ENERGY SAVING IN SEWAGE SLUDGE INCINERATION WITH INDIRECT HEAT DRYER

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ABSTRACT

Among the management costs of sewage sludge treatment, the operational cost of sludge incineration is the greatest and should be reduced in view of the energy savings.

A recently constructed 96 tpd (106 TPD) sewage sludge incineration plant near Tokyo, Japan, features indirect-heat sludge dryers with recovered heat utilization, which is the first of its kind.

Moisture is removed out of the sludge stream to improve consumption of supporting fuel at the fluidized bed incinerator to less than a quarter of conventional ones or even zero.

This system also increased the acceptable sludge capacity of the incineration plant due to its advantage of moisture removal before incineration, as well as achieving a very stable incineration condition.

INTRODUCTION

In the incineration of dehydrated sewage sludge cake from the regional sewage treatment plants, much supporting fuel is consumed by the conventional type incinerators. Therefore, some counter-measures for energy savings are required in this fuel consumption.

Conventional fluidized bed incinerator processes have already utilized the preheated combustion air by the heat recovery of incinerator exhaust gas, but this heat utilization is not enough.

Here, to achieve better heat recovery and higher plant utilization, a new system was developed. An additional heat exchanger was installed and the dehydrated sludge cake was dried indirectly by this recovered heat, to reduce the sludge volume and improve the combustion condition, and save a great amount of combustion supporting fuel.

This paper introduces the operational data of this newly constructed commercial plant which has been operated since February, 1984.

GENERAL DESCRIPTION OF PLANT

This sewage treatment facility is processing about 60,000 t of regional sewage water with the normal activated sludge method, and the gravity-thickened sludge is dewatered by the belt press type dehydrator and then incinerated in this incineration plant, of which general descriptions are shown in Table 1. The incineration process with drying is shown in Fig. 1.

Dehydrated sludge cake is conveyed by belt to the constant feeder, and then pumped up to the indirect-heat cake dryers, where thermal oil, which is heated by incineration exhaust gas, heats up the sludge cake indirectly via hollow screw surfaces to evaporate the

TABLE 1 GENERAL DESCRIPTION OF INCINERATION PLANT

Location	Arakawa river regional sewage treatment facility, Saitama Prefecture, Japan
Plant capacity	96 metric tons per day with drying
	80 tons per day at and after fluidized bed incinerator
Processes	
Cake receiving and feeding	Hopper with constant screw feeder and belt weigher
Cake transportation	Mohno type one axis eccentric sludge pump and pipings
Cake drying	Hollow screw type indirect heat dryers with thermal oil
Incinerator	Fluidized bed incinerator (12 ft I.D.[3.64m I.D.])
Air heater	Shell and tube type air heater
Heat recovery	Tube type thermal oil heat exchanger (Waste heat boiler)
Gas treatment	Cyclone, Gas scrubbing tower, wet E.P.
White smoke prevention	Dehumidifier with direct water cooling, and hot gas mixture
Other	Shot cleaning system for dust removal
	SS filter for waste water

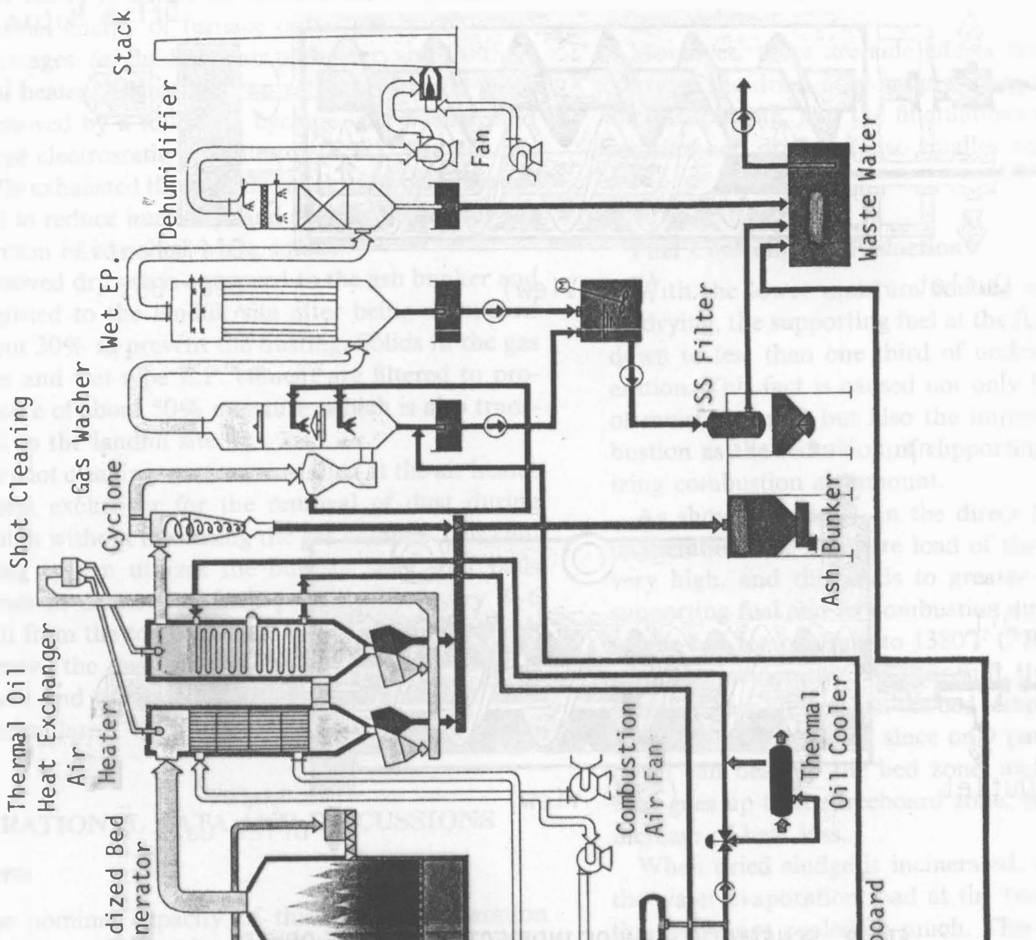

FIG. 1 SIMPLIFIED FLOW DIGRAM OF SEWAGE SLUDGE INCINERATION PLANT WITH INDIRECT HEAT DRYER

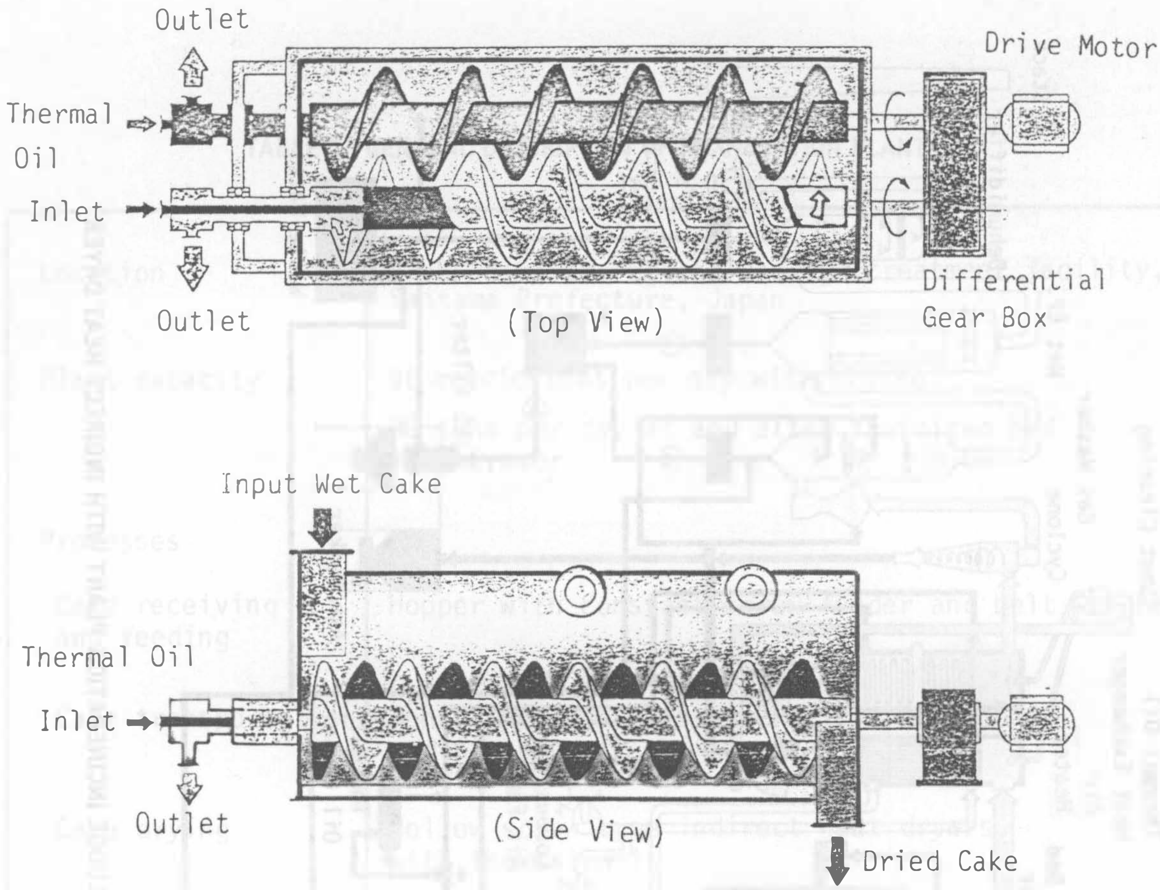

FIG. 2 SCHEMATIC VIEW OF INDIRECT HEAT CAKE DRYER

moisture and reduce the cake volume by more than 20% as well as the production of higher calorific value per unit volume. Dried sludge cake is then pumped again to the cake feeders at the side of fluidized bed incinerator, and incinerated almost instantly.

A schematic view of cake dryer is shown in Fig. 2. This is designed as a hollow screw type where thermal oil of about 480°F (250°C) flows inside the screws to have the indirect heating for the drying of sludge outside the screws while conveying. By the differential action of changing the rotational phase, one side of paired screw moves to and fro periodically to approach the surfaces of the other screw faces to achieve the (self-)cleaning of the heating surfaces of dryers.

Evaporated water content of sludge cake is induced to and condensed by the jet condenser type gas washer, and then the condensate flows back to the sewage treatment facility, that is, the evaporated moisture with little volume of low-boiling point volatiles is separated from the combustion process stream. The small amount of uncondensed vapor and leaked air mixture is induced by fan to the freeboard zone of fluidized bed incinerator, where odor compositions are decomposed at a high temperature of about 1470°F (800°C) or more.

Through this dryer, the sludge cake is produced at a lower ratio of moisture, which creates a lower rate of supporting fuel for less water evaporation at the incinerator. Furthermore, the dried sludge can be incinerated in much better condition of stable and uniform temperature distribution inside the furnace, to achieve greater fuel savings.

Thermal oil is circulated in a completely closed cycle, and heated to about 480°F (250°C) by the exhaust gas/thermal oil heat exchanger. Then it is circulated between the cake dryers and the heat exchanger at a low pressure of about 72 psi (500 kPa), where the system is automatically controlled only by three flow control valves to adjust the thermal oil temperatures.

Thermal energy of furnace outlet gas is recovered in two stages: *(a)* fluidizing air preheater; and *(b)* thermal oil heater. Then the flown ash and harmful gases are removed by a following cyclone, gas washer, and wet-type electrostatic precipitator (E.P.). The flue gas is finally exhausted through the stack after being water-cooled to reduce humidity, and slightly heated for the prevention of so-called white smoke.

Removed dry ash is conveyed to the ash bunker and transported to the landfill site after being dampened to about 30% to prevent the dusting. Solids in the gas washer and wet-type E.P. effluent are filtered to produce cake of about 50% moisture, which is also transported to the landfill site.

The shot cleaning system is installed at the air heater and heat exchanger for the removal of dust during operation without increasing the gas volume. This shot cleaning system utilizes the bulk of steel shot balls 3–5 mm in diameter, which periodically (every 3–6 hr) fall from the top of heaters with scattering actions to remove the dust on the element surfaces. Dust is removed and separated at the bottom and shot balls are recirculated.

OPERATIONAL DATA AND DISCUSSIONS

General

The nominal capacity of this sludge incineration plant is 80 tpd (96 TPD with drying) and operated by adjusting the operation hours in accordance with the daily amount of produced dehydrated sludge cake, as the combination of day-time and continuous 24 hr/day operation.

Table 2 shows the operation data at continuous operation conditions. In Fig. 3, the changes of moisture and effective heat value (lower calorific value at wet basis) before and after the drying process.

Effect of Cake Drying

As shown in Fig. 3 and Table 3, the ratio of evaporated moisture is 22–25% of the inlet sludge cake weight, which makes the reduction of sludge volume at such a rate, as well as being able to achieve the improvement of calorific values of 2.3–2.4 times for better combustion property, as shown in Table 4. The evaporated moisture is removed out of the combustion stream, and the water evaporation load at the incinerator is reduced. These facts allow the increase of plant capacity and the energy savings of fuel consumption per unit volume of received sludge cake, with fewer plant utility costs and smaller equipment operational volumes.

Moreover, there are side effects such that the viscosity of the dried hot sludge is observed to be easier for transporting, and the fluctuations of furnace temperature and draft are also smaller and stable.

Energy Saving Effect

Fuel Consumption Reduction

With the lower moisture content of sludge caused by drying, the supporting fuel at the furnace is reduced down to less than one third of undried sludge incineration. This fact is caused not only by the reduction of moisture itself, but also the improvement of combustion as the reduction of supporting fuel and fluidizing combustion air amount.

As shown in Fig. 4, in the direct (undried) sludge incineration, the moisture load of the fluidized bed is very high, and this leads to greater consumption of supporting fuel and its combustion air volume to keep up the bed temperature to 1380°F (750°C) or more for complete incineration. As the result, the freeboard temperature goes higher than the bed temperature by about 180°F (100°C) or more, since only partial heat energy of oil can heat up the bed zone, and the rest of the heat goes up to the freeboard zone, which leads to an increase of heat loss.

When dried sludge is incinerated, on the contrary, the water evaporation load at the bed is smaller, and the bed is not cooled so much. This leads to the reduction of supporting fuel and its combustion in air. Therefore, as shown in Fig. 5, the most favorable combustion state of homogeneous temperature distribution can be achieved inside the furnace from bed to freeboard and outlet, and total energy saving is performed to save about 70% or more of fuel consumption.

Plant Capacity Increase

The maximum capacity of fluidized bed furnace is mainly determined by the moisture load [e.g., 0.33 lb H_2O / in.^{2}hr (230 kg H_2O/m^2h)] and by the exhaust gas volume due to the fans' capacities. The drying of cake can reduce both of these values, as shown in Tables 5 and 6.

By calculating these values in Table 6, there is still 17% [(80 × 0.847)/(96 × 0.601) = 1.17)] more capacity of moisture load and still 30% [(80 × 4.018)/(96 × 2.564) = 1.306] more of wet gas volume at 96 tpd dried (80 TPD undried × 1.2). This indicates that the application of the drying process can increase the capacity of the incineration plant by more than 20%, assumedly 40% (1.2 × 1.17 = 1.40). In other words, any existing sludge cake incinerator plant can increase

TABLE 2 OPERATIONAL DATA

	Direct Incineration (without drying)			Incineration with dried cake				
	Design	Run 1	Run 2	Design	Run 3	Run 4	Run 5	Run 6
1. Input cake (tpd)	80	60	80	96	60	80	96	70
2. Cake property								
moisture (%)	78	83-86 (84.7)	←	75-80 (78)	83-86 (84.8)	←	←	78-80 (79)
combustibles (%ds)	56-64 (60)	80.2-80.7 (80.5)	←	56-64 (60)	80.1-80.2 (80.2)	79.1-79.4 (79.3)	79.3-80.4 (84.7)	(80)
lower heating value (MJ/kg ds)	12.6	18.5-18.9 (18.7)	←	12.6	18.7	18.8	18.5	18.8
3. Dried cake								
moisture (%)	ditto	ditto	ditto	66-73 (70)	80.1-80.9 (80.6)	79.8-80.6 (80.2)	79.2-80.2 (79.7)	70-72 (71)
weight (tpd)	80	60	80	70	46.7	61.8	72.4	43
4. Supporting fuel								
(liter/h)	312	238	265	47	92	94	96	0
(liter/ton cake)	94	95	80	12	37	28	24	0
5. Furnace temperature								
sand bed (°C)	800	790	780-820 (800)	800	770-810 (780)	770-810 (780)	760-810 (780)	(780)
outlet (°C)	850	860	850-950 (900)	800	760-800 (780)	760-800 (780)	760-810 (780)	(780)
6. Fluidizing air (m^3 Normal/h)	7500	6400	7500	5500	5500	5500	5500	5500
7. Excess air ratio	1.40	1.62	1.52	1.56	2.02	1.61	1.41	(1.8)

Note: Values in parentheses ( ) show average values.
All units are in metric (SI).

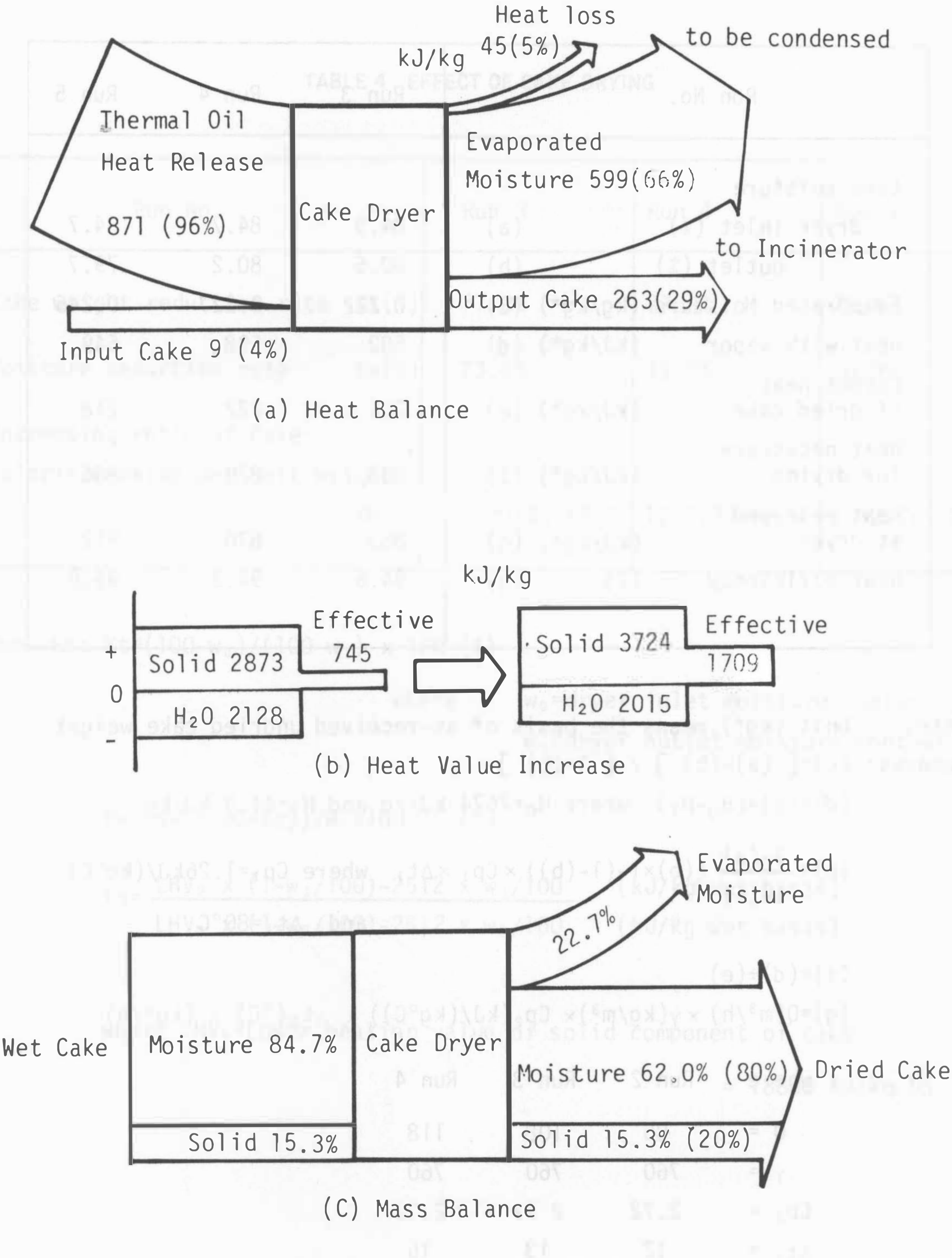

FIG. 3 EFFECTS OF CAKE DRYING

TABLE 3 CAKE DRYING CAPACITY

Run No.		Run 3	Run 4	Run 5
Cake moisture				
dryer inlet (%)	(a)	84.9	84.7	84.7
outlet (%)	(b)	80.6	80.2	79.7
Evaporated Moisture (kg/kg*)	(c)	0.222	0.227	0.246
Heat with vapor (kJ/kg*)	(d)	582	598	649
Latent heat of dried cake (kJ/kg*)	(e)	226	222	218
Heat necessary for drying (kJ/kg*)	(f)	808	820	866
Heat released at dryer (kJ/kg*)	(g)	853	870	912
Heat efficiency (%)	(h)	94.6	94.2	95.0

Note: Unit (kg*) means the basis of as-received undried cake weight

Remarks: (c)=[(a)-(b)] / [1-(b)]

(d)=(c)×(H_o-H_i) where H_o=2674 kJ/kg and H_i=41.9 kJ/kg

$$(e)=\frac{1-(a)}{1-(b)}((b)\times 1-(1-(b))\times Cp_1\times \Delta t_1$$ where Cp_1=1.26kJ/(kg°C) and Δt_1=80°C

(f)=(d)+(e)

(g)=Q(m^3/h) × γ(kg/m^3)× Cp_2(kJ/(kg°C)) × Δt_2(°C) / (kg*/h)

where	Run 2	Run 3	Run 4
Q =	86	108	118
γ =	760	760	760
Cp_2 =	2.72	2 72	2.72
Δt_2 =	12	13	15

(h)=(f)/(g)

TABLE 4 EFFECT OF CAKE DRYING

Run No.	Run 3	Run 4	Run 5
1.Cake weight reduction rate Kt(%)	77.8%	77.3%	75.4%
2.Moisture reduction rete Kw(%)	73.9%	73.2%	70.9%
3.Increasing retio of Cake calorific value per unit weight Kh	1620/707=2.3	1707/749=2.3	1812/749=2.4

Remarks: $Kt=(100-w_0)/(100-w_1) \times 100$ (%)

where w_0=dryer inlet moisture content (%)
w_1=dryer outlet moisture content (%)

$Kw=(w_0-(100-Kt))/W_0 \times 100$ (%)

$$Kh=\frac{LHV_0 \times (1-w_1/100)-2512 \times w_1/100 \quad \text{(kJ/kg wet basis)}}{LHV_0 \times (1-w_0/100)-2512 \times w_0/100 \quad \text{(kJ/kg wet basis)}}$$

where LHV_0=Lower heating value of solid component of cake

= 18800 kJ/kg DS

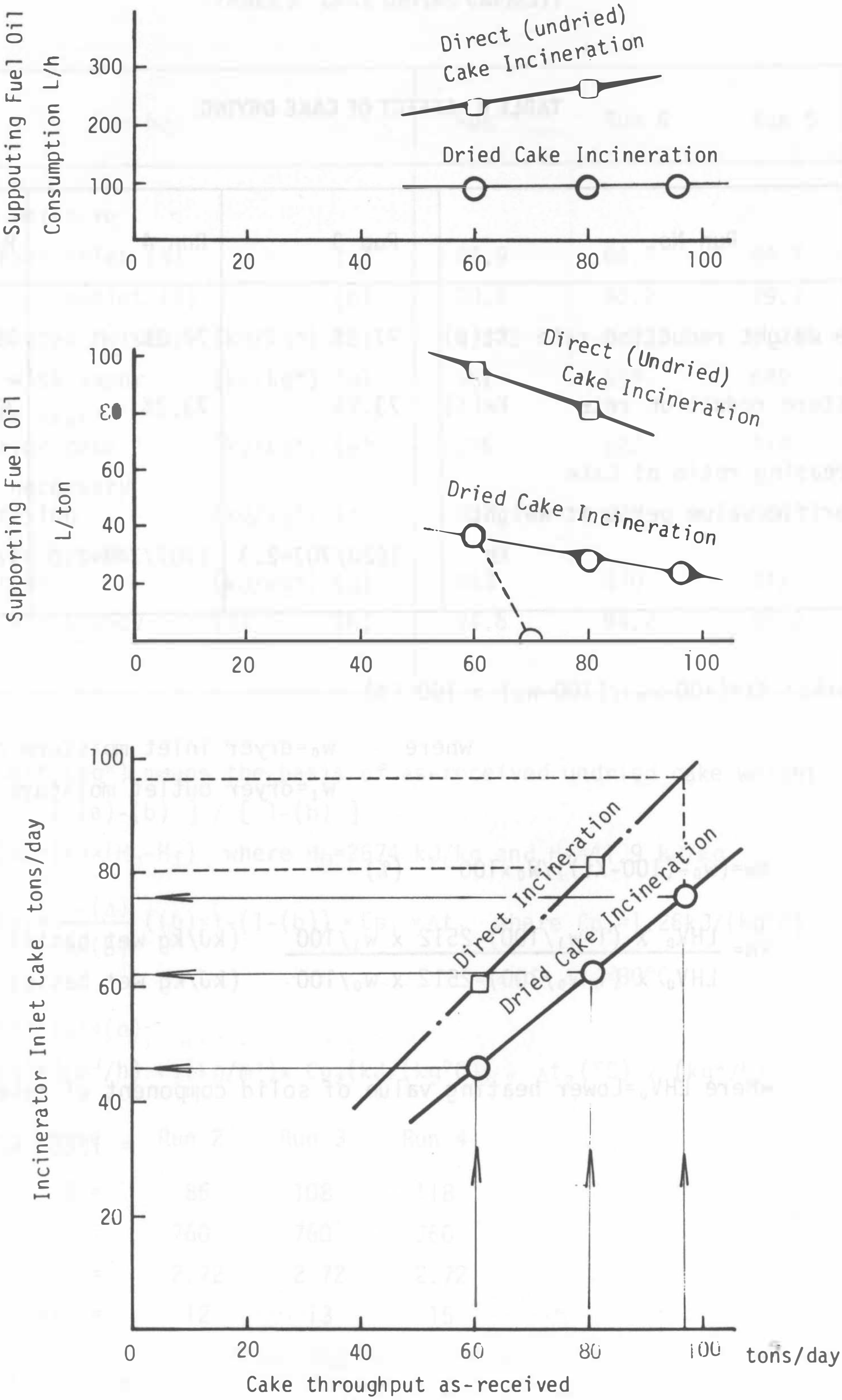

FIG. 4 OPERATION DATA

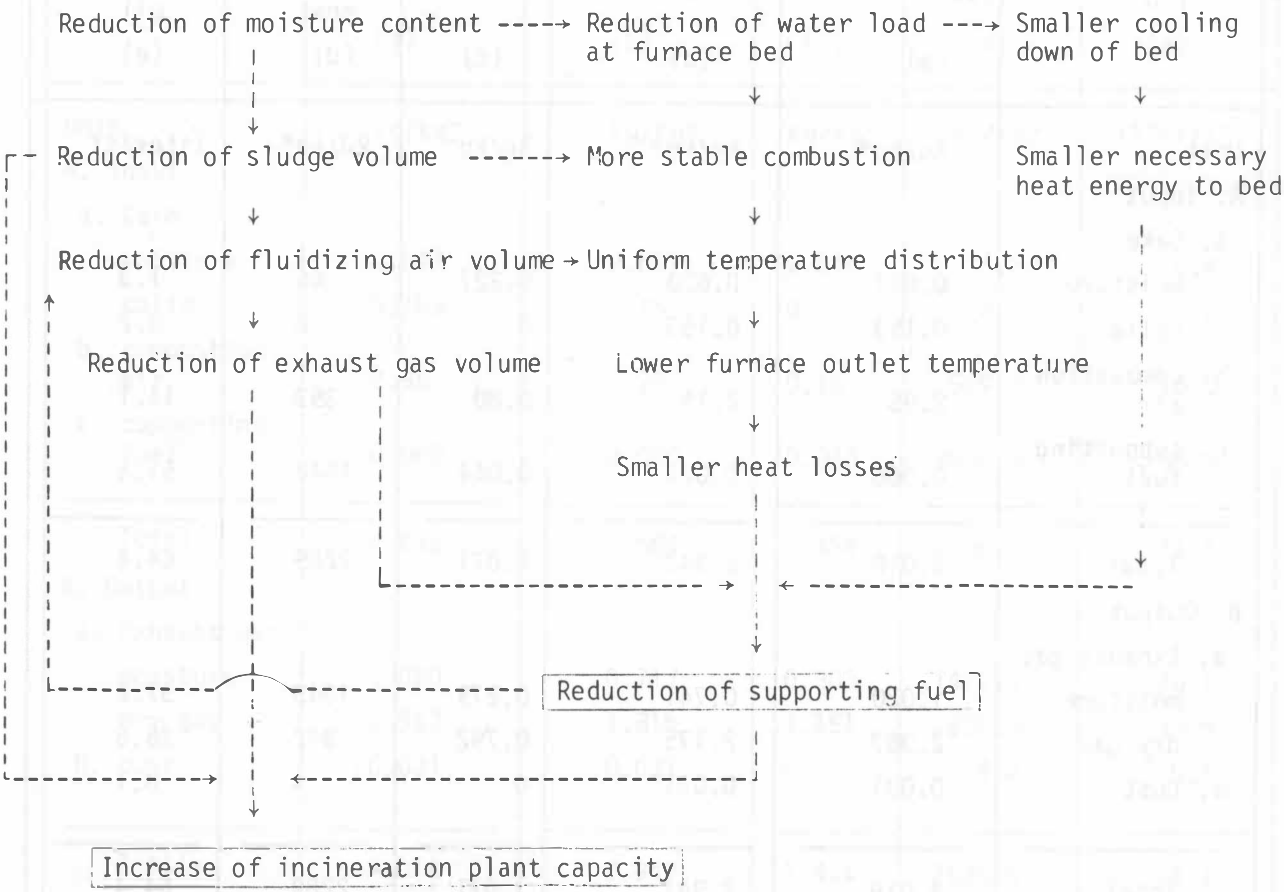

FIG. 5 SCHEMATIC DIAGRAM OF ENERGY SAVING EFFECTS AND PLANT CAPACITY UP BY INDIRECT HEAT CAKE DRYING

TABLE 5 ENERGY SAVING EFFECT TO INCINERATION PLANT

Items	Undried cake incineration 80 tpd (a)	Dried cake incineration 80 tpd (Run 4) (b)	Reduction rate		
			amount (c)	equivalent heat (d)	equivalent oil (e)
Unit	kg/kg*	kg/kg*	kg/kg*	kJ/kg*	liter/t*
A. Input					
a. Cake					
moisture	0.847	0.620	0.227	46	1.3
solid	0.153	0.153	0	8	0.2
b. combustion air	2.95	2.15	0.80	393	11.1
c. supporting fuel	0.068	0.024	0.044	1842	51.8
Total	4.018	2.947	1.071	2289	64.4
B. Output					
a. Exhaust gas					
moisture	1.020	0.741	0.279	1343	37.8
dry gas	2.967	2.175	0.792	942	26.5
b. Dust	0.031	0.031	0	4	0.1
Total	4.018	2.947	1.071	2289	64.4

Note: Mark (*) shows as-received wet cake weight basis

Remarks: (c)=(a)-(b)

(d)=Equivalent heat (increase) to reduced moisture

at cake moisture-- (d)=(c) x 4.186 (kJ/kg °C) x 50 (°C)

at combustion air--(d)=(c) x 1.046kJ/(kg °C)) x 470 (°C)

at supporting fuel-(d)=(c) x 41850 (kJ/kg)

at gas moisture----(d)=(a) x 4319(kJ/kg)-(b) x 4135 (kJ/kg)

at dry gas --------(d)=(a) x 937(kJ/kg)-(b) x 845(kJ/kg)

enthalpy at - [870 °C] [790 °C]

(e)=(d) / (1000 x 35570)(kJ/liter oil)

TABLE 6 ENERGY SAVING EFFECT TO INCINERATION PLANT

Items	Undried cake incineration 80 tpd	Dried cake incineration	Reduction rate		
			amount	equivalent heat	equivalent oil
	(a)	(b)	(c)	(d)	(e)
Unit	kg/kg*	kg/kg*	kg/kg*	kJ/kg*	liter/t*
A. Input					
a. Cake					
moisture	0.847	0.601	0.246	5.2	0.4
solid	0.153	0.153	0	8.4	0.2
b. combustion air	2.95	1.79	0.16	569.2	16.0
c. cupporting fuel	0.068	0 020	0.048	2008.8	56.5
Total	4.018	2.564	1.454	2636.6	74.1
B. Output					
a. Exhaust gas					
moisture	1.020	0.717	0.303	1427.1	40.1
dry gas	2.967	1.816	1.151	1205.3	33.9
b. dust	0.031	0.031	0	4.2	0.1
Total	4.018	2.947	1.454	2636.6	74.1

Note: Mark (*) shows as-received wet cake weight basis

Remarks: (c)=(a)-(b)

(d)=Equivalent heat (increase) to reduced moisture

at cake mousture--- (d)=(c) x 4.186 (kJ/kg °C) x 50 (°C)

at combustion air-- (d)=(c) x 1.046 (kJ/Kg °C) x 470 (°C)

at supporting fuel- d)=(c) x 41850 (kJ/kg)

at gas moisture--- (d)=(a) x 4319 (kg/kg) - (b) x 4156(kJ/kg)

at dry gas --------- (d)=(a) x 937 (kJ/kg) - (b) x 866 (kJ/kg)

enthalpy at [870 °C] [800°C]

(e)=(d)/(1000 x 35570) (kJ/liter fuel oil)

TABLE 7 ECONOMICAL ADVANTAGES OF INDIRECT DRYING

Items	Utility unit cost	Normal undried cake incineration		Newly developed indirectly dried cake incineration	
		amount	cost	amount	cost
Plant capacity		80 tons/d	US$/d	96 tons/d	US$
Operation cost					
1.Supporting fuel	0.35 US$/L	6360 L/d	2226	2304 L/d	806
2.Electricity	0.1 US$/kWh	10800 kWh/d	1080	10300 kWh/d	1030
3 Chemical(NaOH)	0.35 US$/kg	220 kg/d	77	151 kg/d	53
4.Lubrications	2.6 US$/L	0.8 L/d	2	0.8 L/d	2
Total per day	-	-	3385 US$/d	-	1891 US$/d
Unit treatment cost per input cake vol.	-	-	US$/ton 42.3	-	US$/ton 19.7

Note: All units are in metric (SI).

the throughput by more than 20% of the original one, by the optional installation of cake dryer with thermal oil heat utilization.

Plant Economical Advantages

As described, the application of indirect heat dryer with recovered heat utilization gives great amount of economical advantages both on plant investment and operational cost.

As to the initial plant investment, the plant cost is almost the same of normal undried cake incineration plant with the same input capacity (throughput), because the increased cost of dryers and thermal oil heat utilization processes are balanced by the reduced capacity of incinerator and followed gas treatment trains, that comes from the reductions of: *(a)* cake input volume; *(b)* auxiliary supporting fuel; and *(c)* combustion air and exhaust gas volumes. That is, this type of energy saving plant can be constructed at about the same cost as a normal one.

For the operation cost, on the other hand, there are many advantages in the economical aspect as well as in operational merits. As shown in Table 7, there are economical advantages in: *(a)* reduction of supporting fuel consumption of more than 70%; *(b)* reduction of electricity consumption by more than 20%; and *(c)* the reduction of exhaust gas absorbing chemicals of NaOH by more than 40%. In this plant of 96 tpd capacity, the saving of operational costs amounts for as much as 0.8 million U.S. dollars per year.

The installation of cake dryer with thermal oil heat utilization surely gives many economical advantages while keeping the initial plant costs and ease of operation and maintenance.

Operational and Environmental Aspects

This incineration plant is operated by fully automatic control through direct digital control (DDC) and micro-computerized sequencers, the operation

TABLE 8 ENVIRONMENTAL ITEMS

Items	Regulations	Run 1	Run 4
1. Exhaust gas			
Sulfur oxides (SO_x)	292 ppm	4 ppm	25 ppm
Nitrogen oxides (NO_x)	250 ppm	---	41 ppm
Hydrogen chloride (HCl)	93 ppm	3 ppm	---
Dust density	0.05 g/m^3N	0.006 g/m^3N	0.002 g/m^3N
2. Residual ash			
Amount	7.0 tons/d	2.4 tons/d	2.9 tons/d
Ignition loss	<15 %	0.6%	0.6%
Dissolution to water			
Alkyl mercury (Hg)	N.D.	<0.0005	---
Total mercury (Hg)	0.05	<0.0005	---
Cadmium (Cd)	0.1	<0.05	---
Lead (Pb)	1	<0.2	---
Phosphorus (P)	0.2	<0.01	---
Chromium 6+ (Cr(VI))	0.5	<0.05	---
Arsenic (As)	0.5	<0.19	---
Cyanide (-CN)	1	<0.05	---
PCB	0.003	<0.0005	---

Note: Values marked (---) are not measured.

Suffix "N" means the value converted at normal condition of 273 K, 1 atm.

procedure is almost the same as in normal incineration plants, and no special care is actually necessary for the additionally installed cake dryers and the thermal oil heat utilization system.

Sludge cake is pumped inside the pipings, and the dryers are operated in slight vacuum pressure [about −0.05 to −0.072 psi (−0.1 to −0.5 kPa) gage], and the dryer exhaust gas is sent to the high temperature zone of incinerator for the odor decomposition. These systems are achieving the solution to the odor prevention during the sludge transportation and drying, as well as in the incineration process.

As shown in Table 8, exhaust gas at the stack includes 2–6 mg/m^3 (Normal) of dust, 3 ppm of hy-

TABLE 9 WASTE WATER PROPERTY

Items		Feed water	Dryer Condensate	Wet E.P. effluent	Dehumidifier effluent
Tkj-N	mg/liter	24.71	29.67	24.97	24 52
$NH4^+$-N	mg/liter	21.14	24.40	21.24	20.75
Org-N	mg/liter	3.57	5.27	3.73	3.77
$NO2^-$-N	mg/liter	0.18	0.16	N.D.	0.11
$NO3^-$-N	mg/liter	0.63	0.60	0.98	0.62
T-N	mg/liter	25.52	30.43	25.95	25.25
BOD	mg/liter	6.86	41.5	2.24	3.44
CODmn	mg/liter	12.2	21.4	38 8	12.5
SS	mg/liter	3.3	15.7	84.0	2.3
Cl^-	mg/liter	74 3	74.5	58.3	76.1

drogen chloride (HCl), 4–25 ppm of sulfur oxides (SO_x), and 41 ppm of nitrogen oxides (NO_x); those values are much lower than regulations required.

Residual combustibles in ash and the values of dissolution of heavy metals in ash to water are also much lower than required.

For waste water, as shown in Table 9, even the condensate of dryers increased by only 35 ppm of BOD (biochemical oxygen demand) and 12 ppm of SS (suspended solids), and almost no odors are detected. The amount of condensate is very small among the overall plant waste water volume.

The shot cleaning system is operated automatically every 3–6 hr with shot recirculations, which means little cost is required.

CONCLUSIONS

The energy saving effects and the improvements of operation conditions by the application of indirect-heat sludge drying with recovered heat energy are as follows:

(a) By the indirect-heat drying of dehydrated sludge cake, the moisture volume is reduced by about 27%, and the weight is reduced by 23%, whereas the calorific value per unit weight of cake is increased by about 2.3 times. These facts lead to the increase of plant capacity by more than 20%.

(b) Dried cake can reduce the moisture load at the fluidized bed furnace, which can achieve the even temperature distribution of bed through freeboard areas, which is a most favorable combustion condition. These can reduce the combustion air amount per sludge volume and also the supporting fuel consumption by more than 70%, as well as the smaller exhaust gas volume.

These remarkable improvements in the operation conditions are achieved by the indirect drying of sludge before incineration.

Here, since this plant is designed with a somewhat unmatched larger furnace diameter due to the safety factors for the first of its kind in keeping a large capacity without dryers, and the sludge moisture contents and organic ratio are higher than the design values, further improvements in the operation and fuel savings can be expected by approaching the design values of sludge and plant.

PERSPECTIVES

As described above, the first commercial sewage cake incineration plant with the combination of indirect heat dryer and fluidized bed incinerator has been showing remarkable advantages of economy in the operational costs and in increase of plant capacity. This successful achievement is clearing the way for the authorities for planning and modification of sewage sludge incinerators so that this "indirect-drying and fluidized bed incinerator combination" can fulfill their best economic requirements. After this success, several authorities of leading cities in Japan have been constructing this type of drying-incineration plants with capacities of about 100–250 tpd per unit. Many plans by them and other authorities are still under this criteria. These facts indicate that a new era of better and economical sludge cake incineration has already been established within a short time.

This type of energy saving sewage sludge incineration system with an indirect heat dryer will surely continue to be the most economical one, by the time the combustion property of cake improves to achieve the self-supporting incineration at the furnace, that can be achieved by the lower moisture content of cake with higher organic content, and when a new, more efficient sludge dehydrator is developed with low operation cost of coagulants, for instance.

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Key Words: Cost Reduction; Drying; Energy; Incineration; Sewage; Waste Heat