DEVELOPMENT OF AN MSW ASH MELTING SYSTEM OF LOW RUNNING COST

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ABSTRACT

Given the current situation of Japan, where the disposal of municipal solid waste (MSW) is mainly through incineration and discarding the ashes in land reclamation, volume reduction and recycling of ash as a useful resource as well as pollution prevention are of the primary importance. As a means to satisfy all these requirements simultaneously, an MSW ash melting system, one in which the residual carbon contained in the combustion ash is utilized as a major heat source to melt the ash itself, has been developed.

The efficacy of this system has been verified in full scale for an operating rotary combustor-with-after-burning stoker type MSW incineration plant of 150 t-MSW/24 h in capacity over a period of 2 months. It is shown that the operating cost is one-third to one-fifth of competitive systems, that low pollution emission is attained clearing all the national regulations with ample margin, and that stable operation is achieved on a process computer control system that works on an artificial intelligence program incorporating an expert consultation system.

INTRODUCTION

In Japan, where the disposal of municipal solid wastes (MSW) is overwhelmingly through gross incineration and land reclamation with the combustion ashes generated thereby, shortage of available reclamation sites calls for significant reduction in the volume of ash to be disposed of. In addition, prevention of pollution by and recycling as a useful resource of the ash are the orders of the day. It is with these as a background that the MSW ash melting process is drawing attention as a promising means of satisfying all these requirements simultaneously.

Several kinds of ash melting systems have already been put to practical use [1–3]. However, since either oil or electric power is used as the heat source for melting the combustion ash, their operating costs turned out to be unjustifiably high. This is the main reason why the idea of ash melting itself failed to gain the popularization it deserves.

In this paper, we intend to report on development of a new MSW ash melting incineration system, i.e., the one that is based on the notion of utilizing the residual carbon the combustion ash contains in melting the ash itself, and on the successful verification of this notion in a test conducted at full scale for an operating MSW incineration plant of 150 t-MSW/24 h in capacity over a period of 2 months.

PRINCIPLES OF ASH MELTING

Figure 1 illustrates the operation of conventional rotary combustor-with-after-burning stoker type MSW incinerator. The MSW is incinerated in the rotary combustor as fed from the MSW dump, and the combustion

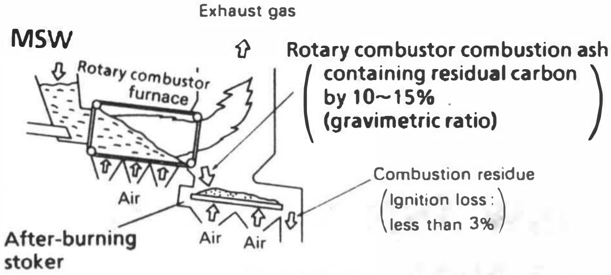

FIG. 1 CONVENTIONAL ROTARY COMBUSTOR

ash is reincinerated in the after-burning stoker mounted on the downstream end of the rotary combustor.

The ash from the after-burning stoker is discarded as a combustion residue of an ignition loss less than 3%.

Now the combustion ash that comes out of the rotary combustor is noted for two features:

(a) It contains an appreciable amount of residual carbon, usually to 10–15% (gravimetric) as free carbon (Fig. 1).

(b) It maintains a high temperature of 600–700 °C. This means that this residual carbon is burnt in the after-burning stoker, generating a considerable combustion heat as in:

$$C + O_2 = CO_2 + 33.9 \text{ MJ/kg}$$

The reality is, however, that this heat is utilized only as a part of the total thermal output in the existing systems.

In the ash melting system we have conceived, on the other hand, an ash melting furnace is provided downstream to the after-burning stoker in such a way as to generate sufficient heat by burning the residual carbon to melt the hot combustion ash that the after-burning stoker discharges. It turned out the residual carbon could be burnt readily by blowing hot air of about 500 °C.

Figure 2 presents schematically the principles of controlling the process described above. We have realized early that for our system to be successful, the amount of residual carbon (C) in the combustion ash would have to be controlled adequately. For this, we found a solid correlation in the rotary combustor has progressed, a quantity which can be defined as the distance ($L_{b.o.p.}$) between the position of the burn-out point—i.e., the place where the flame ceases to be observable—and the furnace rear wall (Fig. 2), and that the amount of C that was needed to melt away the combustion ash in the ash melting furnace could be secured by operating the rotary combustor so as to have $L_{b.o.p.}$ to fall in a certain range.

Since determination of the burn-out point, or $L_{b.o.p.}$ for that matter, on direct observation is simply impossible, we have devised an indirect method. This is shown in Fig. 2. An ITV camera monitors the flame, viewing its lower portion as it emerges from the rotary combustor. The image is processed real-time in an image processor, which dissolves the image into the three primary colors, and picking up only the green components, draws a two-dimensional brightness map for the cross-section of the flame under assessment. From this map, the $L_{b.o.p.}$ can be estimated accurately enough.

As the controlling of $L_{b.o.p.}$ in the specified range despite the ever varying MSW is a task that calls for quite a know-how, however, we have formulated an expert consulting system based on a highly skilled operator's modus operandi, and have incorporated it in the process computer control system as a part of the artificial intelligence guidance unit (Fig. 2).

ASH MELTING FURNACE

Figure 3 shows the structure of the ash melting furnace. The features of this furnace are as follows:

(a) The combustion ash supplied from upstream by the after-burning stoker, hot and containing an adequate amount of residual carbon, is sorted on the hearth.

(b) The carbon in the ash is burnt with hot air (ca. 500 °C) blown in through the hearth, and the ash is melted down from under.

(c) The hearth is heated with appropriately disposed electric hearth heaters so as to prevent the molten matter from sticking to it and also to assist in the ash melting.

(d) The molten ash is continuously discharged from the furnace rear end, where it flows into a water bath to undergo spontaneous granulation into spherical slag granules of several mm in diameter.

(e) The combustion gas is led to the rotary combustor uptake to be a part of the plant flue gas, but before that it serves as the sole heat source for the hot gas air heater (HGAH) to preheat furnace's own combustion air.

(f) In addition to above, all the combustion airs, those for the rotary combustor, the after-burning stoker, and the secondary combustion in the rotary combustor uptake alike, are drawn through the MSW dump as a part of deodorizing measure, and are preheated in the same HGAH (and partially by the flue gas air preheater), thereby achieving considerable re-

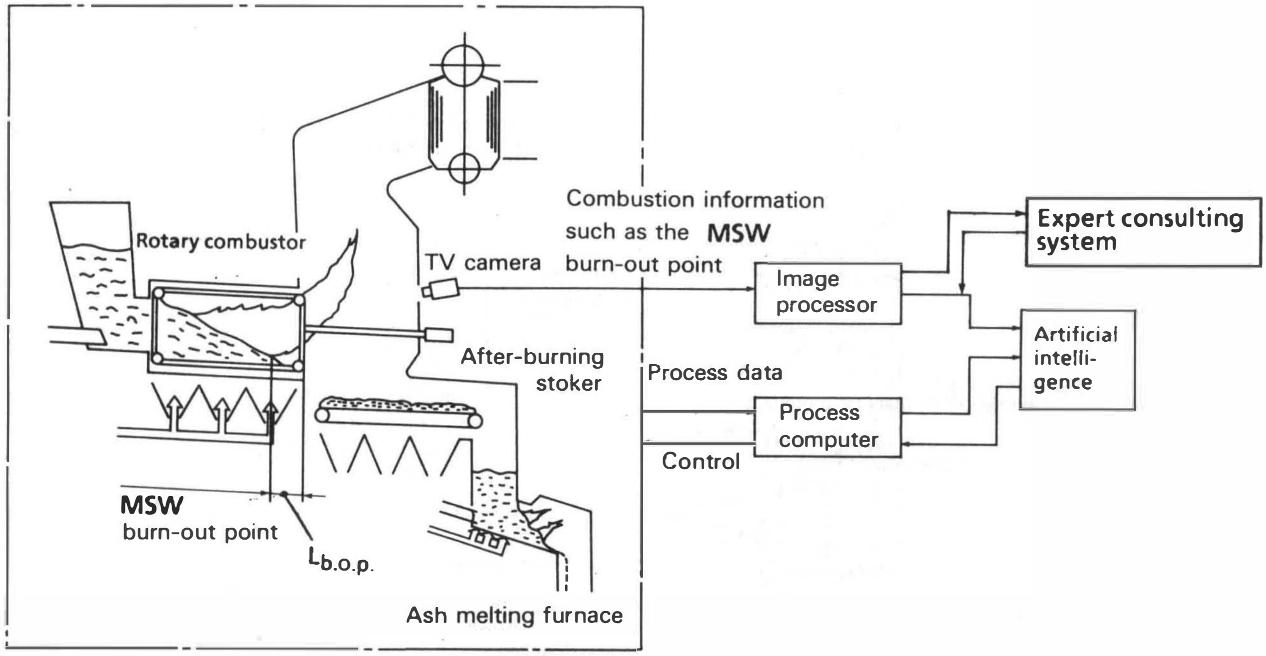

FIG. 2 PROCESS CONTROL SYSTEM

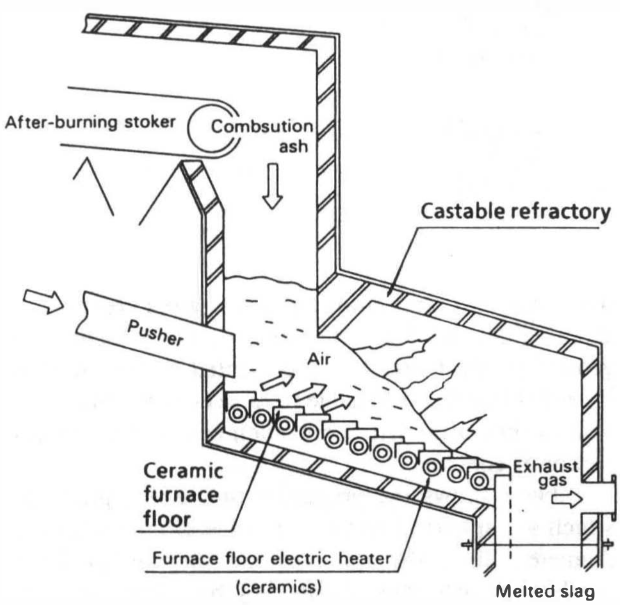

FIG. 3 STRUCTURE OF ASH MELTING FURNACE

duction in the operating cost (this will be discussed later on in more detail).

TEST RESULTS

Plant Heat Economy

Figure 4 shows the plant heat balance, where the area the dotted lines surround denote the ash melting furnace. Here, we find that, since the generated heat is ultimately absorbed by the boiler bank (partially via the water-jacketed furnace wall), and since the heating value of the electric hearth heaters is so small compared to the total that it can be ignored safely, the heat loss is held to a very low level.

Of the total heat expended in melting the ash, about 65% comes from the heat of combustion of the residual carbon as well as the sensible heat the combustion ash has brought. Of this ash melting heat, moreover, about 25% is recovered as a source of preheating all the combustion airs. Namely, some 90% of the heat needed to melt the ash is intrinsically provided for.

This is the basis on which an agreeable plant economy has been realized: the fuel consumption is no more than about 150 kW/t-ash, and the operation cost is about 2250 yen/t-ash ($16/t-ash), a figure which is one-third to one-fifth of those of other ash melting systems now operating in Japan.

Properties of MSW, Ash, Slag, and Exhaust Gas

Table 1 presents the results of analyses conducted on a typical MSW used in the test. The plant being operated for daily public service, the MSW was delivered unpretreated, i.e., as collected routinely. Although this particular MSW may seem to be rather high in the moisture and low in the lower heating value, therefore, it is typical of any Japanese MSW. As we understand it, the common MSW disposal practice in the United

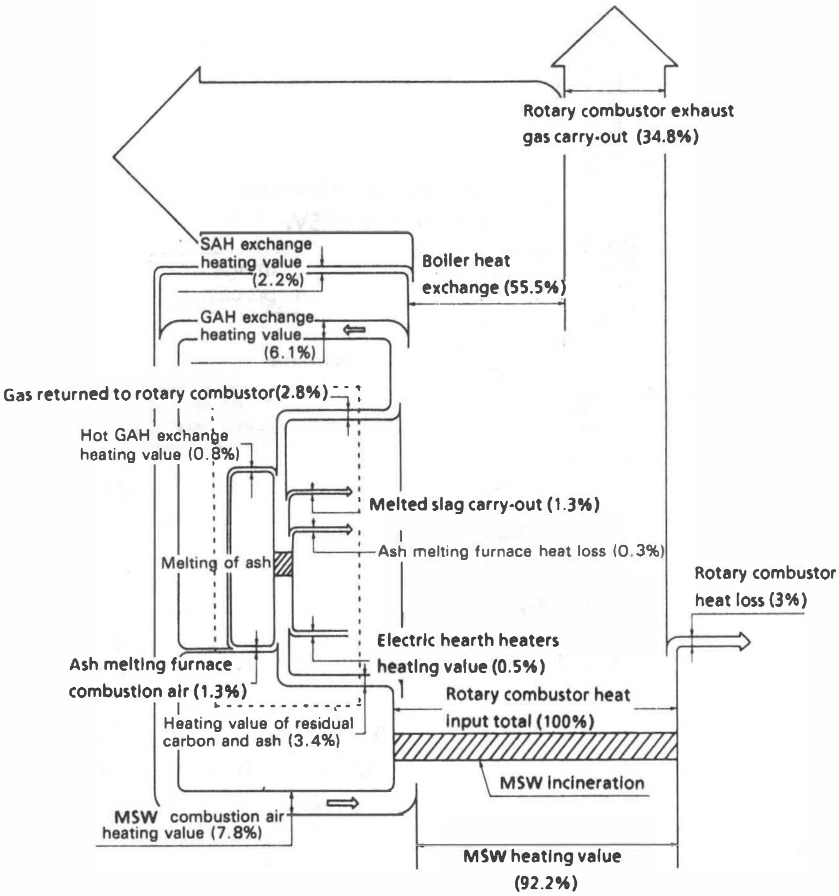

FIG. 4 HEAT BALANCE DIAGRAM

States is to separate the food stuff to be disposed in the waste water treatment plant together with sewage, whereas no such practice is taken anywhere in Japan: the MSW are collected en masse (except large furniture pieces, metallic articles, and such) to be incinerated indiscriminately. It would seem, therefore, that American practice should improve these values, making incineration that much easier.

Table 2 shows the combustion ash analysis. Owing to the combustion control (Fig. 2), much residual carbon has been retained in the ash in both cases. Nevertheless, these two ashes differed in the ease of ash melting. Namely, even though we have been able to achieve stable ash melting readily enough with Sample C, maintenance of stable melting was difficult in the case of Sample D. This experience has been taken as indicating that a border line of carbon content for stable ash melting lies somewhat between 12% and 14%, the values that were used to define the range for controlling $L_{b.o.p.}$.

Table 3 shows the thermal characteristics of these two ashes. The agreement between the two despite the difference in their melting behaviors gives credence to these values. At the same time, it gives a theoretical ground to the basic notion presented earlier on: it is indeed theoretically feasible to raise enough amount of heat to melt away the combustion ash on the residual carbon it contains.

Table 4 shows the properties of the slag granules, which are spherical particles of several millimeters in diameter. Since the apparent specific gravity of the combustion ash from which they have been made is 0.6–0.8, an apparent specific gravity of about 2.7 as slag granules amounts to a volume reduction to one-third to one-quarter. The 0% ignition loss, coupled with the results of leaching test (Table 6, to be discussed a little later), attests to their nonpolluting quality. Moreover, the compressive strength of about 29 MPa, which compares favorably with that of concretes of 17.6–23.5 MPa, and the spherical shape they retain suggest that they can be used quite well as an aggregate for various civil works, such as road construction and making of concrete structures.

TABLE 1 ANALYTICAL RESULTS OF TYPICAL MSW

Analytical item \ Sample		A	B	Analytical method
3 components (mass %)	Combustibles	37.47	42.97	Environmental protection regulation No. 95
	Non-combustibles	6.36	7.05	
	Total moisture	56.17	49.98	
Physical analysis (mass %)	Synthetic resin, leather	17.20	15.94	ditto
	Papers	60.72	43.66	
	Wood, bamboo, straw	3.11	6.41	
	Garbage	11.12	21.92	
	Fiber	0.27	6.24	
	Miscellaneous (less than 5 mm)	3.60	2.56	
	Noncombustibles	3.98	3.26	
Elementary analysis (mass %)	C	17.67	19.21	JIS M 8813
	H	2.69	2.70	
	N	0.31	0.10	
	Cl	0.18	0.30	
	S	0.10	0.14	
	O	16.53	20.51	
Apparent specific gravity (t/m^3)		0.23	0.22	Environmental protection regulation No. 95
Lower heating value (MJ/kg)		5.28	6.53	JIS M 8814

TABLE 2 ANALYTICAL RESULTS OF TYPICAL COMBUSTION ASH FROM ROTARY COMBUSTOR (Environmental Protection Regulation No. 95, etc.)

Item \ Sample		C	D
Ignition loss	(mass%)	21.8	17.5
Residual carbon	(mass%)	14.8	11.8
SiO_2	(mass%)	40.02	42.56
Al_2O_3	(mass%)	12.4	15.2
CaO	(mass%)	19.3	17.0
Fe_2O_3	(mass%)	6.26	6.38
MgO	(mass%)	2.44	2.68
Na_2O	(mass%)	4.24	3.48
K_2O	(mass%)	1.54	1.68
CN	(mg/kg-ash)	3.4	3.2
Cd	(mg/kg-ash)	3.2	2.8
Pb	(mg/kg-ash)	790	516
As	(mg/kg-ash)	2.8	2.0
Cr^{6+}	(mg/kg-ash)	Not detected	Not detected
T-Cr	(mg/kg-ash)	110	100
R-Hg	(mg/kg-ash)	Not detected	Not detected
T-Hg	(mg/kg-ash)	0.01	0.01
Organic-P	(mg/kg-ash)	Not detected	Not detected
Cu	(mg/kg-ash)	1100	910
Zn	(mg/kg-ash)	210	190
F	(mg/kg-ash)	120	120
PCB	(mg/kg-ash)	Not detected	Not detected

"Not detected" means the followiong conditions. CR6+: less than 2; R-Hg: less than 0.01; Organic-P and PCB: less than 0.1 each.

TABLE 3 THERMAL CHARACTERISTICS OF ROTARY COMBUSTOR ASH

Item \ Sample	C	D
Melt starting temperature (°C)	1,102±32	1,105±16
Melting point (°C)	1,223±20	1,241±20
Melting heat (kJ/kg)	267±44.0	243±36.0

TABLE 4 PROPERTIES OF SLAG GRANULES (JIS K 2151, etc.)

Item		Effects
Specific gravity, apparent*1 Specific gravity, true*3	2.74 3.10	Volume reduction*2
Ignition loss (%) Resistance to leaching	0 excellent*4	Pollution prevention
Compressive strength (MPa)	29.4*5	Resource recycling

*1 as compacted into a 2cm cube;
*2 the apparent specific gravity of the original ash is 0.6 to 0.8,
*3 as pulverized;
*4 see Table 6;
*5 the compressive strength of concrete is 17.6 to 23.5 MPa.

Further properties of the slag are presented in Table 5 (slag analysis), Table 6 (results of slag leaching test), and Fig. 5 (distribution of heavy metals among the three major products of any MSW incineration plant). Namely, the slag granules made in this way can absorb away quite a lot of heavy metals (Table 5) and retain them for indefinite period of time (Table 6), rendering them harmless to satisfy the Japanese government regulations. It will be seen in Fig. 5, furthermore, that given the present status of MSW incinerator plants, where an electrostatic precipitator (ESP) is a standard equipment and where a method of disposing the ESP dust has been established, the only exception is Hg, which is not subjected to any regulations today because of its scarcity. In anticipation of this problem to become a public concern, it has been suggested that bag filters should be able to remove Hg (together with dioxins) effectively.

Finally, Table 7 presents the exhaust gas data. The ash melting furnace gas is noted for high concentration of NO_x, which is evidently due to the thermal NO_x generated under the high heat, and of HCl, which is due most probably to condensation of Cl. On mixing with the rotary combustor exhaust, however, they are

TABLE 5 ANALYTICAL RESULTS OF TYPICAL SLAG (JIS K 0102)

Item \ Sample		E	F
SiO_2	(mass %)	32.54	36.16
Al_2O_3	(mass %)	16.02	14.30
CaO	(mass %)	21.19	20.28
Fe_2O_3	(mass %)	17.15	17.44
MgO	(mass %)	2.88	2.43
Na_2O	(mass %)	3.61	4.11
K_2O	(mass %)	0.99	0.96
MnO	(mass %)	0.22	0.30
TiO_2	(mass %)	1.13	0.88
ZnO	(mass %)	0.47	0.47
CN	(mg/kg-slag)	Not detected	Not detected
Cd	(mg/kg-slag)	Not detected	Not detected
Pb	(mg/kg-slag)	83	250
As	(mg/kg-slag)	3.0	3.0
Cr^{6+}	(mg/kg-slag)	Not detected	Not detected
T-Cr	(mg/kg-slag)	1000	700
R-Hg	(mg/kg-slag)	Not detected	Not detected
T-Hg	(mg/kg-slag)	Not detected	Not detected
Organic-P	(mg/kg-slag)	Not detected	Not detected
Cu	(mg/kg-slag)	810	3900
PCB	(mg/kg-slag)	Not detected	Not detected

"Not detected" means the followiong conditions. CN: less than 0.5, CR^{6+}: less than 2; T-Hg and R-Hg: Less than 0.01;Organic-P and PCB: Less than 0.1; Cd: less than 0.05.

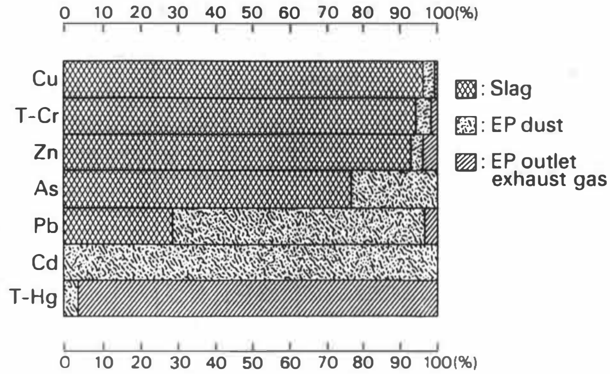

FIG. 5 DISTRIBUTION OF HEAVY METALS (JIS K 0222)

TABLE 6 RESULTS OF SLAG LEACHING TEST (JIS K 0102)

	Mercury alkyl (R-Hg)	Total mercury (T-Hg)	Cadmium (Cd)	Lead (Pb)	Organic phosphor (P)	Chromium (hexad) (Cr^{6+})	Arsenic (As)	Cyanides (CN)	PCB (CN)
Leachate test results	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected	Not detected
Regulation detection limit*	0.0005 mg/ℓ	0.0005 mg/ℓ	0.01 mg/ℓ	0.1 mg/ℓ	0.05 mg/ℓ	0.01 mg/ℓ	0.01 mg/ℓ	0.01 mg/ℓ	0.003 mg/ℓ
Regulation tolerance criteria*	Not detected	Less than 0.005 mg/ℓ	Less than 0.3 mg/ℓ	Less than 3.0 mg/ℓ	Less than 1.0 mg/ℓ	Less than 1.5 mg/ℓ	Less than 1.5 mg/ℓ	Less than 1.0 mg/ℓ	Less than 0.003 mg/ℓ

* Japanese acts for environmental pollution protection

TABLE 7 EXHAUST GAS DATA
(Averages, JIS B 7983)

	Ash Melting Furnaces*1	Rotary Combustor*2
O_2 (%)	7	8
NOx (ppm, O_2 12%)	110	80
CO_2 (%)	6	11
HCl (ppm)	1,460	430
SOx (ppm)	9	60
Gas flow (Nm^3/h, wet)	1,200	34,000
Dust (g/Nm^3, dry)	16.0	0.07

*1 at HGAH outlet;
*2 at ESP outlet, i.e., after mixing with the ash melting furnace gas.

diluted down to 80 ppm and to 430 ppm, respectively, satisfying the government regulation values for flue gas of 150 ppm and 430 ppm. Further reduction of these values should be possible by optimizing the operation.

SUMMARY AND CONCLUSIONS

To achieve volume reduction, pollution prevention, and recycling as a useful resource simultaneously for the combustion ash of municipal solid wastes (MSW), a new system of ash melting, one that is based on a notion of utilizing the residual carbon the ash contains in melting the ash itself as the major heat source, has been developed and verified full-scale for an operating rotary combustor-with-after-burning stoker type MSW incineration plant of 150 t-MSW/24 h in capacity over a period of 2 months.

It was found that:

(a) The amount of residual carbon (C) necessary to melt away the ash can be secured by controlling in the rotary combustor the distance between the MSW burn-out point and the furnace rear wall ($L_{b.o.p.}$).

(b) The ash so molten can readily be made into spherical slag granules of several mm in diameter simply by letting it flow into water, thereby achieving volume reduction to one-third to one-fourth, rendering it perfectly pollution-free, and recycling it as an aggregate for civil works.

(c) The present method is quite economical, as the operating cost is only about one-third to one-fifth of those of competitive methods that use either electric power or oil to melt the ash.

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