



THE BEHAVIOR OF ASH COMPONENTS IN THE SLUDGE MELTING PROCESS

Tunekazu Fukui*, Tadahiro Murakami** and
Muneharu Ichikawa†

*Japan Sewage Works Agency, 2-3-13, Toranomon, Minatoku, Tokyo 105, Japan

**Japan Sewage Works Agency, Nagano Construction Office, 4-739-2, Nagisa,
Matsumoto, Nagano 390, Japan

†Osaka Gas Engineering CO., Ltd 4-2, Nakamichi 1 chome, Higashinari-ku,
Osaka 541, Japan

ABSTRACT

The Coke-bed sludge melting process is used for incinerating sewage sludge and producing slag that is recycled as construction materials. The behavior of ash exiting the melting furnace was examined. Heating tests were carried out with different kinds of sludge. Heating from 600°C to 1200°C, weight reduction of around 30% was measured, but reduction rate was due to the kind of sludge. Weight reduction was big when heating up to 815°C, and reduction at a temperature over 815°C was due to the type of sludge. Main materials causing weight reduction were unburnt carbon (C) and some other elements like sulfur (S), chlorine (Cl), some metals like sodium (Na), potassium (K) and oxygen (O) released from some kinds of oxides. Even though very small quantity, zinc (Zn) and lead (Pb) were also vaporized. Some of these vaporized substances precipitate and produce fine particle dust at the low-temperature section of gas treatment facilities. Washing harmless salts out from the dust then recycling the dewatered dust in the melting furnace was found to be effective in maximizing slag recovery and reducing the precipitator load.

KEYWORDS

Sludge melting process, coke-bed, slag recovery rate, weight reduction, ash component, dust washing, heating test. Areawide Sewage Sludge Treatment.

INTRODUCTION

Since the amount of raw sewage sludge increases with increasing proliferation of sewers, the question of how to process and dispose of the sludge steadily and effectively is indeed an important one. Land-fill has been the major disposal method in Japan, with the incineration of raw sewage sludge being introduced into urban areas to reduce the volume of sludge (Murakami, 1989). However, even if the sludge is incinerated to ash and dumped in land fills, the long-term acquisition of disposal sites remains a serious problem in densely populated regions such as the Tokyo Metropolitan area and the Kinki district.

In these circumstances the Areawide Sewage Sludge Treatment and Disposal Project (or "ACE plan"), involving several local governments, was developed in 1986 to process raw sewage sludge for a wide area. In 1989, the Japan Sewage Works Agency began processing raw sewage sludge through the sludge melting process at two processing plants: one in North-eastern Osaka ACE Center in Hirakata city, Osaka; and the other is Western Hyogo ACE Center in Himeji city, Hyogo.

These two processing plants take in raw sewage sludge generated from wastewater treatment plants, produce slag from the sludge by the coke-bed melting process and recycle this slag as construction materials.

TABLE 1. Outline of ACE Centers

	North-eastern Osaka ACE Center	Western Hyogo ACE Center
Type of Sludge Handled	Lime Conditioned Sludge Polymer Conditioned Sludge	Lime Conditioned Sludge Polymer Conditioned Sludge Leather Treatment Sludge Gluey Sludge
Type of Melting Furnace, Capacity	Coke-bed Melting Furnace 10tDS/day x 2	Coke-bed Melting Furnace 40tDS/day x 4 trains
(Final Plan)	(10tDS/day x 2 trains) (15tDS/day x 1 trains)	(40tDS/day x 2 trains) (20tDS/day x 1 trains)

at 1993

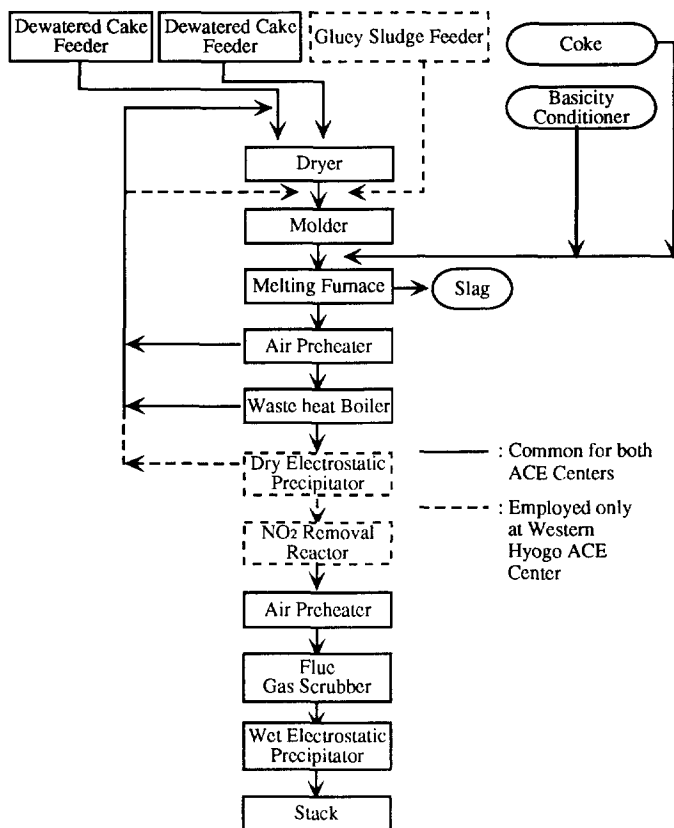


Fig. 1. Sludge melting process flow diagram.

Outlines of the processing plants and a flowchart of the melting process are given in Table 1 and Figure 1, respectively. Although the initial temperature of exhaust gas from the melting furnace is approximately

900°C, the gas is cooled to less than 400°C by recovering its heat through an air preheater and waste heat boiler.

In the case of the Western Hyogo ACE Center, because severe restrictions on dust and NO_x of exhaust gas are required by local regulation, the Dry ESP is employed for reducing dust and preventing clogging trouble of NO_x removal reactor.

PROBLEMS ASSOCIATED WITH THE MELTING PROCESS

Figure 2 shows the structure of a coke-bed melting furnace. The freeboard section on the upper side of the furnace serves as a combustion zone for combustible components contained in sewage sludge, and also as a settling and separating zone for dust particles blown up by combustible gases. The terminal velocity of the dust particles is calculated from equation (1) (Kunii *et al.*). The diameter of the free boards of the furnaces in the above-mentioned processing plants is larger than that of furnaces constructed before so that their dust separating performance is greatly improved (see Table 2).

$$U_t = \left[\frac{4g\phi_s D_p (P_p - P_f)}{3P_f C_d} \right]^{1/2} \quad (1)$$

U_t = terminal velocity, m/s
 g = gravitational acceleration, m/s²
 P_p = density of particle, g/m³
 P_f = density of fluid, g/m³
 D_p = diameter of particle, m
 ϕ_s = shape factor, -
 C_d = drag coefficient, -

Equation (1)

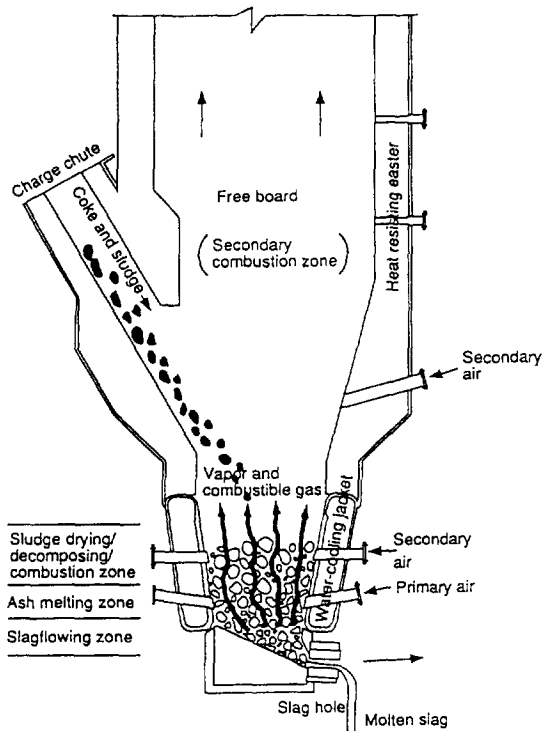


Fig. 2. Coke-bed melting furnace.

TABLE 2. Design Factors of the Furnace

	Demonstration Plant	North-eastern Osaka ACE Center	Western Hyogo ACE Center
Size of Freeboard Dia. x Height (mm)	∅ 1700 x 8800	∅ 2700 x 8800	∅ 5030 x 1200
Volume (m ³)	18.0	40.0	189.0
Retention Time of Flue Gas (sec)	3.1	6.0	6.0
Gas Velocity (m/s)	2.6	1.2	1.2
Maximum Size of Floating Dust (∅ mm)	0.40	0.20	0.20

Although the furnaces in the ACE Centers had all been designed to have the same capability for dust particle separation, the amounts of slag from the sludge mixture charged (i.e. sludge, coke and basicity controlling material) varied considerably, and the slag recovery rate was not satisfactory as shown in Table 3. (Note that the ash components are defined as the residue produced when the sludge is heated at a temperature of 600°C according to a test method specified in the Japanese Industrial Standard (JIS K0102).)

TABLE 3. Ash Balance

	Unit	Western Hyogo ACE Center	North-eastern Osaka ACE Center
Sludge	Kg-Ash/day	16,500	3,530
Coke	Kg-Ash/day	1,600	500
Basicity Conditioner	Kg-Ash/day	3,000	350
Total	Kg-Ash/day	21,100	4,380
Slag	Kg-Ash/day	14,300	3,430
Slag Recovery Rate	%	68	78

HEATING TEST OF ASH COMPONENTS

The low slag recovery rate is thought to be due to the fact that ash produced in the melting furnace turns both to 1) scattered ash dust, which is carried in the combustion exhaust gas, and also to 2) vaporized ash (vaporization being caused by the high temperatures inside the furnace) which is subsequently discharged by way of the gas exhaust line. The slag recovery rate has until now been based on the value of ignition residue measured at a temperature of 600°C. However, the slag recovery rate and the amount of ash vaporized at high temperatures both vary widely depending on the precise ash content of the sludge. For this reason, we carried out lab-scale tests on a wide variety of different sludges in order to ascertain the weight reduction and change in composition of the ash content produced by heating to high temperatures.

For the purposes of the current tests, sludge was heated to a high temperature in an electric furnace and the changes in weight and composition were measured.

The sludge used in the tests consisted of the four types of sludge typically handled by the two ACE Centers, namely lime conditioned sludge, polymer conditioned sludge, leather treatment sludge and gluey sludge.

The leather treatment sludge referred to here is that produced by the treatment of wastewater generated by the tanning process. Gluey sludge, on the other hand, is sludge of the sort produced by treating wastewater generated in the manufacture of gelatin from leather. This sort of sludge is high in animal proteins and congeals or solidifies readily when heated. Table 4 lists some of the components of these types of sludge.

TABLE 4. Characteristics of Sludge

Type of Sludge		Polymer Conditioned Sludge	Lime Conditioned Sludge	Leather Treatment Sludge	Gluey Sludge
VTS	(%D.B.)	72.4	52.3	65.6	54.4
Ash Component	Ca	(%A.B.) 4.3	27.1	18.4	31.8
	Si	(%A.B.) 12.0	3.9	4.4	1.4
	Al	(%A.B.) 6.8	2.2	1.3	0.4
	Fe	(%A.B.) 3.9	9.3	4.5	4.5
	P	(%A.B.) 8.0	2.2	0.9	1.6
	Cr	(%A.B.) 0.0	0.0	9.8	1.8
	Mg	(%A.B.) 1.7	1.0	2.6	1.8
	Na	(%A.B.) 2.9	0.3	1.3	0.3
	K	(%A.B.) 1.7	0.3	0.6	0.1
	C	(%A.B.) 21.0	10.0	11.0	10.0
	S	(%A.B.) 0.3	1.1	3.5	1.7
	Cl	(%A.B.) 0.7	1.4	1.3	0.4
	O	(%A.B.) 35.2	40.8	39.3	44.0
	Others	(%A.B.) 1.3	0.3	1.1	0.1

Each of the sludges was dried, separated into four crucibles for each, and heated strongly in an electric furnace for about 30 minutes at a temperature of about 600 +/- 25°C in accordance with the method prescribed in JIS K0102 for the measurement of ignition residue. The resultant ashes were each then heated separately to temperatures of 815°C, 1,000° and 1,200°C for approximately one hour after which the specimens were weighed and their components analyzed. The temperature of 815°C was used in the measurement of the ash content of the coal and coke (defined in JIS M8812).

Test results

(1) Changes in weight.

The changes in weight observed at each different temperature are shown in Figure 3.

The lime conditioned sludge and the gluey sludge exhibited weight reductions of between 24% and 29% when heated from 600°C to 815°C. Thereafter, they exhibited little further change up to 1,200°C. The polymer conditioned sludge and the leather treatment sludge, on the other hand, exhibited weight reductions of between 19% and 23% when heated from 600°C to 815°C and, although the subsequent rate of weight loss was lower, the final weights, measured after heating to 1,200°C, exhibited reductions to between 60% and 70% of the weights measured at 600°C.

The data indicate that sludges having higher VTS show more reduction at temperatures over 815°C.

(2) Changes in components

Constituent analyses were carried out on the specimens obtained by heating to different temperatures as described above. The results are shown in Figure 4, 100 represents the absolute amounts of all the elements measured at 600°C, with relative changes being subsequently recorded at 815°C and 1,200°C.

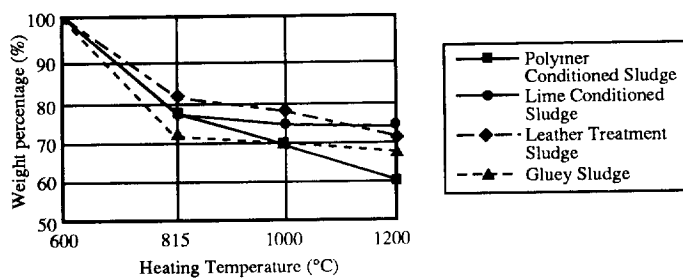


Fig. 3. Thermal reduction with different kinds of sludge (Based on ash measured at 600°C).

Results from the various kinds of sludge reveal that most components, e.g., Ca, Si, Fe, Al, Mg, Cr and P, remain relatively constant although there is some scatter. On the other hand, the alkali metals Na and K, unburnt carbon and S and Cl each exhibit very significant decreases at the higher temperatures. There is also a concomitant decrease in oxygen (O) levels.

There is some possibility that weight reduction in carbon is due to decomposition of carbonate, but all kinds of sludge show the decrease of carbon from 600°C to 815°C and only polymer conditioned sludge shows the reduction of carbon at a temperature over 815°C. Considering that most carbonates decomposed at a temperature over 800°C, most of the remaining carbon at 600°C can be assumed to be as unburnt carbon.

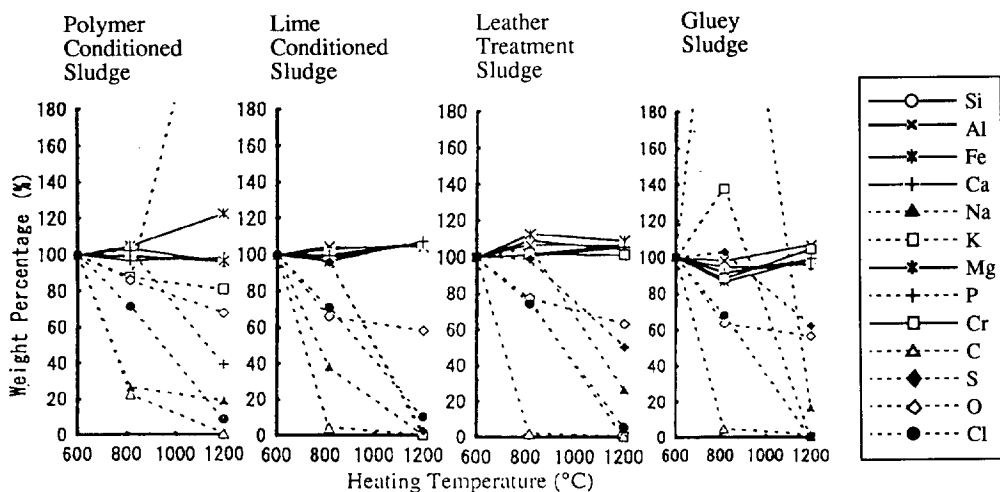


Fig. 4. Thermal reduction of each component of ash (Based on weight at 600°C).

Figure 5 shows the results obtained by grouping the amounts of ash recorded at 600°C and setting the absolute values to 100. Figure 5 shows that, even at 600°C, there are still substantial amounts of between 10% and 20% of combustible components, such as C, S or Cl, remaining. In the case of the lime conditioned and gluey sludges, these amounts are reduced to around 2% when the temperature is raised to 815°C. On the other hand, these elements are only reduced to about 5% in the case of the polymer conditioned and leather treatment sludges. This is a major factor in subsequent reduction when the sludges are heated from 815°C to 1,200°C. Oxygen levels are also substantially reduced during the above reductions, but the reduction in

oxygen is in fact about twice as much as would be required to account for the generation of CO, CO₂ or SO₂ from C or S. It has therefore been assumed that oxygen is being released from other oxides.

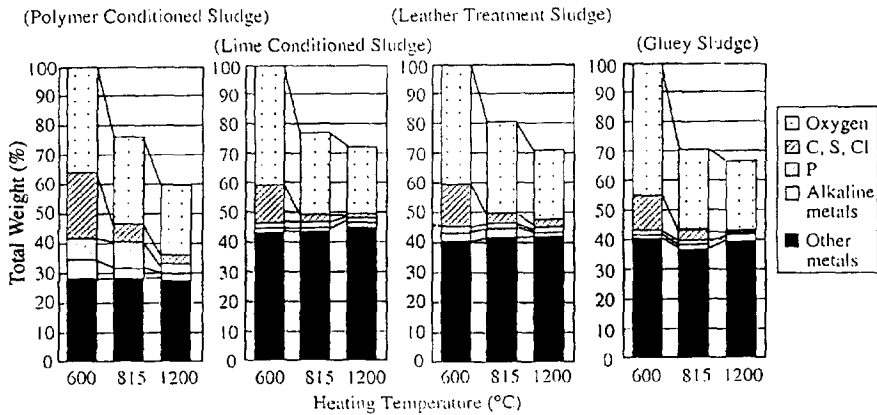


Fig. 5. Thermal reduction of each group of ash component (Based on ash measured at 600°C).

There are only minimal amounts of zinc and lead contained in the sludges and their visible effects are predictably also only minimal. At the same time, however, these metals have low boiling points and thus vaporize at comparatively low temperatures. The concentration of these elements in the ash of the sludges and the slag are shown in Table 5. Neither element was detected in the slags.

TABLE 5. Metals Having Low Vaporizing Point

	Ash Component	
	Zn (mg/kg)	Pb (mg/kg)
Polymer Conditioned Sludge	1560	210
Lime Conditioned Sludge	520	70
Leather Treatment Sludge	270	490
Gluey Sludge	800	40
All Slag	N.D.	N.D.

As shown above, the ash amounts measured at 600°C are reduced to about 70% of those levels by heating to 1,200°C. The ash balance was recomputed from Table 3 on the basis of these results and the result, which is shown in Table 6, clearly represents a closer match.

TABLE 6. Ash Balance (Based on Ignition Residue at 1200°C)

	Unit	Western Hyogo ACE Center	North-eastern Osaka ACE Center
Sludge	Kg-Ash/day	16,500 x 0.7 = 11,550	3,530 x 0.7 = 2,470
Coke	Kg-Ash/day	1,600	500
Basicity Conditioner	Kg-Ash/day	3,000	350
Total	Kg-Ash/day	16,150	3,320
Slag	Kg-Ash/day	14,300	3,430
Slag Recovery Rate	%	89	103

HANDLING OF ASH DUST

Scattered ash dust and vaporized ash components from the melting furnace are trapped in a high-temperature air preheater, a waste heat boiler (WHB) and dry-type electrostatic precipitator (Dry ESP). However, particularly at Western Hyogo ACE Center, the vaporized ash components are deposited at a relatively low temperature in the Dry ESP which is not employed at the Northeastern Osaka ACE Center. It is uncertain how these should be handled.

In Figure 6, ash components in the sludge mixture charged into the furnace at the Western Hyogo ACE Center are compared with those of dust from the high-temperature air preheater and WHB, dust from the Dry ESP and those of the slag obtained. The analyzed samples were taken from actual full-scale plants.

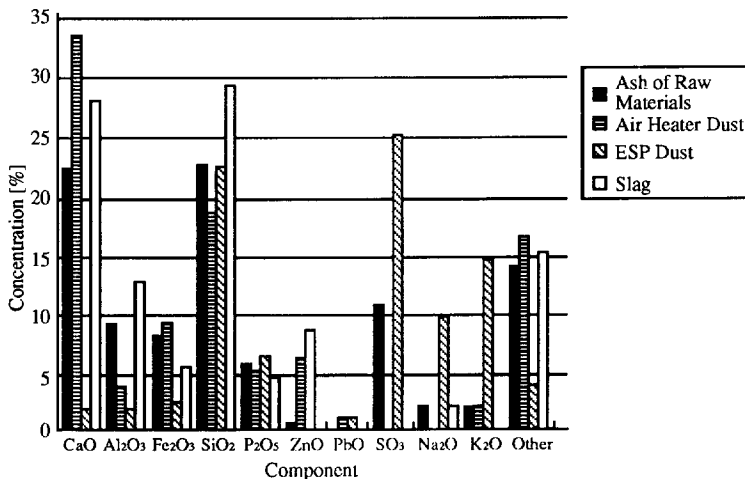


Fig. 6. Comparison of ash components.

It was found that dust trapped in the high-temperature air preheater and WHB contained elements such as Ca, Fe and Al, most of which should be integrated into the slag, while the dust trapped in the Dry ESP contained such elements as K, Na, and S, which are not supposed to be integrated into the slag.

Among such elements as Si/P and Zn/Pb contained in each of the dusts, the former two elements had been integrated into the slag, while the latter two elements had not. The Zn and Pb accumulate primarily in the dust. The transfer rate of each ash component of raw materials into the Dry ESP dust and the slag agreed well with the thermal reduction of ash components obtained at lab-tests (Fig 4, Table 5).

Therefore, in order to improve the recovery of slag in the melting process, it may be effective to recycle the dust collected in the high-temperature air preheater and WHB. This dust has a specific gravity of around 2.0 and a diameter of 0.3 ~ 0.5 mm. On the other hand, the dust obtained in the Dry ESP has a low bulk density of 0.2 ~ 0.4 and recycling this dust may be less effective and may produce such an adverse effect as the condensation of substances with lower boiling points.

In actual plants, lower boiling point substances, such as Zn, are deposited on the electrodes of the Dry ESP, causing the weakening of electric charges and other problems.

In the search for a solution, the application of a bag filter as a dust trap was considered. It has been reported that the average diameters of dust particles generated from a general multi-stage combustion furnace and a fluidized furnace are 1 to 3mm, and approximately 70 μ m, respectively (JWSA Report, 1976). On the other

hand, the diameter of dust particles trapped in the Dry ESP during the melting process is smaller than those. Figure 7 shows the distribution of particle diameters of Dry ESP dust.

There are two peaks at $1.5\mu\text{m}$ and $20\mu\text{m}$. Larger size particles are considered to be the dust swept out by the gas flow, and smaller size particles are precipitated from the vaporized material.

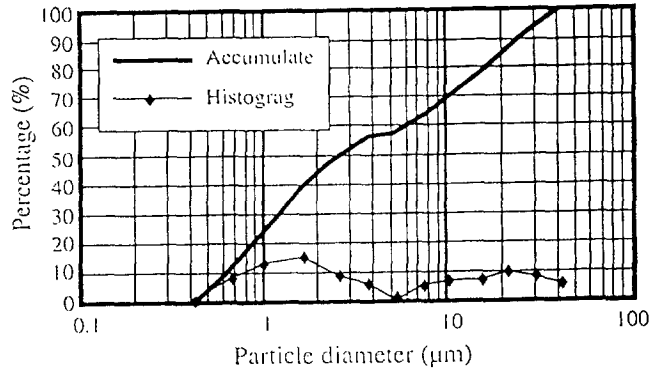


Fig. 7. Distribution of dust particle diameters.

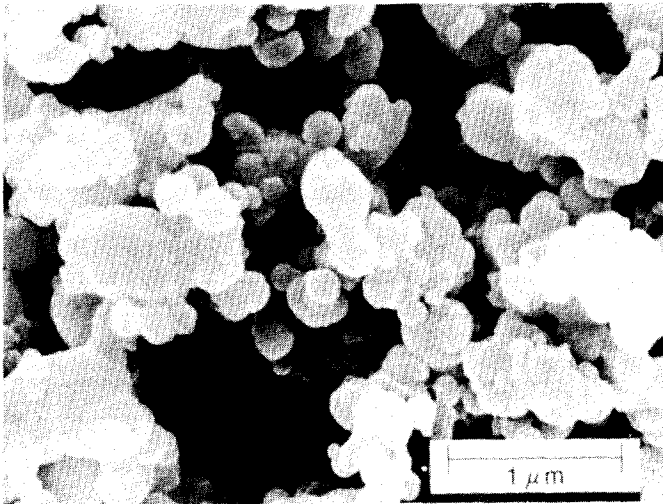


Fig. 8. Electron microscope photo of dust.

Figure 8 is a photo of Dry ESP dust with an electron microscope.

Most of the dust consists of agglomerations of submicron-sized particles and it is thought that the vaporized components precipitate when cooled in the low temperature zone.

These fine particles may cause filter clogging so that bag filters have not yet been used.

In view of the fact that the dust trapped in the Dry ESP contained a lot of water-soluble salts, the dust was recycled, after being washed with water to reduce the load to the Dry ESP, and a satisfactory result was obtained.

By this dust washing method, harmless salts of Na, K and S contained in the dust were dissolved in water and removed as shown in Figure 9. After being precipitated, separated and dewatered, the residual components of the dust were re-fed into the melting furnace. This method provided a higher slag recovery rate, while reducing the load to the Dry ESP.

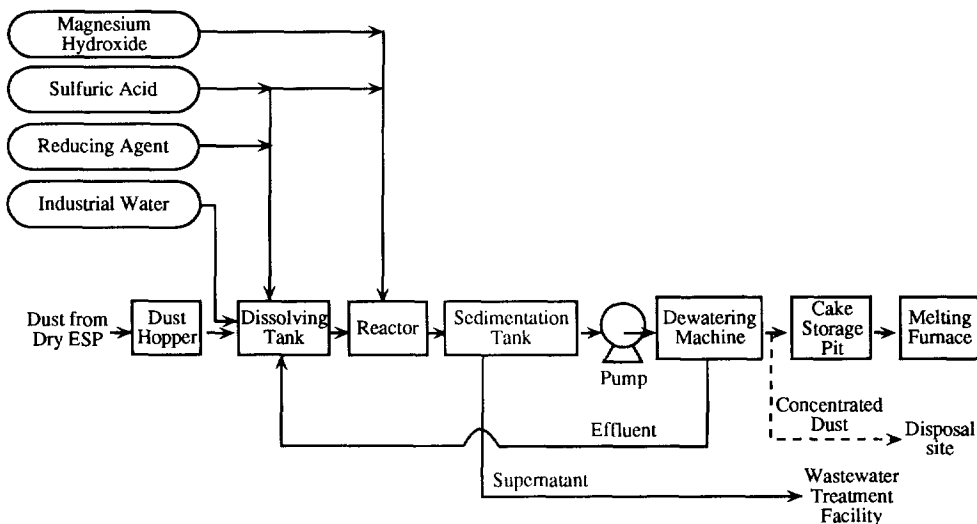


Fig. 9. Dust-washing facility flow diagram.

Table 7 shows the recovery of each component after the dust was processed by this washing method. (Note that the pH of water used in this process should be maintained in the neutral range to prevent leaching of Zn and Pb.) When the concentrations of Zn and Pb in the dust become higher because of dust recycling, the washed dust should be removed from the system and properly treated.

TABLE 7. Recovery by Washing Dry ESP Dust

	Raw Dust (g)	Washed Dust (g)	Recovery Rate
CaO	19	14	76%
Al ₂ O ₃	17	16	93%
Fe ₂ O ₃	23	22	96%
SiO ₂	220	220	100%
P ₂ O ₅	70	63	91%
ZnO	87	79	90%
PbO	16	14	91%
K ₂ O	151	28	19%
Na ₂ O	101	18	18%
SO ₃	255	9	4%
Other	41	33	80%
Total	1,000	516	52%

CONCLUSION

We have examined the scattered ash dust and vaporized ash components in the sludge melting furnace and the method of processing trapped dust. The findings of these examinations are summarized as follows.

- (1) Some particles generated in the furnace are swept out and scattered and others are vaporized by heat and deposited in gas treatment equipments.
- (2) Such elements as Na, S, Zn and Pb are vaporized while the temperature is raised from 600°C to 1200°C. Depending on the sludge type, up to 30% of ash components in sludge is vaporized.
- (3) Dust particles trapped in the high temperature section can be separated easily because of their high specific gravity. To increase slag recovery it is very effective to re-feed this dust, then recycle.
- (4) Dust particles trapped in the low temperature section are very fine, and most of them are generated as a result of precipitation of vaporized ash components. Before the recovered dust is re-fed into the furnace, harmless salts can be removed by washing out with water, thus reducing the load to the dust precipitator.

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