EXPERIENCE ON CO-FIRING OF MUNICIPAL SOLID WASTE AND SLUDGE IN JAPAN

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ABSTRACT

This paper addresses the systems used to destroy sewage sludge by combustion, the fuel being municipal refuse. The principle focus is on the systems used for drying the sludge — a required step that gives the sludge the ability to burn. The operating characteristics of each system are described. Combination refuse incineration/sewage treatment plants are discussed to complete the look at today's disposal systems in Japan.

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Sludge treatment and disposal have been major problems for a long time. For more than ten years, Takuma has treated these problems by co-firing a mix of MSW and sludge. Many achievements have been realized; however, not without lots of changes while ascending the learning curve. In this paper, the choices of co-incineration systems are described from information on Takuma's experience in Japan.

1. Co-incineration of Refuse and Dewatered Sewage Cake in a Mass Burn System

Co-incineration of sewage sludge in the form of dewatered cake and as-received refuse has been done in refuse incineration plants for some time. In general, the mix ratio of sludge to refuse is 1:10, although it depends mainly on the water content of the dewatered cake. This value is not based on a theoretical approach but is an apparent limit where an incineration plant is operated under the following essential conditions:

a) The furnace temperature is maintained to ensure stable combustion without a reduction of the refuse throughout.

b) The resulting ash is within the limit for unburned combustible matter.

The lower calorific value of dewatered sludge is 180-300 KCal/KG at best. This equates to an HHV between 1200 and 1400 Btu/#. On the other hand, the lower heating value of Japanese municipal refuse is 1000-2500 KCal/KG, an HHV of 2500-4800 Btu/#. Note that Japanese refuse has less heat content than typical U.S. refuse (HHV 3800-6500 Btu/#). When sludge in quantities of 10% of the MSW weight is added to the refuse, the calorific value of the mixture is reduced minimally. From the standpoint of calorific value, the limit of the mix ratio actually exists at a higher level. (See Figure 1)

Another reason for the mix ratio being limited to 1:10 is that the incinerator was not initially designed for sludge burning. The greatest risk is that of excess unburned combustibles in the ash due to the weak combustibility of the dewatered sludge.

Dewatered sludge having a water content of 70-80% even when crushed tends to become nodular due to coagulation of the sludge particles. The combustion of nodular sludge requires a long residence time. The sludge receives heat through its surface and dries. Dryness gradually proceeds to the nodule interior. The initial viscosity is reduced, promoting break-up of the nodules and complete burning. An additional limiting factor for combustion is that the sludge must be a uniform substance consisting of combustible and inorganic matter.

As for the refuse, easily burned materials such as paper and difficult burning materials exist at random. There is a wide difference in the combustion characteristics of sludge and refuse. Consequently, when dewatered sludge is subjected to incineration in a stoker designed for municipal refuse, it is difficult to burn the sludge completely. Takuma had carried out test operations for co-firing in an operating plant previously. Unburned sludge nodules were observed in the resulting ash, a confirmation of the difference in combustibility. It should be noted that mixing and stirring in the refuse pit were done carefully using the crane.

As described above, the direct mix incineration process, using dewatered cake of 70-80% water content and mixed in the refuse pit, is not feasible. The needed solution is distribution feeding or a drying process.

2. Co-Incineration of Refuse and Dry Sewage Cake

Sludge, when dried to a water content of 30%, takes on a lower heating value of more than 1500 KCal/KG (3300 Btu/#). In addition, its dispersibility is improved. Thus, stable and continuous combustion on stokers is assured. (See Figure 2)

The practice of co-incineration using dewatered cake, previously dried by refuse combustion heat and then mixed with the refuse, originated in Europe. The case of Krefeld, West Germany, where this operation was started in 1975, has been well publicized through several reports. Many drying/mixed incineration plants have been in actual operation for extended periods, e.g., Ingolstadt, West Germany and Lisieux, France.

In 1976, Takuma carried out numerous sludge drying experiments that used heat in the incineration exit gas to learn the effectiveness and practical uses of the following systems.

a. Flash Dryers
b. Rotary Dryers
c. Steam Dryers

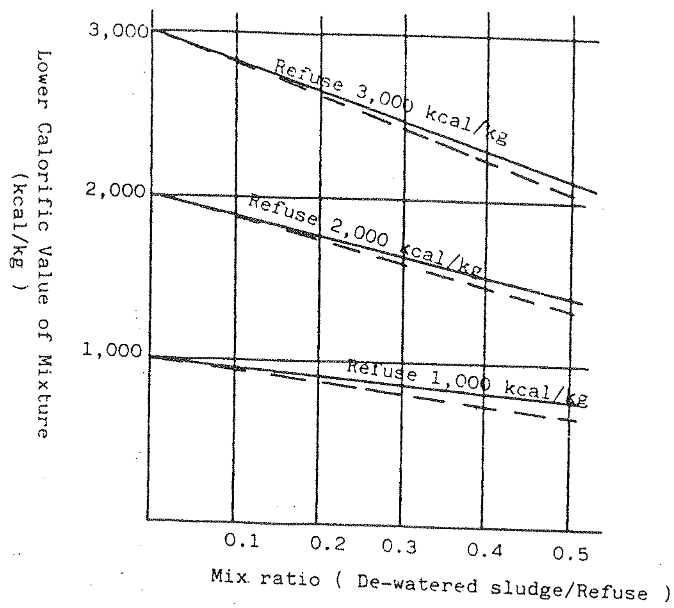
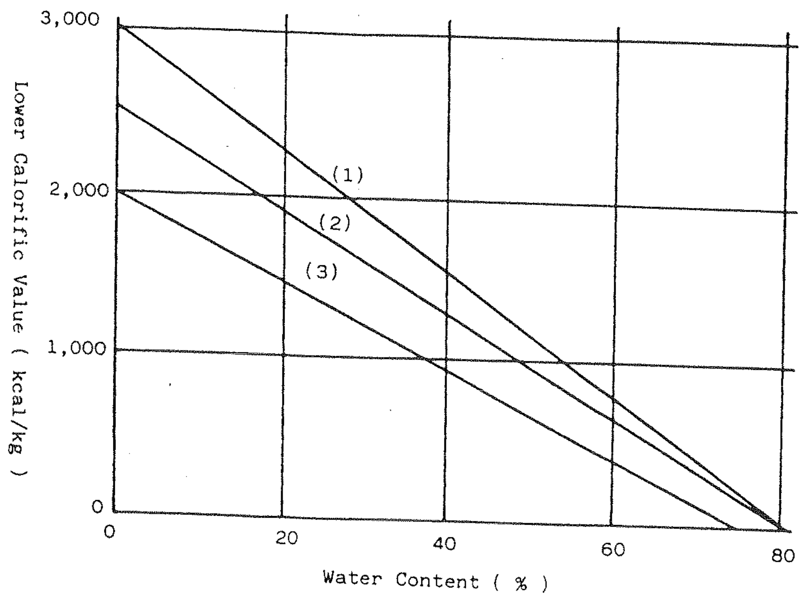


Figure 1 *Calorific Value of Refuse-Sludge Mixture*



Conditions : Combustible matter content in dry matter......50%

Lower calorific value of dry matter

(1) 3,000 kcal/kg
(2) 2,500 kcal/kg
(3) 2,000 kcal/kg

Figure 2 *Water Content and lower Calorific Value of Sludge*

The outline and operation data of each are described below.

2.1 Sludge Drying by Flash Dryer

This drying system is used in Krefeld, Ingolstadt, and other cities. In Japan, this system is in operation at Kanazawa and Zushi. In addition, a full scale system was tested by Takuma at an Osaka plant from February to May of 1985.

(1) Outline of the System

Figure 3 shows the flow chart of a flash-drying/co-incineration system installed in the Seibu (West) cleansing plant, Kanazawa.

The capacity of the plant is:

Refuse incineration capacity - 350 tonne/day (175 tonne/day x 2 streams)
Sludge treatment capacity - 50 tonne/day (25 tonne/day x 2 streams)
Completion - September, 1980

When the plant was completed, the sludge drying/co-incineration system was launched into trial operation. In the autumn of 1983, the associated sewage treatment plant construction was completed, and since then, the system has been in full scale operation.

Sludge having a water content of 65% is transported from the adjacent sewage treatment plant by truck. After brief storage in a sludge pit, it is delivered to the sludge hopper by a crane. Then the sludge is fed in a controlled volume by a screw feeder, mixed with dry sludge powder in a mixer/crusher conveyor to regulate the water content to 40-50%, and then sent to a cage mill dryer.

Refuse combustion exit gas, controlled at 400°C (750°F), is blown into the cage mill to dry the sludge. The drying period is short, and extensive cake break up takes place. The dried and crushed sludge is then transferred by the gas flow through a drying tube into a cyclone separator to take out the dry sludge powder.

Part of the dry sludge powder is returned to the mixer/crusher conveyor for use in water content regulation. Any excess volume is distributed into the feedchute to be incinerated with the refuse.

The gas from which the dry powder was separated in the cyclone is kept at 180-250°C (350-400°F) in order to prevent dew point corrosion of the downstream equipment. Part of it is mixed with 700°C (1300°F) gas drawn from the upper part of the incinerator resulting in 400° (750°F) gas for drying. The remaining gas is returned to the higher temperature zone in the incinerator to decompose it odors.

(2) Operating Data

The characteristics of sludge and refuse used in the operation are as follows:

Sludge:

HHV of dry matter 2000-2400 KCal/KG (3600-4320 Btu/#)
Ash content of dry matter 0.56 - 0.71 % by wt.
Water content 59 - 70%

Refuse:

L.H.V. 900-1500 KCal/KG (2400-3400 Btu/- HHV)

(a) Operation Processes

This system is very easy to operate and consists of three principle processes.

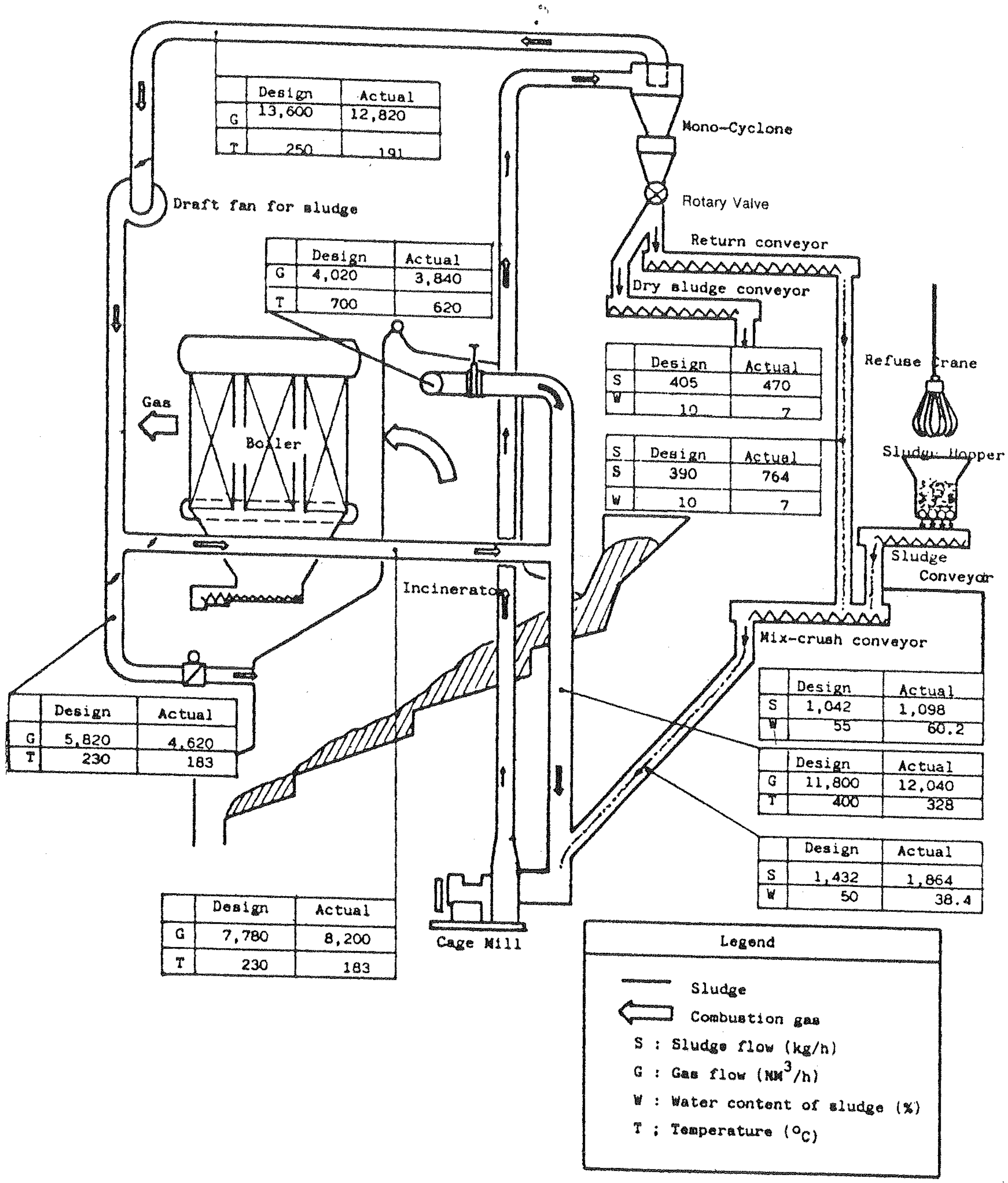


Figure 3 Flow Sheet for Sludge Drying Facility Cleansing Plant - Kanazawa

(a-1) Regulation of the Sludge Feeding Rate

The speed of the sludge conveyor and a series of succeeding conveyors are regulated in response to the mill discharge temperature which is an indication of the sludge particle dryness.

(a-2) Regulation of the Gas Circulating System

The discharge volume of the sludge draft fan is controlled so as to keep the mill inlet gas duct at a negative pressure. The cage mill internal fan causes the suction at this location.

(a-3) Regulation of the Gas Temperature at the Mill Inlet

The mixture ratio of the return gas and the gas drawn from the incinerator is regulated to keep the gas temperature at the cage mill inlet at a fixed value.

Cage mills attain a greater heat transfer coefficient than other systems. The equipment is compact and the ability to regulate operation is excellent. Stable operation can be obtained simply by regulation of the sludge input rate.

(b) Effect on Incineration Ash

As shown on Table I, the ignition loss in the final ash is not significantly affected by co-incineration.

	Test No. 1		Test No. 2		Test No. 3	
	No. 1 (Refuse only)	No. 2 (Mixed incineration)	No. 2 (Refuse only)	No. 1 (Mixed incineration)	No. 1 (Mixed incineration)	No. 2 (Mixed incineration)
Incineration ash %	1.9 ~ 3.0	1.7 ~ 2.6	1.4 ~ 4.3	1.4 ~ 3.8	2.1 ~ 3.9	0.8 ~ 2.8
Boiler dust %	7.0	1.0	2.0 ~ 4.5	2.0 ~ 3.9	2.0	—
Precipitator dust %	3.0 ~ 4.0	2.7 ~ 2.9	3.5 ~ 4.2	3.2 ~ 4.2	1.5 ~ 2.3	0.1 ~ 2.3

Note: Ignition losses tested at 600°C, 3 hrs. — muffle test using air

Table I Ignition Losses for Incineration Ash and Dust Samples Kanazawa Cleansing Plant (1)

Concerning heavy metals, a small increase in the Fe and Mn content has been observed. However, in some cases, elution test values have actually decreased. It is thus considered that no significant differences exist between refuse firing and mixed refuse/sludge firing when evaluating the incineration ash, fly ash collected in the boiler, and fly ash collected in the precipitator.

(c) Effect on Exit Gas

With the flash dryer, a greater proportion of sludge powder fed into the incinerator burns in suspension. Its ash content is carried by the gas into the boiler and precipitator. Thus, the higher dust content in the precipitator will require enhanced dust conveyor systems. At the inlet of the precipitator, HCl and NO_X are not affected by the co-incineration. SO_X tends to increase slightly. The data obtained in the test series is shown in Table II.

Factor		Unit	Test No. 1: No. 1 (Refuse only)	Test No. 1: No. 2 (Mixed incineration)	Test No. 2: No. 2 (Refuse only)	Test No. 2: No. 1 (Mixed incineration)	Test No. 3: No. 1 (Mixed incineration)	Test No. 3: No. 2 (Mixed incineration)
Exit gas volume (dry)		Nm^3/h	30,890 ~ 33,600	31,450 ~35,250	36,600 ~40,600	36,060 ~42,200	32,000	28,000 ~32,000
Water content of exit gas		%	16.1 ~ 22.7	19.3 ~25.2	19.1 ~19.8	21.1 ~21.3	21.1 ~26.1	23.6 ~25.7
O_2 concentration		%	11.0 ~ 12.8	10.6 ~12.0	11.0 ~13.0	9.8 ~12.0	9.6 ~10.7	9.8 ~11.2
Dust concentration	Precipitator inlet	g/m^3N	1.02 ~ 5.23	1.8 ~6.49	1.99 ~3.09	4.77 ~6.14	7.45 ~9.82	6.17 ~7.65
	Precipitator outlet	g/m^3N	0.0095 ~ 0.0109	0.0091 ~0.0122	0.0081 ~0.011	0.015 ~0.022	0.005	0.007
HCl (converted to 12% O_2)		ppm	498. ~540	390 ~584	350 ~513	411 ~423	342 ~371	425 ~482
SO_x		ppm	33~45	55~63	34~45	41~53	62~94	54~65
NO_x (Converted to 12% O_2)		ppm	64~87	63~92	67~89	75~92	60~64	59~72

Note: All data shown was taken at the precipitator outlet.

Table II Characteristics of Exit Gas Kanazawa Cleansing Plant

	Completion year	Mixture: Sludge	Mixture: Refuse	Drying system	Combustion system	Remarks
1. West Saitama Cleansing Association (Soka)	1981	0.42 tonne/h × 1	6.25 tonne/h × (2)	Rotary kiln	Stoker combustion	Night-soil sludge W 80→30% *
2. Oogaki City	1981	1.0 tonne/h × 1	3.75 tonne/h × (2)	As above	As above	As above
3. Fujisawa City	1982	0.7 tonne/h	6.25 tonne/h × (2)	As above	As above	Sewage sludge W 85%→15%

*Night Soil Sludge

In Japan residencies not connected to sewage systems discharge their effluent into outdoor holding tanks. In the evening, municipal sewage trucks evacutate these tanks on a periodic basis and convey it to the regional sewage system plant. Hence the term "night soil."

Table III Cases of Mixed Incineration Systems Using a Rotary Dryer

2.2 Sludge Drying Using a Rotary Dryer

A rotary dryer is frequently used for small scale drying systems. As shown in Table III, several plants of this type are operating in Japan. To present a typical case for this system, Kokubu (North) cleansing plant of Fujisawa City, which was completed in the autumn of 1982, is described in the following summary.

(1) Outline of the System

Figure 4 shows the flow chart of the system. The plant is equipped with two refuse incinerators of 150 tonne/day capacity and one sludge dryer having a capacity of 16 tonne/day.

Dewatered sludge is stored in a bunker. It is discharged by a screw located at the bunker bottom.

The sludge is fed by a pump into the dryer and comes in contact with high temperature gas at 750°C (1380°F). It dries to approximately 15% moisture content. The dry sludge particles are then conveyed by a blower and collected by a single cyclone separator. Then they are fed into the incinerator to burn with the refuse.

Combustion gases at 900-1000°C (1650-1830°F) are generated in the incinerator and used for drying. The inlet gases to the dryer are controlled at 750°C (1380°F) by mixing with dryer exit gases of 200°C (390°F).

Exit gas discharged after sludge drying, is returned to the high temperature zone in the

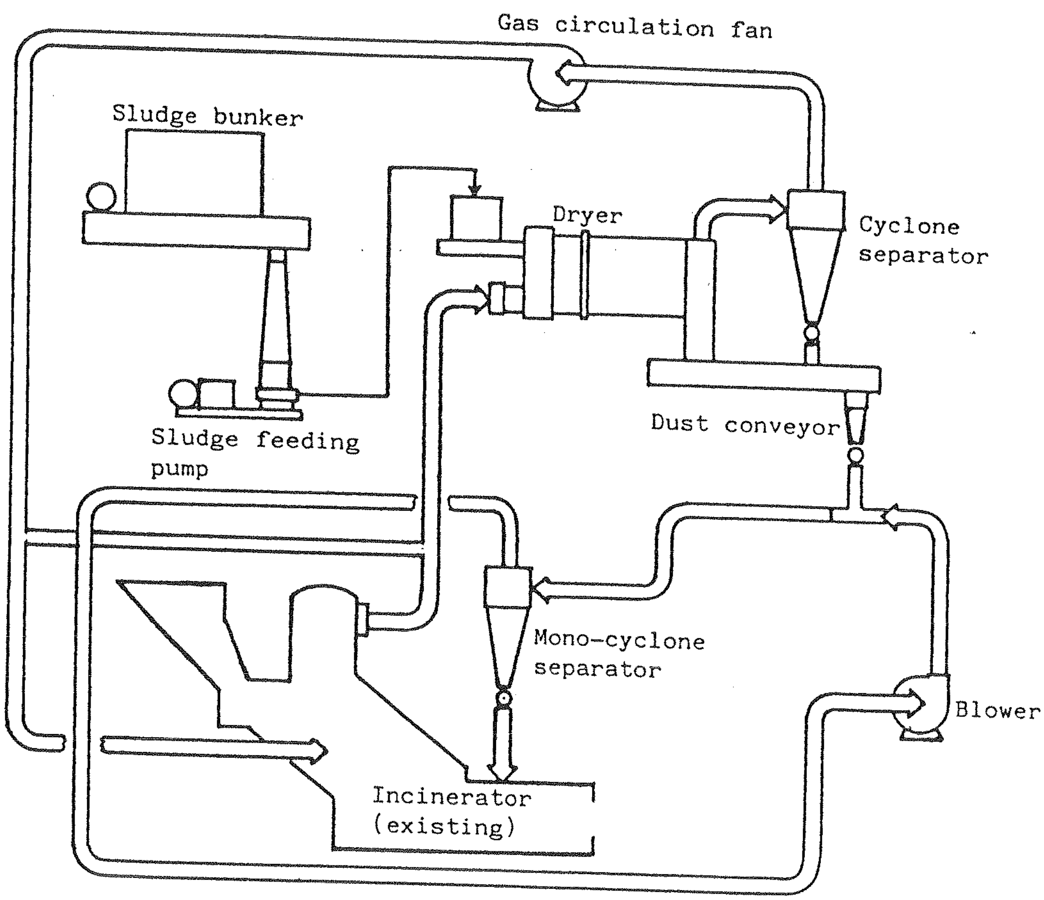


Figure 4 Flow sheet for Sludge Drying and Incineration Facilities (Fujisawa City)

incinerator after the dust is removed. Odors in the gas are decomposed and oxidized. The return gas also functions as a coolant for the internal part of the incinerator.

In this case, a rotary kiln with moving paddles is used. Crushing and pelletizing are done simultaneously with drying. Dry cake has a non-uniform particle size as delivered by the pelletizer. However, this causes no limitation in normal use when the proper type stoker is selected.

Similar systems are in operation in Ogaki City, Soka Cleansing Plant, and other plants. In some cases, the dry cake produced is returned to farms for fertilizer at seasonal times of the year.

(2) Operating Data

The water content of sludge initially is about 82%, and the lower calorific value of the bone dry sludge is 4400 KCal/KG (8200 Btu/# HHV).

(a) Odor

As shown in Table IV, hydrogen sulfide, trimethylamine and ammonia were detected in trace quantities at the outlet of the dryer. But at the inlet of the precipitator, their concentrations are comparable to those of a refuse incinerator.

(b) Effect on Incineration Ash

In the co-incineration of sludge and refuse, the heavy metal content in the residue ash tends to increase slightly in comparison to refuse incineration, but overall, there is little difference in the elution test values.

(c) Effect on Exit Gas

As shown in Table V, the dust content during co-incineration is slightly higher than for refuse incineration, but the difference is not as great as in the system that uses a flash dryer.

This happens because the sludge is agitated less in the drying process and its water content is slightly higher (about 15%). Further, the particle size distribution is in a higher range because of the nature of the kiln granulating action.

The content of HCl and SO_X showed similar values between both incinerator systems.

2.3 Sludge Drying by a Steam Dryer

Paddle type dryers using steam as a heat medium are well known.

A unique sludge/waste wood treatment system in which a paddle type dryer is used was constructed in the Teine Sewage Sludge Incineration Center by the Sapporo City Government. Its effectiveness has been confirmed in the operation of the system since the spring of 1983. The outline of this plant is as follows3):

	1ST STAGE PLAN	FINAL PLAN
Sludge treatment capacity	100 tonne/day	200 tonne/day
Waste wood capacity	25 tonne/day	50 tonne/day
Sludge characteristics		

Water content - 75%

Lower heating value of sludge on a dry basis - 1850 KCal/KG (3800 Btu/# HHV)

Lower heating value of waste wood - 2750 KCal/KG (5600 Btu/# HHV)

Measuring point \ Compounds	Hydrogen sulfide	Methyl mercaptan	Methyl sulfide	Dimethyl disulfide	Trimethyl-amine	Ammonia	Styrene	Acetal-dehyde	
Heat gas duct	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 2	< 0.01	< 2	
"	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 2	< 0.01	< 2	
Dryer outlet	< 0.81	< 0.01	< 0.01	< 0.01	< 0.06	< 65	< 0.01	< 2	
"	< 2.37	< 0.01	< 0.01	< 0.01	< 0.9	< 82	< 0.01	< 2	
No. 2 incinerator Precipitator inlet	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 13	< 0.01	< 2	
"	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 3	< 0.01	< 2	
No. 1 incinerator Precipitator inlet	< 0.01	< 0.01	< 0.01	< 0.01	< 0.1	< 3	< 0.01	< 2	*
"	< 0.01	< 0.01	< 0.01	< 0.01	< 0.1	< 4	< 0.01	< 2	*

Note: Data with * apply to exclusive incineration of refuse.

Table IV Odor Analysis Data, Cleansing Plant - Fujisawa City

Measuring point \ Pollutant	Dust g/Nm^3	SO_x ppm	HCl ppm	
Heat gas duct	0.744	43	502	
"	0.862	51	739	
Dryer outlet	0.735	76	285	
"	0.554	109	414	
No. 2 incinerator Precipitator inlet	1.07	—	—	
"	1.14	—	—	
No. 2 incinerator Precipitator outlet	0.156	47	211	
"	0.0775	71	367	
No. 1 incinerator Precipitator inlet	0.677	—	—	*
"	0.785	—	—	*
No. 1 incinerator Precipitator outlet	0.108	44	580	*
"	0.0957	49	439	*

Note: Data with * are for exclusive incineration of refuse.

Table V Gas Analysis Data, Cleansing Plant - Fujisawa City

Figure 5 shows the flow of sludge and waste wood in this plant. Sludge fed from the storage tank is mixed with return sludge having 10% moisture to control the water content at 50%. It is then sent to the dryer. Steam from the incineration of waste wood and sludge is used to further reduce the water content of the sludge to 40%. Part of the dry sludge is returned to regulate the water content. The remaining dry sludge is fed to the incinerator and burned autogenously.

Waste wood, after an initial crushing, is stored in a retention tank and fed to the boiler for steam generation. This steam is used to power turbines for the induced draft fan and the boiler feed pump. This maximizes energy savings.

Systems similar to this can be efficiently used for the following conditions:

a) for any waste that has a combustible content, and

b) where equipment for waste fuel pretreatment/incineration, and sludge drying/sludge incineration are located in close proximity.

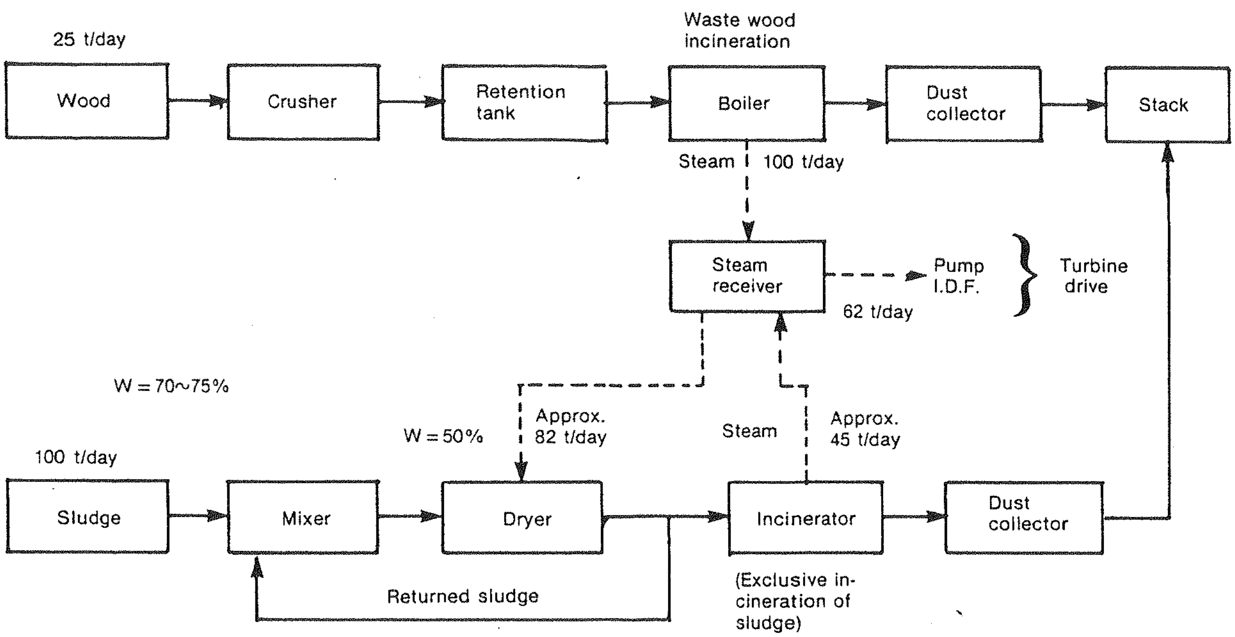


Figure 5 Flow Chart for the Teine Sewage Sludge Incineration Center, Sapporo City

3. Choosing the System

The arrangements and operating cases of the three representative systems have been described above. In choosing a system, the characteristics, location and conditions of each must be considered.

Table VI shows a comparison of the characteristics of the systems. The features of each system from the point of view of alternative choices are as follows:

a) Flash Dryer:

Because a greater heat transfer coefficient can be obtained, this equipment is compact and suitable to large scale plants. However, additional large scale equipment is required because gas is used as a medium. In addition, dust content in the exit gas increases due to fines carryover.

Type	Heat medium	Evaporation water quantity (max value for each dryer) kg/H	Heat transfer coefficient (ha) kcal/hr, °C, m^2 / Ultimate thermal conductivity (U) kcal/hr, °C, m^2	Dry product form	Dust generation
Flash dryer	Gas	9000	ha = 5000 ~ 6000 (Crusher) 2000 ~ 3000 (Drying tube)	Powder	More
Rotary dryer	Gas	3000	ha = 200 ~ 500	Powder	Inter-mediate
Paddle type steam dryer	Steam	1500	U = 70 ~ 30 (Low speed) 100 ~ 400 (High speed)	Powder	Less

Table VI Comparison of Characteristics for the Three Systems

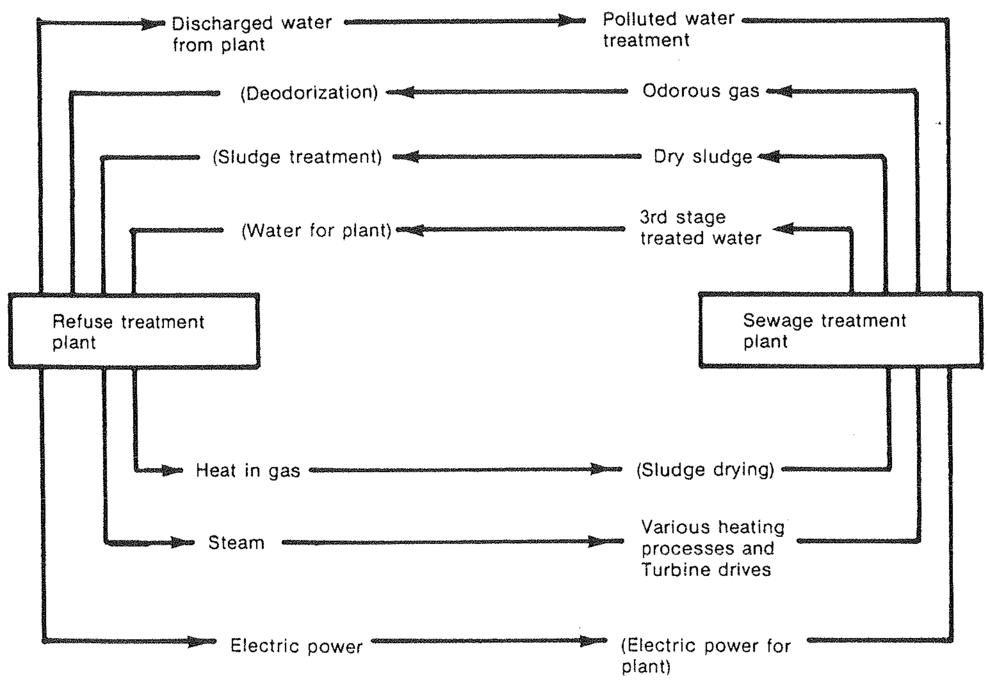


Figure 6 Energy Trading in Combination Refuse and Sewage Treatment Plants

b) Rotary Dryer:

This uses gas as does a flash dryer, but it is not suitable for large scale plants because the heat transfer coefficient is significantly lower. One advantage is that the water content of the dry powder can be regulated.

c) Steam-Paddle Type Dryer:

This is unsuitable for large scale plants due to the limited water evaporation per dryer. In contrast to the above two systems in which the gas is used directly, this system used steam.

Starting year	City name	Refuse treatment plant		Sewage treatment plant	
		Plant name and capacity			Plant Name
1969	Osaka	Morinomiya 600 tonnes/day	High pressure steam →	→ Aeration blower turbine drive	Nakahama
			Refuse treat-ment plant waste water →	→ Water treatment	
1975	Kitakyushyu	Kogozaki 600 tonnes/day	Produced electric power →	→ Electric power for plant	Kogozaki
1976	Fukuoka	Tobu (East) 600 tonnes/day	Water for plant ←	← 2nd stage treated water	Kamata
1980	Kyoto	Tobu (East) 600 tonnes/day	Produced electric power →	→ Electric power for plant	Ishida

Note: Items in ▭ are system outputs

Table VII Cases of Combination Refuse and Sewage Treatment Plants

Therefore, the heat transfer is more uniform and the process simplified. Thus, the plant designer has more freedom of choice for the dryer location. As in the case of rotary dryers, the water content of the dry powder can be controlled at the outlet.

4. Combination Systems of a Refuse Incineration Plant and Sewage Treatment Plant

Refuse incineration plants and sewage treatment plants both function to treat municipal waste. The former generates energy and the latter consumes energy. Recognizing this, the idea of energy trading becomes apparent. The various systems that use combustion heat energy have been described above.

If a refuse incineration plant and a sewage treatment plant are combined, not only is energy trading done concurrently, but the completion of both treatment processes can be achieved simultaneously.

Combination plants are now fully accepted. This can be attributed to those already in operation which have functioned with minimal technical problems.

Table VII shows a case where both plants are combined. Figure 6 shows the relation of energy trading in a combination plant.

5. Conclusions

The volume of sewage sludge generated in Japan in 1980 was 7,000,000 m^3 (sludge of 70% water content), and there is a prediction that this volume will double in five years (1985). Similar predictions are being made for the U.S. The requirement for volume reduction becomes more acute each year as land used for sludge disposal becomes more scarce.

The key to efficient sludge processing is the design of an effective sludge drying system which leads to a better burning material and high quality ash (low combustible content).

From the energy point of view, energy trading plants minimize fuel usage. This concept is now a proven system and the expectation is that it will spread as an efficient waste disposal method.

LIST OF FACILITIES: CO-FIRING OF MUNICIPAL SOLID WASTE AND SLUDGE IN EUROPE AND U.S.A.

Plant Name	Location	Year Comp.	Co-firing Sludge	Ratio Refuse
EssenKarnap	W. Germany	1957	1500-2000 T/D	1500 T/D
Krefeld	W. Germany	1975	2-6.4 t/h	2-12.2 t/h
Krefeld	W. Germany	1975	1-9.0 t/h	1-12.2 t/h
Ingolstadt	W. Germany	1978	1-3.2 t/h	1-7.5 t/h
Faerstenfeldbruck	W. Germany	1974	1-1.15 t/h (Solid)	1-6.0 t/h
Diepe	France	1973	2-0.75 t/h	2-2.5 t/h
Brive	France		3-2.5 t/h	2-3.5 t/h
Deuville	France		1-0.9 m^3/h	2-2.5 t/h
Lisieux	France	1981	0.8 m^3/h	2.1 t/h
Waterbury, CT	U.S.A.	1968		2-6.25 t/h
Glen Cove, NY	U.S.A.			

LIST OF FACILITIES: CO-FIRING OF MUNICIPAL SOLID WASTE AND SLUDGE IN EUROPE AND U.S.A. (Cont.)

Plant Name	Drying Method	Combustion System	Remarks
EssenKarnap	Flue gas	Inject sludge above refuse fired grate	Sludge moisture 40% Modified Pulverized Coal fired boiler
Krefeld	Flue gas/HGS Mill	Inject sludge above refuse fired grate	Sludge moisture 75 to 10%
Krefeld	Flue gas/HGS Mill	Inject sludge above refuse fi fired grate	Sludge moisture 75 to 10%
Ingolstadt	Flue gas/Flash dryer	Inject sludge above refuse fired grate	Sludge moisture 75 to 15%
Faerstenfeldbruck	Flue gas/CN Mill	Inject sludge above refuse fired grate	Sludge moisture 80 to 10%
" (for solids)	Steam/Film evaporator	Spread sludge	Sludge moisture 96.5 to 60%
Diepe	Steam/Film evaporator	Spread sludge above refuse fired grate	Sludge moisture 83 to 45%
Brive	Steam/Film evaporator	Spread sludge above refuse fired grate	Sludge moisture 83 to 45%
Deuville	Steam/Film evaporator	Spread sludge above refuse fired grate	Sludge moisture 83 to 45%
Lisieux	Flue gas/Flash dryer	Spread sludge above refuse fired grate or storage	Sludge moisture 78 to 5%
Waterbury, CT	Flue gas/Flash dryer	Spread sludge above refuse fired grate	
Glen Cove, NY	Without dryer	Charge sludge to refuse hopper front of grate	

REFERENCES

1. H. Tejima, Present State of Sludge Mix Incineration in Seibu Cleansing Plant of Kanazawa City, '83 Sludge Research Annual.

2. T. Miwa et al., Nigh Soil Drying and Mix Incineration with Refuse Using Excess Heat from Refuse Incinerator, 1983.

3. M. Uozumi et al., Incineration of Sewage Sludge Using Waste Wood, Journal of Japan Sewage Works Association, Vol. 21, No. 236, 1984.

4. Newspapers issued on November 11, 1981 (Daily Industrial News, Nihon Kogyo Shimbun and others).

APPENDIX

CONVERSION FACTORS

For the sake of clarity, only metric values appear on the various graphs and flow charts throughout the text. For your convenience, the following conversion systems are presented to convert to English units of measurement.

Temperature: $^{\circ}C \times 1.8 + 32 = {}^{\circ}F$

Heating Value: $HV \text{ in } \frac{KCal}{KG} \times 1.8 = HV \text{ in Btu/lb}$

Sludge Flow: $S \text{ in } \frac{KG}{h} \times 2.205 = S \text{ in } \frac{\#}{h}$

Gas Flow: $G \text{ in } \frac{NM^3}{h} \times 35.31 \times \frac{(T_{Gas}\,^{\circ}C + 273)}{273} = \frac{FT^3}{h}$

1 tonne = 2205 # = 1.1025 U.S. tons (short)