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OPERATION RESULTS OF THE SEWAGE SLUDGE MELTING SYSTEM AND ESTIMATION OF SCALE-UP METHOD FOR THE REFLECTOR TYPE MELTING FURNACE

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ABSTRACT

Sludge melting systems have been recently applied to the treatment of a great deal of sludge generated from sewage treatment plants, and the plant scale has become bigger and bigger in accordance with the social requirements. This paper reports operating data of one of the biggest scale melting plants for sewage sludge equipped with two reflector type melting furnace trains and includes running cost data as well as estimates for scaling up the process.

KEYWORDS

Sewage sludge, reflector type melting furnace, slag, exhaust gas, utility consumption, air distribution system, fluid flow analysis, load per bed area.

INTRODUCTION

Because of the increasing size of sewage systems, the treatment of large amounts of sludge generated form sewage treatment plants has become a great problem in Japan. Especially in heavily populated regions, it becomes almost impossible to secure final disposal sites for sludge.

In consideration of the above circumstances, a new 'completed area wide sewage sludge treatment and disposal projects' 'ACE PLAN' has been implemented since 1986 to cope with requirements of local municipalities featuring:

- effective treatment and disposal by centralization of treatment capacity collecting sludge from neighbouring treatment plants

– effective use (no disposal) by adoption of the melting system.

Provided here is the outline of the melting system employed for one of the above mentioned projects, operational results and estimation of the scale-up factors for the core equipment, i.e. 'reflector type melting furnace', to enable the treatment of large quantities.

THE ACE SEWAGE SLUDGE MELTING PLANT

The plant treats two (2) different types of sludge. One is lime-dosed dewatered sludge (cake) transported by vehicles from neighbouring sewage treatment plants and the other is polymer-dosed dewatered sludge. The polymer-dosed sludge is thickened and dewatered in the ACE center after being transported from neighbouring treatment plants by means of a piping system. Therefore, two (2) types of sludge are actually mixed before being treated with the mixing ratio of about one to one. This enables the reduction of the melting temperature of sludge by adjustment of the basicity.

The plant has two (2) melting furnace trains. The capacity of one furnace is twenty five (25) tons-dry solid per day. Figure 1 shows the outline of the treatment.

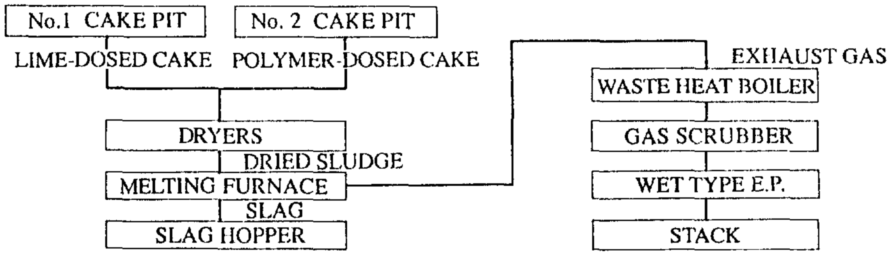

Fig. 1. Basic flow.

Sludge dryer

Dewatered sludge is dried in a low temperature indirect heating type dryer using steam until the moisture content is 20% of so. The ability to decrease the moisture content to 20% from 78% in a single stage allowed us to adopt the spiral type drive.

Melting furnace

Dried sludge is constantly fed into the melting furnace. This is a reflector type melting furnace with the structure shown in Figure 2.

The reflector melting furnace consists of a feeding hopper, primary combustion chamber and secondary combustion chamber. The primary combustion chamber is of a conical shape in the roof of which the combustion aiding device is incorporated. The heat generated by the burning sludge reduces the external heat input required for the melting process. The furnace is of a vertical rotating type. The inner cylinder is held stationary while the outer cylinder rotates. Feeding the sludge into the primary combustion chamber is performed evenly around the full circumference by rotating the outer cylinder slowly. Also moving the internal cylinder up and down , which is the roof of primary combustion chamber, makes it possible to adjust the capacity of the combustion chamber. Sludge melted in the melting furnace is taken out as slag from the bottom of the furnace. In the primary combustion chamber, just the necessary calorific value of the dried sludge is incinerated to maintain the temperature at above 1300°C and the rest is completely burned as decomposed gas in the secondary combustion chamber. In this way, double stage combustion in the reflector melting furnace generates less than 150 ppm of nitrogen oxides (NOx).

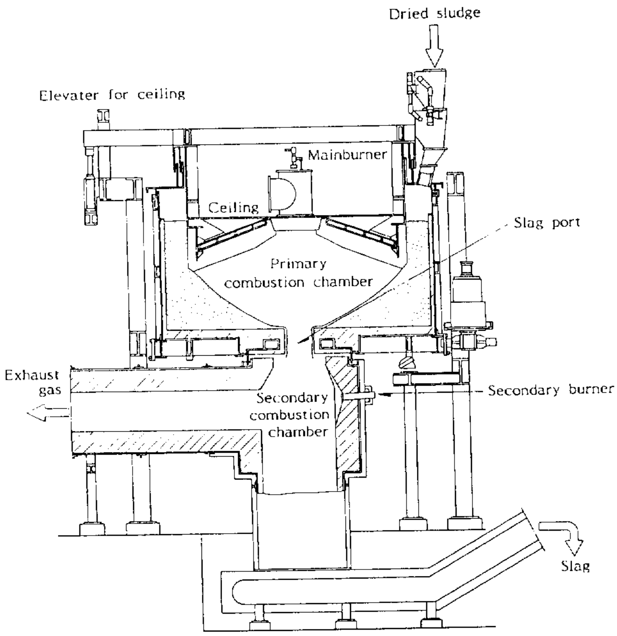

Fig. 2. Structure of melting furnace.

Waste heat boiler

Because of the high temperature of the exhaust gas from the melting furnace, the heat in the gas is utilized for drying the sludge. The recycling facility consists of the waste heat boiler and its auxiliary equipment. For the design of the heat recycling facility, the exhaust gas temperature at the inlet of the waste heat boiler is 1100°C while the exhaust gas temperature at the outlet is 230°C.

Exhaust gas treatment facility

This is a facility to remove components like SOx, HCl, dust and others from the exhaust gas. After cooling down to 40°C–60°C in a cooler mounted at the lower part of the exhausted gas treatment tower, SOx and HCl are removed from the exhaust gas by the $Mg(OH)_2$-rich liquid circulated in the upper part of the absorption tower. Furthermore, dust is removed by a wet type electrostatic precipitator.

THE ACE SEWAGE SLUDGE MELTING PLANT

Performance test results

The performance test of the plant was undertaken for three months from November 1990 through January 1991. The test was planned with three (3) variations as follows:

– treatment of only polymer-dosed sludge (RUN1)

– treatment of only lime-dosed sludge (RUN2)
– treatment of mixed sludge of polymer-dosed sludge and lime-dosed sludge (RUN3).

Table 1 shows operational data for the furnace. The data are average figures for a day.

TABLE 1. Performance Test Results (Furnace)

Date (1990 ~ 1991)		Nov. 08	Dec. 25	Jan. 10	
RUN NO.		1	2	3	Design Value
Sludge		Polymer	Lime	Mixed	–
Sludge properties					
• Moisture content	(%)	13.0	5.4	20.0	20~30
• Volatile content	(%)	60.8	51.0	50.2	70
• Ash content	(%)	39.2	49.0	49.8	30
• Higher calorific value	(kcal/kg)	3631	2815	2908	4000
Results					
• Combustion air quantity of primary combustion chamber (PCC)	(Nm^3/h)	4766	5240	4200	3244
• Combustion air temperature of PCC	(℃)	348	500	390	300
• Dried sludge feeding rate	(kg/h)	1076	1093	1160	1042
• PCC temperature	(℃)	1400	1373	1336	1400
• Air quantity for secondary combustion	(Nm^3/h)	1800	1800	2000	2400
• Secondary combustion chamber temperature	(℃)	1038	1029	989	1100
• Slag generation quantity	(kg/h)	409	520	560	312.5
• Steam generated	(kg/h)	3340	3380	2910	4260
• Oil consumption	(ℓ/h)	0	64	48	–

Table 1 shows that data for each case basically satisfied the design requirements although the sludge properties varied significantly. The reason the steam generation for each case was less than the design value is because the higher calorific values are smaller than the design value.

Table 2 shows the data measured on each run for the properties of the exhaust gas.

TABLE 2. Exhaust Gas Analysis Resutls*

RUN NO.		1	2	3	Design Value
Gas quantity at outlet of the boiler	(Nm^3-dry/h)	8800	9900	8200	
Content of oxygen at outlet of the boiler	(%)	9.6	9.2	10.4	
NOx (12% O_2)					
• at outlet of the furnace		63	57	101	150
• at outlet of the boiler		35	44	43	110
SOx (12% O_2)					
• Scrubber inlet	(ppm)	1740	389	798	517
• Scrubber outlet	(ppm)	26.7	8.5	40	20
HCl (12% O_2)					
• Scrubber inlet	(mg/Nm^3)	522	1790	848	2730
• Scrubber outlet	(mg/Nm^3)	< 9	17.9	< 9	700
Dust					
• Furnace outlet	(g/Nm^3)	2.06	2.42	2.4	3.0
• at stack (12% O_2)	(g/Nm^3)	0.001	0.027	0.02	< 0.02

* De-NOx device, i.e. NH_3 injection device is employed in the boiler.

The double combustion system for NOx reduction has resulted in a low value of nearly 100 ppm in spite of the combustion at high temperature in the furnace.

Treatment records

Figure 3 compares sludge input quantities to the plant and the treated quantities in the plant.

The month-average sludge input was 1041 ton-dried sludge(tds) and the quantity of treated sludge in the plant was almost equal to the sludge input.

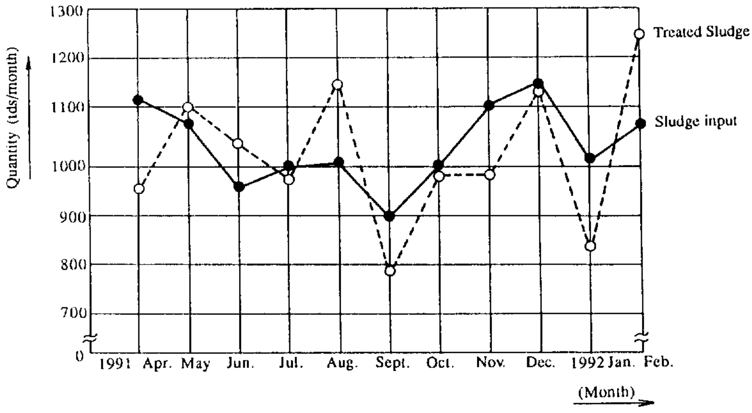

Fig. 3. Sludge input and the treated sludge.

As shown in the Figure, the plant was operated to accommodate the quantity of input sludge though it varied 20% of the average in each season. The operation ratio, i.e. the treatment capacity versus the designed capacity (25 tds/day), is about 67%.

Cost evaluation

Table 3 shows the plant running costs compared with another plant, 'Futagami Plant', which has the same reflector type melting system but os considerably smaller capacity.

The Table shows that most of the utility consumption is for auxiliary oil and electricity and that the running cost is affected by the plant scale. This means that the area wide sewage sludge treatment system is effective in this aspect as well.

ESTIMATION OF THE SCALE-UP FACTOR FOR THE FURNACE

As indicated in Table 1, it was confirmed that the dried sludge feeding rate satisfied the design value (1042 kg/h). But at the design stage, we had not enough confidence to design the 25 tds furnace because we only has operating data for the 5.3 tds sludge melting system furnace which was mush smaller than the 25 tds furnace. Figure 4 shows the visual comparison of scale for out reflector type melting furnace. The dot-lined furnace is for an ash melting system in which the melting process is much different from that of the sludge melting system since ash has few combustibles.

TABLE 3. Running Costs Data Per Month

Plant		ACE	Futagami
Capacity	(tds/day)	25 (×2 trains)	5.3 (×1 train)
Treated sludge quantity	(tds)	1151	115
Slug generated	(t)	352	26
Operation days	(days)	25	23
Utility consumption			
• Auxiliary oil	(ℓ)	241600 (210)	28000 (243)
• Electricity	(kWh)	706230 (614)	92500 (804)
• City water	(m^3)	2617 (2.27)	370 (3.2)
• Industrial water	(m^3)	32920 (28.6)	19800 (172)
• Chemicals		54000 kg (46.9)	5200 ℓ (45.2)
• Sand-filtered water	(m^3)	160430 (139)	—
• SiO_2 (for basicity adjustment)	(kg)	11000 (9.6)	—
Total cost	(yen)	26.5×10^6 (23000)	3.41×10^6 (29600)

* ( ) indicates data per t-dried sludge.

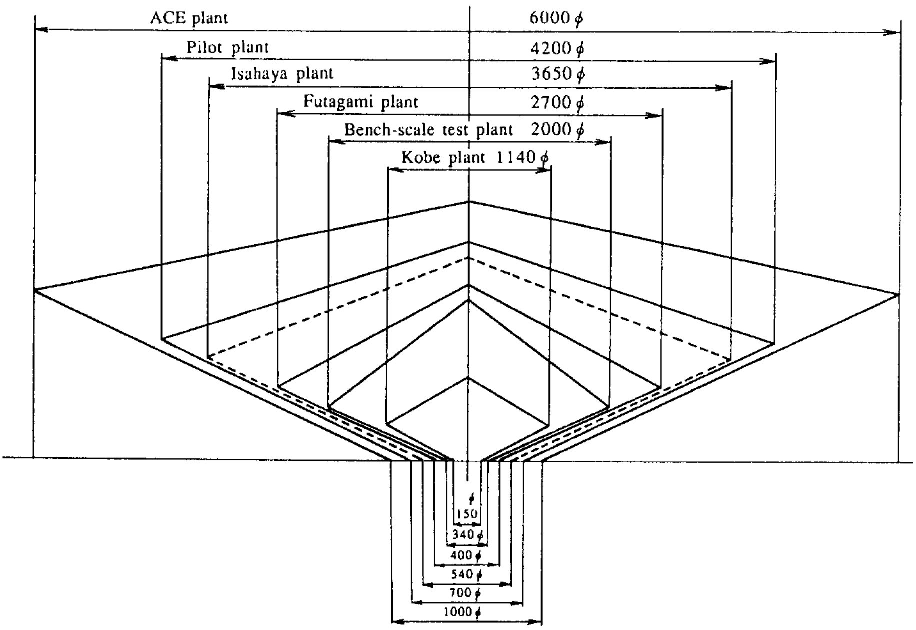

Fig. 4. Visual comparison scale (dimensions marked in mm).

Therefore, before designing the 25 tds furnace, a pilot plant with the capacity of 12.5 tds (half of 25 tds) was constructed and confirmation tests were undertaken for 2 years.

Pilot-scale test

As shown in figure 4, the inner diameter of the plant is 4.2 metres. The main aim of the test was to secure the design capacity, i.e. 521 kgds/h by effective sludge combustion in the primary combustion chamber using the combustion air distribution system.

Figure 5 shows the air distribution system for the primary combustion chamber.

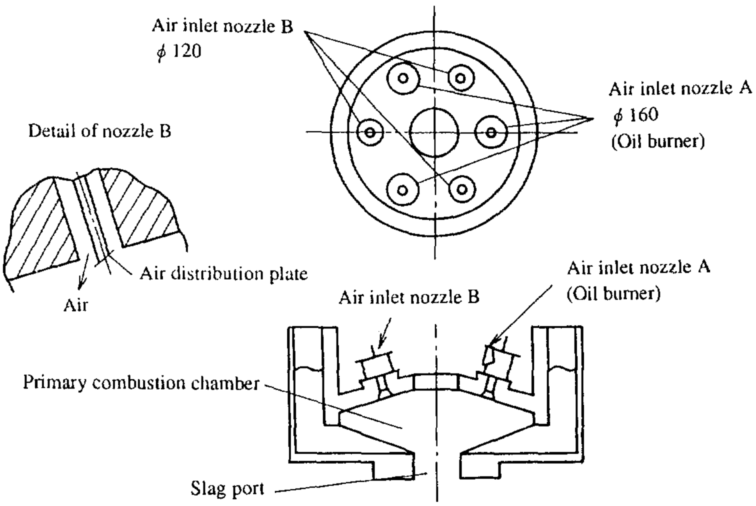

Fig. 5. Air distribution system.

The primary combustion chamber has three (3) air inlet nozzles A through the oil burner and three (3) air inlet nozzles B. Air inlet nozzle B has an air distribution plate at the top of the nozzle to let the combustion air blow toward the outside of the chamber for effective sludge combustion there.

Table 4 shows the operation data of the test.

TABLE 4. Operation Data of Air Distribution System

Unit		RUN1	RUN2	RUN3
Air distribution rate (Air Q'ty through nozzle B/Total air Q'ty)	–	0.24	0.5	0.7
Moisture content of dried sludge (ds)	(%)	34.4	20.2	20.2
Volatile content of ds	(%)	70.2	59.5	59.5
Basicity of ds	–	0.23	1.0	1.0
Sludge feeding rate	(kgds/h)	360	473	704
Oil consumption	(ℓ/h)	53.5	36.4	24.0
Combustion chamber temperature	(℃)	1288	1353	1330

Data in Table 4 are indicated in Figure 6 as well.

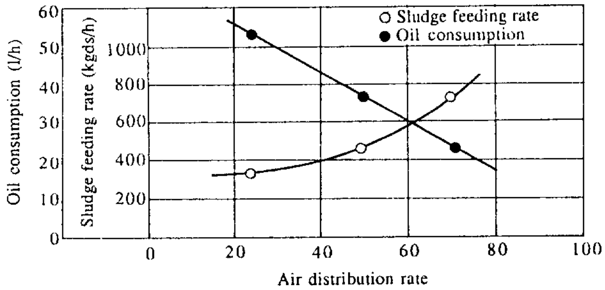

Fig. 6. Operation data of air distribution system.

Table 4 shows that the air distribution system is clearly effective for the furnace capacity and for reduction of oil consumption. The reduction of oil consumption means that the air distribution toward the outside of the furnace results in effective combustion of sludge just when the sludge is fed into the furnace.

Fluid flow analysis in the primary combustion chamber

To confirm the above mentioned effectiveness of the air distribution, a theoretical fluid flow analysis was undertaken using differential calculus.

The analysis model for ambient temperature and the following basic equations are employed:

(a) Continuous equation

$$\frac{\partial Vi}{\partial Xi} = 0$$

(b) Navier-Stokes equation of motion

$$\frac{\partial Vi}{\partial t} + \frac{\partial ViVj}{\partial Xi} = - \frac{\partial P}{\partial Xi} + \frac{\partial}{\partial Xj}\left| V\left(\frac{\partial Vi}{\partial Xj} + \frac{\partial Vj}{\partial Xi}\right)\right| - gi\,\beta\,\Delta T$$

where : Xi ; position vector
Vi ; velocity vector
P ; Pressure/density
V ; coefficient of kinematic viscosity
β ; coefficient of cubic expansion
gi ; gravitational acceleration
T ; temperature

In the Navier-Stokes equation of motion, the coefficient of kinematic viscosity is calculated by means of Boussinesq's model of kinematic viscosity as applied to turbulent flow.

Table 5 shows the analysis conditions.

Table 6 shows the air distribution conditions.

Two examples of the analysis result are shown in Figure 7 and Figure 8. The figures show that the air velocities around nozzles A are reduced and the air velocities in the chamber become equal when the air quantities from nozzles B become larger (Case 2).

TABLE 5. Analysis Conditions

Analysis conditions	(1) Fluid is of in compressible fluid. (2) Fluid temperature is constant (ambient). (3) Combustion chamber is of symmetric model.	
Analysis grid	X (horizontal) Y (horizontal) Z (vertical)	42 divisions 21 divisions 42 divisions

TABLE 6. Air Distribution Conditions

	Case 1	Case 2
Air inlet nozzle A	800 Nm^3/h	600 Nm^3/h
Air inlet nozzle B	200 Nm^3/h	400 Nm^3/h
Total	1000 Nm^3/h	1000 Nm^3/h

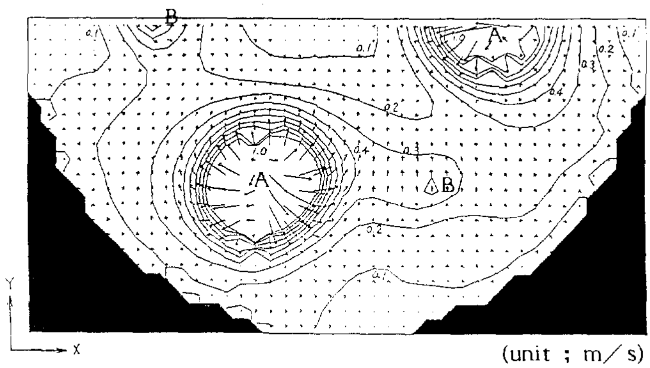

Fig. 7. Velocity vector (Case 1).

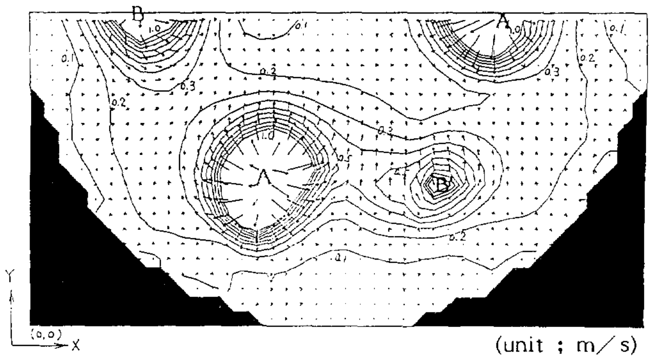

Fig. 8. Velocity (Case 2).

Confirmation of 'load per bed area'

The scale of the reflector type melting furnace is determined basically by means of 'load per bed area'. On the other hand, the results of the pilot scale test confirm that the capacity of the furnace is enhanced by the effective combustion of the volatile materials. That means the 'load per bed area' is a function of the volatile materials. Figure 9 shows the relation between the volatile materials and the 'load per bed area'.

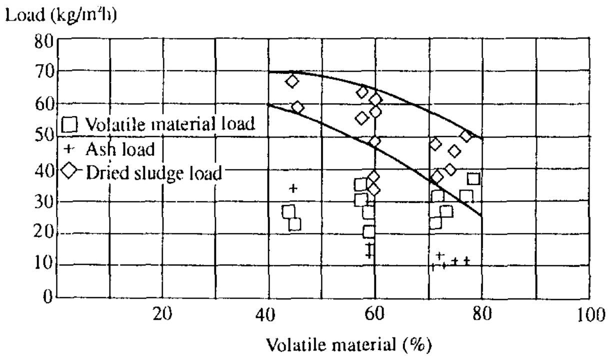

Fig. 9. Volatile materials and load per bed area.

In accordance with Figure 9, the 'load per bed area' for the 25 tds furnace was set at 38 kgds/m^{2}h because the design figure for the volatile materials was 70%. Similarly, the inner diameter of the furnace was set at 6.0 metres. The scale-up history of the furnace is summarized in Table 7.

TABLE 7. Scale-Up History of the Furnace

	Demonstration Plant			Commercial Plant		
Model	1300	2000	5000	3000	3800	6800
Location	Kobe Plant	Laboratory Kubota	Osaka Plant	Futagami Plant	Isahaya Plant	ACE Plant
Treatment object	Sewage sludge	Sewage sludge, refuse, ash (Bench-scale test plant)	Sewage sludge (Pilot plant)	Sewage sludge	Municipal waste incinerated residue	Sewage sludge
Treatment Capability	2.5 t/d × 1 unit	2 - 6 t/d × 1 unit	12.5 t/d × 1 unit	5.3 t/d × 1 unit	12.3 t/d × 1 unit	25 t/d × 2 unit
Combustion Chamber Inner Diameter	1140 mm	2000 mm	4200 mm	2700 mm	3650 mm	6000 mm
Operation Period	Delivered in Mar., 1979	Aug., 1985 to today	From Dec., 1988	Delivered in Aug., 1988	Delivered in Mar., 1987	Delivered in Dec., 1990

CONCLUSION

We have described the operational data of one of the biggest sludge melting plants in Japan as well as the scale-up method for the reflector type melting furnace which the plant employs. Since we have another project employing a larger melting furnace of 35 tds/day, we are now accumulating further data for scale-up.

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