyclable has been developed using a high power plasma arc system. The maximum power and the melting efficiency of the plasma arc system is 240KW and 200kg/h, respectively. The ash used for the experiments is from the incinerator in Chiba city. This report describes mainly about the heat and material balances of the system, the controlling of exhaust gas compositions and the elongation of the electrode lifetime.

2. Experiment

2.1 Equipments

2.1.1 Plasma System

The plasma system, made by Plasma Energy Corporation, consists of a power supply, a cooling water pump, a plasma gas feeder and a plasma torch. The capacity of the power supply is 240KW DC and its external characteristics is constant current.

The plasma torch shown in Fig.1 is specially designed to extend the electrode life and is used in transfer mode with electrode positive polarity. Plasma gas (air) flows spirally up along the inner surface and then blows down through the axial part of the hollow electrode with its pressure periodically pulsating.

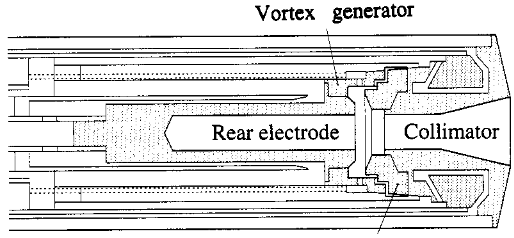

Fig. 1 Sectional view of plasma torch

The gas motion forces the anode spot to sweep over the wide area of the inner surface to avoid local damage of the electrode. Electrode and torch body are water cooled to protect against the anode energy and the radiation heat from the arc and melt. Electrode is made from chromium-copper alloy.

2.1.2 Melting furnace

The schematic diagram of the melting process is shown in Fig.2. Ash is supplied into the melting furnace using a pusher, and melted by the plasma arc generated between the plasma torch and the bottom electrode. The molten slag is discharged from the furnace through the cascade, and cooled rapidly by the water jet. For the efficient discharging operation, the slag fluidity should be high. Toward the aim, the slag basicity is adjusted at approximately one (1) by adding 25wt% of lime. The melting furnace is a cylindrical type with the dimensions of 860mm height, 760mm ID and 1500mm OD.

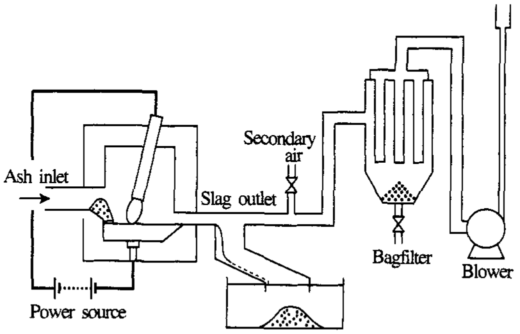

Fig. 2 Schematic diagram showing ash melting process

2.1.3 Waste gas exhaust system

The waste gas generated in the furnace is led to the exhaust system. On its way, the waste gas loses some amount of heat to warm up the cascade system. Then the waste gas is forced to cool to a temperature around 200°C by the secondary air and exhausted to the atmosphere through the bagfilter.

2.2 Operational conditions

2.2.1 Reduction of erosion damage for electrode of plasma torch

At an early stage of the experiment, an expected lifetime of the electrode could not be achieved because of the severe erosion damage of the electrode. Preliminary investigations on the influence of the operational factors and the torch assemblies on the erosion damage of the electrode have indicated the following two facts: 1) the erosion damage is influenced significantly by the structure of the collimator which is located at the tip of the torch and used for the arc energy concentration, and 2) the erosion damage decreases with increasing the operational current. Consequently, operations have been done by selecting the collimator structure and by controlling the current values.

Under various operational conditions, erosion rate V(g/sec) was estimated from the weight loss of the electrode during a given period of arctime. The erosion damage of electrode was evaluated in terms of the erosion ratio which is defined as the amount of erosion per unit electric charge:

$$ER(ng/C)=V/(I\times10^{9}) \qquad (1)$$

where, V is erosion rate (g/sec), and I is current (A).

To clarify the arc behavior in the electrode hollow, the pressure distribution and the flow characteristics of the plasma gas were measured using cold models. For the pressure measurement along the inner surface of the electrode, four pressure gauges were set at an interval of 40mm along the axial direction as shown in Fig. 3. For the pressure measurement along the electrode axis, a stainless steel tube having a drilled hole and connected to a manometer was slid up and down along the axis of the electrode.

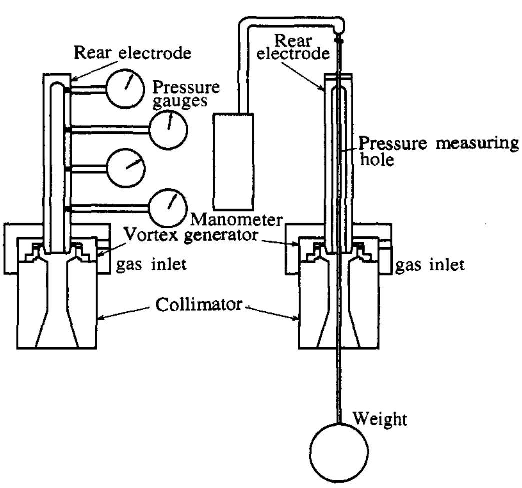

Fig. 3 Cold models for measurement of gas pressure

A transparent electrode made of acrylic resin was used for the measurement of rotational velocities of the plasma gas. After charging a spherical plastic tracer with 6mm diameter into the electrode, plasma gas was supplied. The tracer rotates with the plasma gas. The rotational velocities were measured using a stroboscope.

2.2.2 Ash melting

The ash fresh from the incinerator contains about 40% of moisture, and is to be dried to less than 20% of moisture by natural drying before melting.

Energy and material balances of the melting treatment were measured by the experiments. In case of the air plasma, the order of 1% NO_x is evolved in the plasma gas. To depress the evolution of NO_x, the atmosphere in the furnace is maintained reductive by the addition of hydrocarbon material (Refuse derived fuel) to the ash. The addition of hydrocarbon material evolves reducing CO and H_2. A part of these reducing gases deoxidized NO_x. Finally, the remaining reducing gases are burnt by the addition of the secondary air.

The leachate test for the granulated slag was carried out.

The slag was utilized in making several construction materials.

3. Results and discussion

3.1 Effect of torch assemblies on erosion ratio of electrode

The erosion ratio of the electrode decreases with increasing electric current as shown in Fig.4. Since the erosion of tungsten electrode usually increases with increasing electric current, the present results are in conflict with this fact. The shape of the arc column photographed by a high speed video shows that the arc at 400A is much stabler than that at 300A. From these results, it is assumed that the stability of the arc decreases the erosion ratio of the electrode.

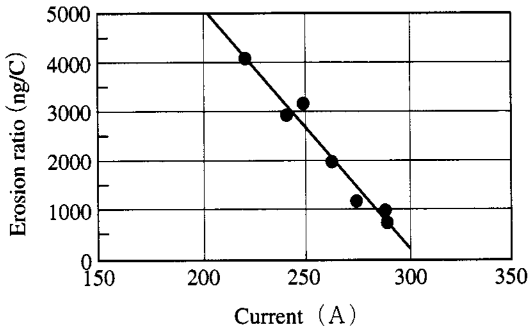

Fig. 4 Variation of erosion ratio of electode with current

Using a collimator with a smaller hole (15mm in diameter), the erosion amount of an electrode was measured during the operational time.

Figure 5 shows the results for the collimator as compared with that with a normal hole (18.5mm in diameter).

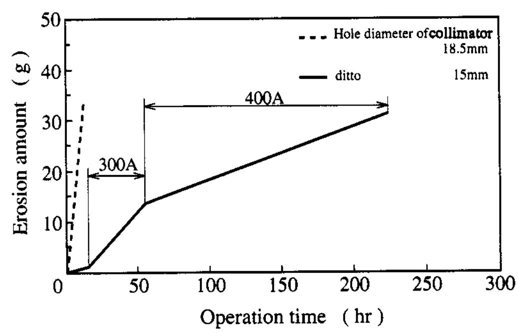

Fig. 5 Variation of erosion amount of electrode with operation time

As for the results with a small hole, the range having a steep gradient corresponds to the case for the current of 300A. From Fig.5 and Fig.7 (to be shown later), erosion ratios for the collimator with a small hole including the cases for the current of 300A and that of 400A result in 100 to 200ng/C. They are only 1/20 to 1/40 of that with normal hole (4,000ng/C). The collimator with a small hole improves significantly the life time of electrode.

Under four different combinations of collimator and vortex generator, erosion were measured by hot operation, while, at the same time, the pressure differences between the axis and the inner surface of the electrode were measured by cold model.

The pressure differences along the axial direction are shown in Fig. 6. The pressure differences for the collimator with a hole of 15mm in diameter becomes twice as high as that with a hole of 18.5mm in diameter. The erosion ratios for four conditions, (ø15, 6 holes), (ø18.5, 6 holes), (ø15, 12 holes) and (ø18.5, 12 holes) are shown in Fig. 7.

Here the operation has been done at 300A. The erosion ratio decreases remarkably with decreasing the hole diameter of the collimater and with increasing the hole numbers of the vortex generator.

To clarify the relationship between the erosion ratio and the pressure difference, the variation of the erosion ratio with the pressure difference in the vicinity of the outlet of electrode (measured distance of 115mm in Fig. 6) is shown in Fig. 8. It is apparent from Fig. 8 that the erosion ratio decreases with increasing the pressure difference.

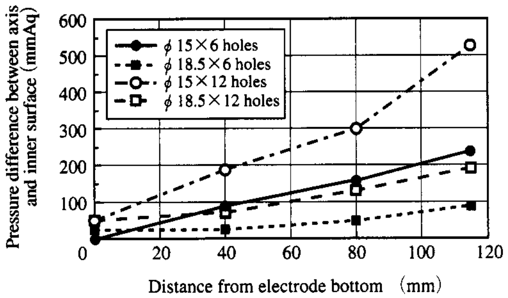

Fig. 6 Distribution of pressure difference between axis and inner surface along axial direction

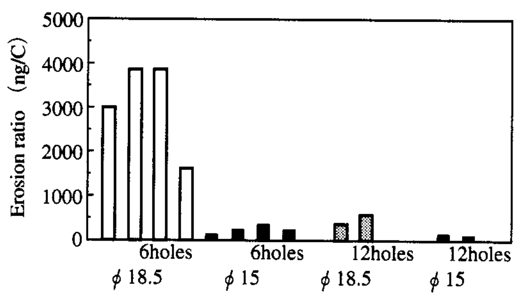

Fig. 7 Effect of collimator and vortex generator on erosion ratio

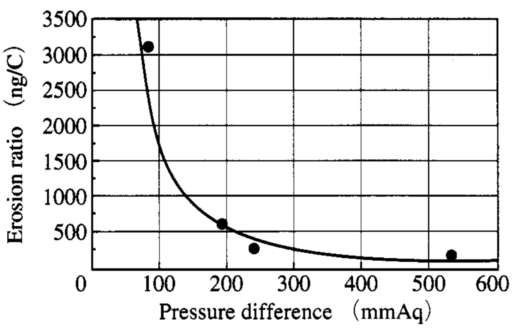

Fig. 8 Effect of pressure difference between axis and inner surface on erosion ratio

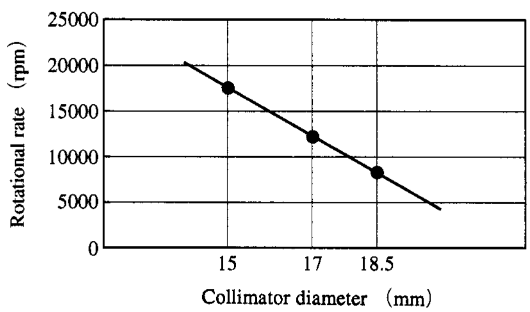

Fig. 9 Effect of collimator diameter on rotational velocity of gas

The variation of the rotational velocity of the plasma gas with the hole diameter of the collimator is shown in Fig. 9. The rotational velocity increases with decreasing the hole diameter and the velocity of ø15 shows twice as high as that of ø18.5. It is assumed that the absolute value of the rotational velocity in hot operation is larger than that shown in Fig. 9, because the gas pressure used in the cold model is only one half (1.5kg/cm^2) of that of the hot operation and the plastic sphere used in the measurement is considered to retard the gas flow.

It is presumed from the facts above mentioned that the increase in the pressure difference caused by the decrease in the hole diameter of the collimator stabilizes plasma arc (2), and the increase in the rotational velocity of plasma gas increases the velocity of the anode spot motion. The combined effects of the above two are considered to decrease the erosion ratio of the electrode.

3.2 Ash melting

3.2.1 Energy and material balances

Energy and material balances during the melting process under the charging condition of 210kg/h are shown in Fig. 10 and Fig. 11, respectively.

As to the energy balance, input energies are 265 KW in total, where 200KW is from the plasma and the balance is from the heat of combustion of the hydrocarbon material. On the other hand, output energies are composed of heat of exhaust gas, heat of ash melting, heat loss from furnace, and heat to cooling water of furnace and plasma torch. Among these output energies, the heat to the cooling water of the plasma torch amounts to as high as 28% of the total energies. This loss is attributable to the long extension of the torch into the furnace. Therefore, it is possible to reduce the loss by the improvement of the furnace design.

The consumption of electric power per ton of the wet ash is 960KWH. It is also possible to decrease the power consumption by reducing the moisture of the ash since the ash contains about 17 to 18% of moisture.

As to the material balance, the overall incoming rate is 225kg/h, where the wet ash is 210kg/h and

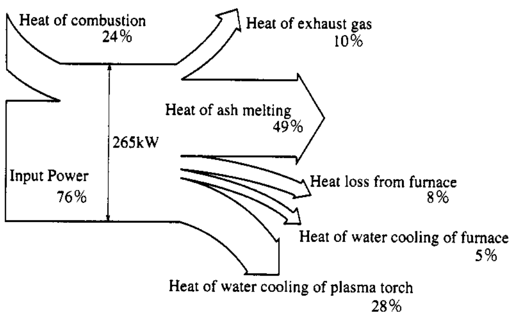

Fig. 10 Energy balance

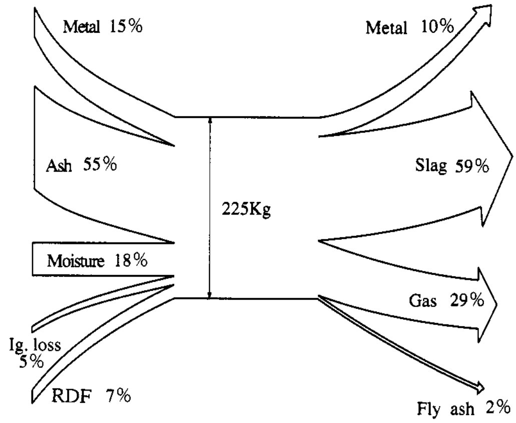

Fig. 11 Material balance

the hydrocarbon material is 15kg/h. Outgoing products are 133kg/h of slag, 22kg/h of metal, 65kg/h of gas and 4.5kg/h of fly ash. Since the moisture in the ash not only consumes the energy, but also causes troubles in charging operations, it is desirable to minimize the moisture of the ash.

Metal elements in the ash are partially oxidized into slag. The remaining part of the metal, however, has to be disposed separately from the slag.

3.2.2 Composition of waste gas

To depress the generation of NO_x, the waste gas in the present experiments should be reductive. Variations of the content of CO and NO_x with time are shown in Fig. 12.

The solid line represents CO values measured at the point immediately after the outlet of the furnace, while the broken line does NO_x values converted at 15% oxygen content. Time is taken from the start of the charging of ash.

The content of NO_x rapidly decreases with increasing the content of CO. When the CO content reaches a value in the neighbourhood of 10%, the NO_x content decreases to approximately 130ppm which clears the environmental quality standards.

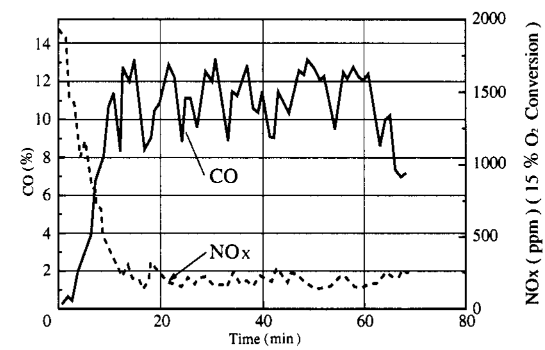

Fig. 12 Variation of content of CO and NO_x with time

The composition of the waste gas have hereinafter been considered based on the equilibrium reaction. The hydrocarbon materials supplied in the furnace react with the oxygen in the plasma gas and the moisture in the ash according to the following equation:

$$A(O_2) + B\langle C_{1.5}H_{2.9}O\rangle + C\{H_2O\} = w(H_2O) + x(CO) + y(CO_2) + z(H_2) \quad (2)$$

where, A, B and C are constants determined by the flow rate of the plasma gas, the supplying rate of the hydrocarbon material, and the supplying rate and the moisture content of the ash, respectively.

The molecular component of the hydrocarbon material has been estimated from the analytical values of the refuse derived fuel. On the other hand, for the production system of the equation (2), the water-gas reaction equilibrium is established as shown by the following equation:

$$CO + H_2O = H_2 + CO_2 \quad (3)$$

The equilibrium constant Kp is given by the following equation:

$$Kp = (p_{H_2}p_{CO_2})/(p_{CO}p_{H_2O}) = (yz)/(wx) \quad (4)$$

Furthermore, the constant Kp is determined by the following equation (5):

$$\log_{10} Kp = 1879/T - 1.67 \quad (5)$$

where, T is equilibrium temperature.

By solving above equations simultaneously, the composition of the waste gas was estimated for the supplying rate of hydrocarbon material as a parameter. Furthermore, from the calculation of the equilibrium for the reducing reaction of NO_x by CO or H2, the NO_x content in the waste gas was estimated. The relationship between the NO_x content and CO content is shown in Fig. 13. The supplying rate of the hydrocarbon material in the present operation has been determined to keep the . NO_x content in the waste gas within the environmental quality standards by the use of these calculations.

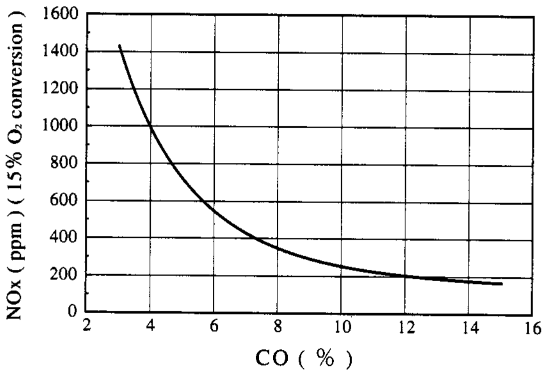

Fig. 13 Relationship between NO_x and CO

The dust in the waste gas has been collected by the use of the bagfilter.

The weight of the dust is about 1 to 2% of the supplied ash.

Because the dust contains harmful metals such as lead and cadmium, an adequate treatment such as by trapping metal elements in the cement (4) is required in order to prevent the metal elements from dispersing.

3.2.3 Properties of the granulated slag and its commercial applications

Specific gravity of the granulated slag is about 2.8 to 2.9 and its volume is about one-third of the original ash. The results of the leachate test for the granulated slag are shown in Table 1. No harmful chemicals have been detected through the test.

Table 1 Results of leachate test for granulated slag

	T-Hg	Cd	Pb	Cr^{6+}	As
Mesured	ND	ND	ND	ND	ND
Upper Limit by Law	0.005	0.1	1	0.5	0.5
	CN	PCB	R-Hg	Org.P	
Mesured	ND	ND	ND	ND	
Upper Limit by Law	1	0.003	0.0005	1	

The slag has been utilized as an additive for producing water permeable tiles. The slag addition of up to 30wt% to the feldspa-silica-clay mixture can provide the tiles with sufficient strength and water penetrability. The tiles can be used as paving materials for promenade and parking lot.

The slag has also been used as an aggregate of cement mortar. The cement mortar with the slag has the strength of 70% of that with the river sand as aggregate and can be used for construction materials.

4. Conclusion

Plasma arc melting experiments for the incinerated ash have been done using a pilot plant with the melting capacity of 200kg/h and with the maximum plasma power of 240KW.

The results obtained can be summarized as follows:

(1) It is clarified by hot and cold models that the reduction of collimator diameter of the plasma torch improves the lifetime of an electrode significantly by depressing the erosion of an electrode.

(2) Energy and material balances during the melting process have been clarified under the charging rate of 210kg/h. The melting treatment metamorphoses ash to granulated slag which is reduced to one-third in volume with no toxic problems. The slag is usable as an additive for water penetrable tiles or an aggregate of cement mortar.

(3) To depress the evolution of NO_x in the plasma gas, the operational method which keeps the furnace atmosphere reducing has been established.

References

1. Tadao Fujimoto, et al. Kankyo-Gijyutsu 17,607 (1988) (in Japanese)
2. Yoshiaki Arata and Akira Kobayashi Trans. JWRI 13 1 (1984)
3. O. Kubaschewski and E. Ll. Evans, Metallurgical Thermo Chemistry, Butterworth Springer (1951)
4. Shinya Takenaka and Michio Nanjo, Bulle, Res. Inst. Mineral Dress. Metal. Tohoku Univ. 40, 49 (1984) (in Japanese)