CASE STUDY

TOSHIMA INCINERATION PLANT
TOKYO, JAPAN

For
IEA BIOENERGY TASK 23
Energy from the Thermal Conversion of MSW and RDF

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NOTICE

This study has been performed for the working group of IEA Bioenergy Task 23: Energy from the Thermal Conversion of MSW and RDF, through the collaboration of CETC/NRCan (Ottawa, Canada) and NEDO (Tokyo, Japan).

Execution of the study was limited to public information and knowledge available to both organizations and to the contribution of the Bureau of Waste Management, Tokyo Metropolitan Government (a half-day plant visit, performance data and publications).

Results are based on Japanese economic conditions and MSW composition, which may vary from typical European standards, due to regulations and waste collection/recycling practices currently in effect.

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BACKGROUND

Japanese Statistics

Japan currently has a population of more than 125 million people, representing 2.2% of the global population; yet her land mass amounts to less than 0.3% of the world area. This inequality, coupled with the fact that a considerable portion of the land area is mountainous, has resulted in a situation where available waste disposal (landfill) area cannot keep up with the rate of waste generation, although that rate, 1.1 kg/person/d, is at or below the world average.

According to Ministry of Health and Welfare statistical data for 1996, Japan produces 400 Mt/a of industrial waste, of which 17% is landfilled, 37% recycled, and 46% volume-reduced (incinerated or comminuted). Residential waste (MSW) amounts to a little over 50 Mt/a. Incineration accounts for approximately 77% of this material while recycling removes another 13%; however, incinerator ash and non-combustibles still result in more than 14 Mt/a of material ending up in the landfill.

Currently (1996) there are 1 872 MSW incineration facilities in Japan, with a combined capacity of 191 kt/d. Although there are almost 2 400 MSW landfills with a capacity of almost 500 Mm^3, remaining landfill space has been estimated at 141.5 Mm^3, sufficient for only 8.8 years at the current production rate. This severe situation has resulted in the Ministry of Health and Welfare declaring the eighth in a series of waste management plans for Japan. The current plan (1996-2002) has as its targets:

- the reduction and sorting of waste;
- the conversion from landfilling to recycling; and
- preservation of the environment.

These targets will be accomplished by achieving the following goals by 2002:

- a reduction in the annual growth rate of waste generation from 1.5% to 0.5%;
- an increase in the proportion of MSW undergoing volume reduction treatment (by various methods) from 87% to 91%;
- an increase in the recycle rate from 9.9% to 15%;
- increasing individual incinerator capacity to >300 t/d (in all cases at least 100 t/d); and
- increasing the rate of power generation from incinerators from 42% to 55%.

The above statistics stress the severity of the waste disposal situation in Japan currently and suggest the reasoning behind the recent shift away from the traditional focus on treatment and disposal, to a greater emphasis on reduction, advanced treatment and recycling. This in part justifies the willingness of the Japanese to invest in high-cost reduction processes such as the Ibaraki City high-temperature melting facility, and to site incineration facilities in expensive locations (central to the MSW source) such as the Toshima plant.

Electric Power Demand

In Japan, energy recovery from waste is mainly in the form of electricity. Only a few facilities recover energy as heat (steam and hot water), due to the low demand. A high importance is attached to waste energy recovery facilities because of both the demand for electricity and the necessity of reducing landfilling. The government also recognizes the importance of waste power generation, and the Ministry of International Trade and Industry (MITI) recently announced a goal for electricity:

- increasing the energy-from-waste generating capacity from 933 MWe (at the end of 1998) to 5 000 MWe by 2010.

The electric companies in Japan have developed 'Electricity Purchase Menus', simplifying the sale of excess electricity from the plant to the company.

In general, waste power generation efficiency in Japan is in the 10-12% range. Plants being built today are managing to exceed 15% efficiency. In order to meet the MITI goal, these efficiency figures must be increased. While high steam pressure and temperature are needed to achieve high waste-to-power efficiencies, temperatures are maintained below 300°C at most plants, in order to lessen superheater corrosion caused by hydrogen chloride. National R&D programs are currently being carried out in Japan to rectify this situation.

Tokyo and the Wards

Metropolitan Tokyo is divided into 23 special wards, and 40 cities, towns and villages, with a total population of about 12 million. The wards, of which Toshima is one, have a population of 8 million and an area of 621 km^2. MSW and business-generated waste accumulate at a rate of about 4 Mt/a (1.38 kg/person/d). Since February 1997, the incineration rate has been 100%, and new incinerators are built as the need arises to maintain this rate. Nineteen plants are currently operating (Toshima is the newest) and two more are under construction.

Oversized and noncombustible waste is pulverized and separated (ferrous metals, aluminum, glass, combustibles and noncombustibles) at the Central Breakwater and Keihinjima Incombustible Waste Processing Centers. Noncombustibles and incinerator ash are disposed of at landfill facilities at Tokyo Harbour. The area contains several sites that are full to capacity, the Outer Central Breakwater Site No. 2 (199 ha) which will close in 2003, and the new Sea Surface Disposal Site (319 ha).

Toshima Incineration Plant

The incineration facility in the Toshima ward was constructed under the philosophy of disposing waste in the area in which it is generated, while minimizing the associated environmental and social burden. As such, three fundamental concepts were followed:

1. Coexisting with the Global and Regional Environment. The plant has been constructed to include state-of-the-art control equipment such that atmospheric pollution, odor, noise, etc., are addressed and minimized. Moreover, the Bureau of Waste Management has self-imposed environmental limits, for several species of concern, that are up to 30 times more strict than the legally stipulated levels.

2. Awareness of Resource and Energy Cycles. Construction of the plant facility made use of several sources of recycled material: wallpaper from waste paper; wall tiles from glass cullet; floor panels from refuse ash slag; roadways from recycled asphalt concrete; and more than 5 000 t of recycled concrete as a building material. Further, a maximum of 7.8 MW of electricity and 15.5 GJ/h of heat are produced from the waste incineration process. Electricity in excess of internal requirements is sold to Tokyo Electric, while heat energy is used for heating and air conditioning for the plant and the attached Toshima city office and health plaza (heated swimming pool). Finally, rainwater is collected for non-potable use.

3. Relationship with Local Citizens. Traffic congestion has been alleviated by provision of two separate access points for refuse collection trucks. Overhead bridges have been built for the convenience of pedestrians in bypassing the facility. The plant is painted in earth-tone colours and a rooftop garden area has been installed to help the plant fit into the surroundings. An emergency well has been drilled for plant and civic water supply in the event of a disaster. The environment in the health plaza is maintained with waste incineration heat. The MSW reception area is under a slight negative pressure and is protected with air curtains to prevent the release of unpleasant odors, and interior air is purged by passing it through the furnace. Finally, the stack has been erected to a height of 210 m (to achieve the necessary buoyancy to avoid the nearby Sunshine 60 building—head office of NEDO) and stack gases are reheated to 210°C so that visual and environmental effects to the surrounding area are minimized.

PROCESS TECHNOLOGY

MSW Reception and Fuel Preparation

The plant is provided with truck scales (exterior) and a MSW unloading area under slight vacuum, to prevent odor leakage. The vehicle reception capacity is 440 trucks daily. MSW is dumped into a garbage hangar of 7 200 m^3 capacity (sufficient to supply the plant for four days). In the hangar, refuse is mixed (horizontally and vertically) every 15 minutes by automatic overhead cranes. Deodorant is also injected. In case of emergency, or when the amount of refuse warrants it, the cranes can be operated manually.

No fuel preparation is carried out onsite; rather, Tokyo has a source separation program in effect. At each household, waste is separated into combustibles (kitchen waste, paper, clothing, etc.), noncombustibles (metals, ceramics, glass, plastics, rubber, leather, etc.) and large-sized waste (over 30 cm, furniture, appliances, etc.). Waste is required to be placed in transparent polyethylene bags containing calcium carbonate (for odor control). The large-sized and noncombustible waste goes to the Central Breakwater site in Tokyo Bay for processing (pulverization, separation of combustibles and recyclables, volume reduction and landfilling), while the small combustibles are trucked to the incinerator. Despite the precautions taken, about 5-10% noncombustibles slip through the system and end up in the incinerator feed. The incinerator feeding system is sized to accept material less than 60 cm.

Incinerators

The Toshima Incineration Plant is equipped with two 200 t/d atmospheric bubbling fluidized bed (BFB) incineration boilers constructed by Ishikawajima-Harima Heavy Industries (IHI). Fluidized bed technology was chosen because of the necessity of minimizing required plant floor area (residential location). Because of the furnace's vertical design, the incineration capacity per unit area is much greater than for a grate-fired unit.

A BFB unit operates by combining fuel (in this case MSW combustibles) and combustion air in hot sand under vigorous mixing. There are basically three zones in the vertically oriented incinerator: the fluidized bed, the freeboard and the boiler. At the bottom of the vessel is the dense bed. Here fluidizing air enters through a horizontal tubing grid (distributor) just above the incinerator floor. At a higher elevation in the fluidized bed, primary combustion air (approximately 7 550 Nm^3/h) is injected. Temperature in the bed is maintained at about 550-630°C, hot enough to drive off volatiles and fully combust the MSW, which is fed at the top of the bed. If the temperature should rise above 630°C, cooling water sprays are activated automatically. Ash and sand periodically migrate downward and are removed at the incinerator bottom. Sand is separated from the ash, graded, and returned to the top of the dense bed. Each incinerator contains 57 m^3 of sand (90 t), some of which is lost as fines with the flue gases, or in the ash stream. It is estimated that periodic make-up results in a complete sand change over a period of one to two years.

Above the dense bed is a tall region known as the freeboard. Here secondary combustion air (approximately 28 800 Nm^3/h) is injected at several levels to completely burn off the volatiles. The temperature in this region rises steadily from about 710°C to 1030°C (automatic cooling water sprays are activated should the temperature exceed 1070°C), and gas velocity is such that a residence time (at 850°C) of at least two seconds is achieved (for dioxin destruction). In addition to fly ash, some sand fines may still be carried by the gases in the freeboard, but these are minimized by prudent velocity control.

Above the freeboard is the boiler. With no combustibles remaining in the gas, and with the aid of cooler air injection, temperatures drop rapidly prior to contact with the boiler tubes (approximately 480-580°C). This is a natural circulation water-tube boiler, equipped with a superheater. Steam is generated at a maximum rate of 33.3 t/h from each unit, usually at 3.14 MPa (abs) and 300°C. The high-pressure steam is routed to a high-pressure steam header, while the flue gases exit the boiler through an economizer to a quick-quench cooling tower.

Air Pollution Control System

Flue gas treatment begins at the exit of the economizer, where a water spray cooling tower quickly quenches the gases to 150°C, minimizing dioxin formation. At the entrance to the fabric filter baghouse, slaked lime and powdered activated carbon are injected into the flue gases to remove heavy metals, dioxins/furans and non-combusted organics, while the baghouse removes particulates. The design gas treatment rate in the baghouse is about 75 000-109 000 Nm^3/h (dry).

Once leaving the baghouse through an induced draft fan, the flue gases enter a wet caustic soda scrubbing tower which removes acid gases (sulphuric and hydrochloric acids), at a gas treatment rate similar to the baghouse.

Upon exiting the scrubber, the flue gases are dried and heated, by heat exchange with steam generated in the plant, to 210°C before entering the selective catalytic reduction (SCR) reactor. Here, ammonia is injected into the gas stream as it passes through a honeycomb catalyst to remove nitrogen oxides (NOx).

From the SCR, flue gases enter the 210 m stack (the tallest concrete stack in Japan), containing two flues (one for each incinerator) and an elevator (for maintenance). The inlet temperature to the SCR was chosen for two reasons: to improve the rate of catalytic conversion of NOx (although a temperature of 250-350°C would have been more appropriate); and to ensure an invisible plume emanating from the stack.

Electricity Generation/Balance of Plant

The plant is equipped with a single condensing steam turbine/generator set which can handle a maximum flow rate of 58.4 t/h of 2.84 MPa steam, and produce up to 7.8 MWe. The maximum figures mentioned are based on firing 400 t/d of waste with a heating value of 13.4 MJ/kg (3200 kcal/kg), the upper design value. Under current operating conditions, however, with the feed heating value at about 9.4 MJ/kg (2250 kcal/kg), only 5.3 MWe is generated.

Approximately 15.5 GJ/h of heat energy is delivered to the adjacent Toshima Health Plaza facilities to provide heating, air conditioning, and water heating for the swimming pool. Other heat energy streams provide heat and process steam to meet the needs of the plant. The plant also requires electricity for operations, approximately 3 MWe. Over the eight-month period between June 1999 (initial commercial operation of the plant) and January 2000, the plant generated 22 362 MWh of electricity. Generation on a monthly basis varied from 1 870 MWh (in September 1999) to 3 499 MWh (in July 1999), presumably reflecting variations in plant availability (down time to solve problems, equipment maintenance, etc.), heating value of the waste fuel, etc. Of this, 4 402 MWh was sold to Tokyo Electric. Sales of electricity varied for the same reasons as did generation, in the range of 229 MWh (in September 1999) to 819 MWh (in July 1999). The remainder was consumed internally. Electricity production is important for the plant, because of the demand in Japan. However, the plant is committed to supplying heat energy to the attached Health Plaza as a first priority.

FUEL CHARACTERISTICS

The bubbling fluidized bed incinerators have been designed to operate on waste feed with a heating value in the range of 7.1-13.4 MJ/kg (1700-3200 kcal/kg). While no waste analysis has been received from the plant, it was stated that the energy content of the currently received waste is 9.4 MJ/kg (2250 kcal/kg), typically with 5-10% non-combustibles.

During construction of the Toshima facility, waste from the area was treated at the incineration plant in the adjacent Itabashi ward. The component analysis for waste treated at that plant in 1998 (April 1998-March 1999) is as follows [1]:

Component	**Average Value (%)**	**Range (%)**
Combustibles	91.56	90.21-93.04
paper	51.25	43.84-55.08
textiles	3.87	2.09-6.76
kitchen waste	25.50	22.23-30.55
yard waste	8.37	3.17-10.59
other combustibles	2.57	1.38-3.47
Unsuitable for incineration	7.65	6.04-8.82
plastics	7.49	5.98-8.37
rubber, leather	0.16	0.01-0.54
Incombustibles	0.79	0.63-0.97
ferrous metals	0.16	0.14-0.21
nonferrous metals	0.22	0.16-0.33
glass	0.16	0.04-0.24
other incombustibles	0.25	0.01-0.57
Carbon [2]	54.7	
Hydrogen [2]	8.1	
Nitrogen [2]	1.0	
Oxygen [2]	35.8	
Sulphur [2]	0.0	
Chlorine [2]	0.4	
Moisture	42.24	35.44-50.87
Combustibles	51.73	43.67-57.88
Ash	6.03	5.46-6.68
LHV (kcal/kg)	2118	1700-2381

MASS AND ENERGY BALANCES

Although the Toshima Incineration Plant recovers both heat and electrical energy, the majority of this is in the form of electricity, owing to the high demand for power generation. Efficiency figures calculated below may seem low by European standards, but are comparatively high by Japanese standards. This is the case because of regional differences, very strict environmental requirements, etc.

Energy Balance

Based on the maximum heating value input, 400 t/d of waste at 13.4 MJ/kg is fed to the incinerators. This is equivalent to 223 GJ/h. Output from the incinerators is 66.6 t/h of steam at 3.14 MPa(abs) and 300°C. Enthalpy under these conditions is 2.99 MJ/kg, and total output is 199.1 GJ/h, yielding incinerator combustion efficiency of 89.2% (excellent for fluidized bed furnaces of this size and typical for a commercial-scale pulverized coal-fired boiler).

A maximum of 58.4 t/h of steam at 2.84 MPa (total energy = 174.6 GJ/h) enters the turbine/generator, where 7.8 MWe (28.1 GJ/h) is generated. Steam at 12 t/h is extracted from the turbine, with 6.5 t/h used in the deaerator, leaving 5.5 t/h (15.4 GJ/h) for rating operation. Electrical generation efficiency for the turbogenerator is thus 16.1%. Waste to electricity efficiency is: 0.161 x 0.892 = 14.4%, a rather low figure by North American standards due to the steam conditions and to the fact that cooling towers rather than water condensers are used.

Of the 66.6 t/h of steam generated, 8.2 t/h is directed elsewhere: 5.2 t/h (15.5 GJ/h) is routed to the Health Plaza for heat, air conditioning and pool water heating; the other 3.0 t/h (9.0 GJ/h) is used in the plant (e.g., for reheating the flue gases prior to entering the SCR).

The gross efficiency of conversion of energy from waste to end use is: (28.1+15.4+9.0+15.5)/223 = 30.5%. This figure is moderately low, considering a percentage of the heat energy is used directly as steam; however, the allowable steam conditions and energy-intensive environmental treatment are largely to blame. The BFBs perform quite efficiently.

Mass Balance

The two furnaces each incinerate 200 t/d of waste. Bed ash and fly ash are collected. The bed ash is passed over a permanent magnet drum separator, which removes 0.15% ferrous metals, or 0.6 t/d (design value is 100-150 kg/h). The remainder (incombustibles) amounts to 0.35%, or 1.4 t/d (design value is 200-450 kg/h), which is removed to the landfill. The fly ash (containing some unburned carbon), recovered in the baghouse fabric filter, is mixed with chelate and water in the ratio of 50:1:15 (to prevent heavy metal leaching). The dry fly ash amounts to 1.7%, or 6.7 t/d (design value is 650-980 kg/h), and is also removed (chelate-treated) by truck to the landfill.

PRODUCT/RESIDUE RECOVERY AND DISPOSITION

As has been stated above, incombustibles (bed ash) and chelate-treated fly ash are removed by truck to the Outer Central Breakwater Site for landfilling. Of prime importance here is that the incineration process reduces the volume of material entering the landfill by 95%. Plant officials have stated that they will consider the recycle of ash residue in the future (e.g., as cement substitute, aggregate replacement, etc.), having the effect of reducing landfilled volume by an even greater percentage.

Ferrous metal is recovered and stored temporarily in a 60 m^3 bunker. Periodically, it is removed by overhead crane to trucks, and is disposed of in the landfill with the ash. Currently, Tokyo Metro is seeking a buyer for this material.

Electricity in excess of in-plant requirements is sold to the Tokyo Electric Power Company (TEPCO). Currently electricity has a value of 8 ¥/kWh.

Low-pressure steam is provided to the Toshima Health Plaza for space heating, air conditioning, pool water heating, and other uses. Some steam is also used in-plant.

ENVIRONMENTAL EMISSIONS PERFORMANCE

At present, no actual plant data is available. In its place, this section deals with regulations applicable to, and which are presumably being met by, the Toshima incinerator.

Bottom Ash

No quality standard currently exists for incinerator bottom ash. At the landfill, the thickness of the layer of disposed ash must be no more than 3 m, and each such layer must be covered by 50 cm of soil and sand. This in turn must be covered with a waterproof membrane. See the section on fly ash below.

Fly Ash

There are two standards for fly ash, depending on final disposition. These standards (maximum concentrations for several species) are listed in the following Table.

Component	Standard 1 (maximum)	Standard 2 (maximum)
Mercury	0.005 mg/l	0.0005 mg/l
Cadmium	0.3 mg/l	0.01 mg/l
Lead	0.3 mg/l	0.01 mg/l
Chromium (6+)	1.5 mg/l	0.05 mg/l
Arsenic	0.3 mg/l	0.01 mg/l
Selenium	0.3 mg/l	0.01 mg/l

Standard 1 applies where fly ash is to be landfilled, and must be handled in the same manner as bottom ash. The more strict Standard 2 applies to the situation where the treated fly ash is to be recycled. Acceptable treatment to meet either Standard 1 or Standard 2 includes: melting and solidification; solidification with cement; elution of heavy metals; and chemical stabilization (e.g., with chelates, as is practised at Toshima). The plant would be required to meet Standard 2 before they could carry out their future plans of using the fly ash.

Gaseous Emissions

Because of the urban location of the Toshima incinerator, and in keeping with the three fundamental concepts guiding the construction and operation of the plant, the Tokyo Metropolitan Government has seen fit to self-impose gaseous emission standards that are more strict than those currently in force and applicable to a plant of this size. The Table below shows these standards.

Pollutant	**Regulated Level**	**Self-imposed Standard**
Dust	0.08 g/Nm^3	0.02 g/Nm^3
Hydrogen chloride	430 ppm	15 ppm
Sulphur oxides	41 ppm	20 ppm
Nitrogen oxides	8.75 Nm^3/h (85 ppm)	6.125 Nm^3/h (60 ppm)
Mercury	No regulation	0.05 mg/Nm^3
Dioxins	1 ng TEQ/Nm^3 (from Dec. 2002)	0.1 ng TEQ/Nm^3
Carbon monoxide	50 ppm (4 hour average)	50 ppm (maximum)

To ensure achievement of the self-imposed standard for dioxins, the Toshima plant has instituted the following measures: a minimum combustion gas retention time of two seconds at 850°C; a rapid quench of gas temperature to 150°C at the filter entrance; maximum CO concentration in the flue gas of 50 ppm; slaked lime/activated carbon injection; and decomposition over the SCR denitration catalyst.

OPERATIONAL PROBLEMS

The Toshima incinerator commenced operation in July 1999. Because of some operational problems, representatives of IHI were on site in November 1999 when the plant visit by IEA members took place.

- Although there were no major sintering problems reported, it was found that molten material occasionally detached from the incinerator walls, leading to incidences of defluidization.
- As there are no spare waste feeders (only one per incinerator), intermittent pluggage problems have occurred with the unsorted feed stream.
- Because the waste is not sorted at the plant (rely on sorting at the source), some difficulties have been encountered extracting the incombustibles (bottom ash).

CAPITAL, OPERATING AND MAINTENANCE COSTS

Construction costs for the facility, excluding the Toshima Health Plaza, but including all infrastructure modifications was 17 billion ¥ (approximately US$140 million at 1997 average conversion rates). While this appears quite high by North American standards, it must be understood that: (1) the plant is in downtown Tokyo, where real estate and infrastructure costs are very high; (2) the location near the Sunshine 60 building (NEDO headquarters) has necessitated the highest concrete stack in Japan, again at great expense; and (3) the plant, stack and associated buildings were built to earthquake standards.

There are seven people in the control room (Tokyo Metropolitan Government employees) for each of four shifts, and the plant operates continuously. No labour rates have been disclosed.

Consumables include: bed sand (approximately 90-180 t/a); ammonia for the SCR (32-47.4 kg/h); chelate resin to treat the fly ash (13-19.6 kg/h); slaked lime and activated carbon for injection into the baghouse (35-51 kg/h); and caustic soda for the SO_2 scrubber (88-128 kg/h). Costs for these chemicals and for the SCR catalyst (which should require replacement after 3-4 years) have not been disclosed. However, operating costs have been quoted by Tokyo Metro as approximately ¥14 000/t of waste (about US$127/t). This does not cover waste collection costs, but does include ash treatment, transportation and disposal.

Maintenance schedules/costs have not been disclosed.

REFERENCES

1. Tokyo Metropolis, 2000.

2. Japan Environmental Sanitation Center, “Fact Book 1997”.