Energy Recovery

Takashi Akehata
Department of Industrial Chemistry, Science University of Tokyo
Kagurazaka, Shinjukuku, Tokyo 162, Japan

SUMMARY: Incinerators in use, power-generating incinerators and pollution-prevention methods in energy recovery from waste incineration are briefly reviewed. Results of a recent energy recovery experiment under real operating conditions are described: The addition of waste plastic to municipal solid waste brought about more stable combustion and no increase in the concentrations of dioxins. It is remarked that energy recovery through incineration is probably the best currently available means of disposal for plastics which are too difficult to recycle.

Energy Recovery Through Incineration

Energy recovery through incineration is probably the best currently available means of disposal for plastics which are too difficult to recycle. The surplus heat of waste incineration is recovered and used in the forms of hot water, steam, and electricity. Municipalities and industries disposing waste via incineration enjoy benefits of space and water heating and power generation. In today's environment with emphasis on economically and environmentally sound integrated resource management, waste-to-energy recovery complements, rather than competes with, conventional recycling.

In a very densely populated country like Japan, the majority of municipal solid waste (MSW) , 75 %, is incinerated. Throughout Western Europe and in many regions of the United States, the considerable amount of MSW that is not landfilled is incinerated. Table 1[1] gives a breakdown of the main disposal techniques currently used for plastics in MSW in Europe.

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Tab. 1. Destination of plastics in MSW, 1990

Country	Incineration with heat recovery (%)	Incineration without heat recovery (%)	Land filling (%)	Mechanical recycling (%)
Belgium/Luxemburg	45	10	45	1
Denmark	60	10	29	1
France	30	16	53	1
Germany	32	0	67	1
Greece	0	0	100	0
Ireland	0	0	100	0
Italy	7	6	86	1
Netherland	36	3	60	1
Portugal	0	0	100	0
Spain	10	8	81	1
UK	2	8	89	1
Austria	25	0	75	0
Finland	3*	4*	93	0
Norway	8	16	75	1
Sweden	56	0	43	1
Switzerland	72	7	20	1

Source: SEMA Group * Estimate

In the United States, the federal Environmental Protection Agency has reported that 16.3 % of all MSW was incinerated in 1990. In some states, especially in the Northeast, incineration rates exceed 50 %. In 1990, 330 major incineration facilities were in operation in Western Europe and there are 125 municipal waste incinerators equipped with energy recovery systems presently operating in the United States. The energy is often recovered for steam, electricity or heat generation. Because of its safety and economy, and also because of a shortage of landfill sites, incineration of MSW will become more common.

The incineration of MSW is conducted to reduce its volume and produce a sterilized ash. MSW containing plastic waste has a high caloric value, as shown in Table 2. The MSW

Tab.2. The caloric value of a few selected compounds[1)]

Materials	Energy released upon combustion
Polystyrene	46.0 MJ/kg
Polyethylene	46.0 MJ/kg
Household refuse	7-8 MJ/kg
Leather	18.9 MJ/kg
Poly(vinyl chloride)	18.9 MJ/kg
Paper and Wood	16.8 and 16.0 MJ/kg

incinerators heretofore in use, which were designed for the mixture of household refuse, paper and wood, must have been operated at reduced incineration throughputs for plastic-containing waste. Therefore, recent incinerators are designed so as to stand up against high load and to recover energy. The corrosive action of gases formed in incineration requires a partial replacement of boiler tubes in an incinerator in five to ten year intervals.

Fluidized bed incinerators, known for their ease of operation and freedom from the problems associated with residual unburned portions of waste, are now widely employed not only for MSW, but also for the direct combustion of waste plastic, rubber, and tires.

Various effluent gas treatments are employed to remove or reduce pollutant gases. Polluting gases and particulate emissions from incineration can now be satisfactorily controlled.[2] Polychlorinated dibenzodioxins and dibenzofurans (PCDD/PCDF) have reportedly been generated during incineration and have been studies in detail.[3] A recent study (1991) compared pollution emissions from a 7 MW fluidized-bed steam boiler using coal only, coal-plastic, and plastic-only feeds. The results were that plastics (up to 25 % PVC) emitted lower total specific emissions than coal, and gaseous PCDD/PCDF emissions were close to the levels obtained when burning coal (and within the most stringent expected limitations). Many researches done to investigate the mechanism of pollutant generation give knowledge on how to suppress their generation and how to remove them from exhaust gases.

Risk assessments of the dioxins and furans dispersing from stacks of incinerating plants show no discernible effects on human health.

Incinerators in Use

Plastics in MSW contribute a high proportion of energy when incinerated, as shown in

Table 2. Some common plastics have combustion-energy values up to almost three times larger than those of wood and paper. As stated before, energy recovery through incineration is probably the best currently available means of disposal for plastics which are too difficult to recycle.

For waste incineration, furnaces of mechanical-stoker type, rotary-kiln type, and fluidized-bed type are employed. The mechanical-stoker type incinerator (Fig. 1) has been used for municipal solid waste incineration for a long time. By the mechanical operation of the stoker grates, the charged wastes are forwarded to the combustion zone. Heat recovery is done with an exhaust heat boiler. Power generation with steam turbines is popular. Since today MSW contains plastic waste, recent furnaces are designed to meet a high heat value of about 12 MJ/kg.

Rotary-kiln-type incinerators (Fig. 2), rotary kilns being often used in cement manufacturing industries, are also introduced into municipal wastes disposal. The incinerator is cylindrical in shape and its body is slightly inclined. With the kiln rotating, the fed wastes are agitated and rolling over to combustion zones at temperature of about 1000 °C. The unburned portion contained in the ash is as little as 3 % or less.

Fluidized-bed reactors in which solid catalyst particles are fluidized, are very widely used in the petroleum and chemical industries. Fluidized-bed incinerators (Fig. 3) have sands of high temperature. The wastes fed to the incinerator burn in the fluidized sand and commingled uncombustibles like steels and stones are drawn out from the bottom of incinerators. Good circulation of high-temperature sand in the bed does not cause any trouble as experienced in the old mechanical stoker-type incinerators, such as molten plastics trickling down through the stoker grates onto the ash receiver. The fluidized-bed

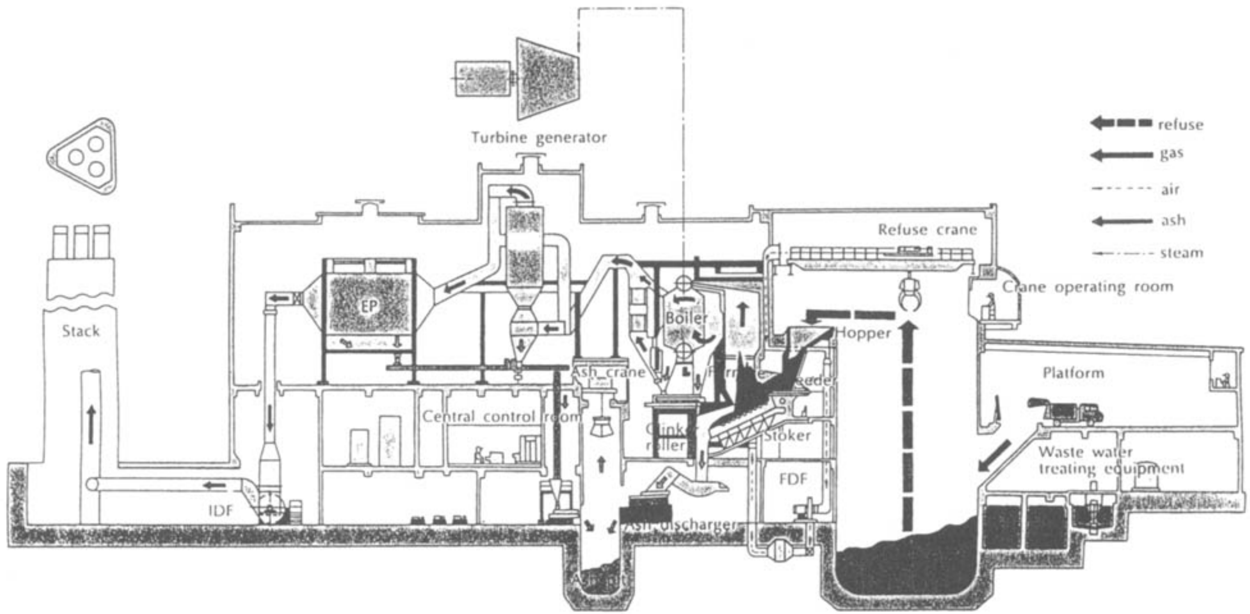

Fig. 1: Incineration flow diagram

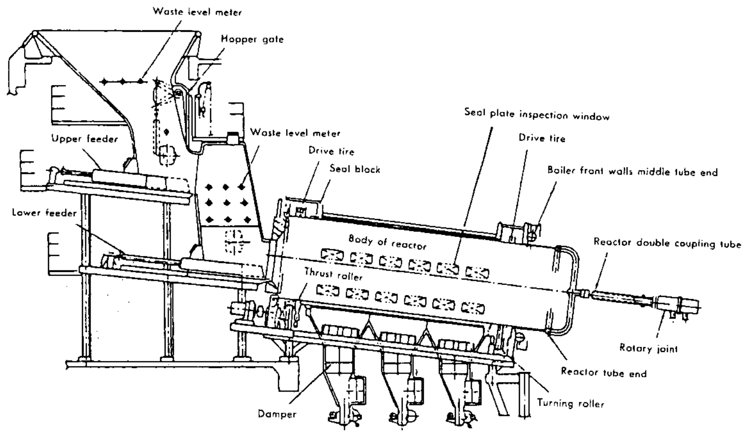

Fig. 2: Body of rotary kiln incinerator

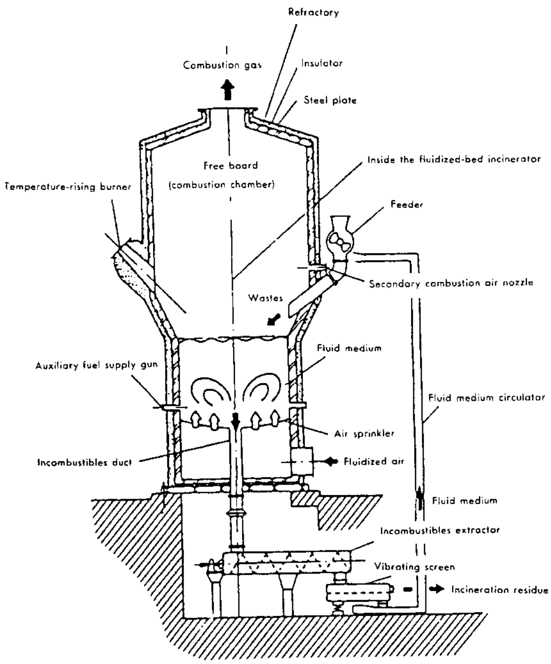

Fig. 3: An example of structure of fluidized-bed incinerator

incinerator responds well to the increasing heat value of wastes. The fluidized-bed incinerator permits (1) combustion control depending on the changing quality of wastes, (2) easy exhaust gas treatment, (3) easy operation, and (4) efficient waste volume reduction. At present, fluidized-bed incinerators of a 150 t/d capacity are available.

Power-Generating Incinerators

Energy recovered from waste incineration is used to generate hot water, steam, and electricity. In order to generate electricity economically, a large amount of waste must be incinerated continuously, say 200 t/d. A medium- or small-size plants, say those of cities of population of 30 to 300 thousand, usually recover heat and use it in the form of hot water or steam. Power generation in small plants is actually prohibitive because of high cost. It is practical that in small plants the refuse-derived fuel is made by compression from collected waste and subsequently transported to continuously operated large plants where highly efficient pollution prevention facilities are installed and the treatment is elaborate and economical.

Many of the waste incineration plants committed to power generation in Europe set steam conditions within the range of 40 to 100 atm and 370 to 500 °C. A similar trend is evident in the United States. A German plant sets the conditions as high as 205 atm and 540°C. On the other hand, in Japan, the conditions of steam generated with the boiler are limited to less than 25 atm and 280°C in order to avoid high-temperature corrosion of superheating tubes by chlorine in the combustion chamber. This results in generation efficiency of around 13 to 14 %.

To increase output, the boiler must be made to withstand high temperatures and pressure with moderate-priced materials. Recent development in Japan is coupling of waste-fuelled power generation and power-generating gas turbine. In the system, the steam from the exhaust heat boiler of the incinerator is superheated by the exhaust gas of the power-generating gas turbine. By this method, the efficiency increases to 30 %.

Pollution Prevention in Energy Recovery

Energy-recovering incinerators are actually combustion furnaces, with fuel being MSW containing plastic waste. Through combustion, hot water and steam, as well as pollution substances such as soot, fly ash, NO_X, HCl, dioxins and dibenzofurans are generated. High-temperature combustion inevitably generates NO_X. Sodium chloride and other chlorides contained in MSW causes the formation of hydrogen chloride and chlorine. Recent laboratory studies[4)] of combustion processes of biomass fuel (sawdust and starch) containing inorganic chlorine (NaCl) revealed that in the flow gas chlorinated organic compounds were identified, such as chlorobenzenes, chlorophenols and octachlorostyrene, as shown in Fig.4. To remove hydrogen chloride and chlorine, slaked lime powder is blown into the exhaust gas line and the powder is collected with a dust collector. Lime is used with or without active carbon to remove dioxins. It is known [5)] with respect to the dust-collection system that the conditions necessary to suppress dioxins and dibenzofurans are: temperature at gas inlet to dust collector (electrostatic precipitator or bag filter) less than 200°C, and suspended particles at outlet of the dust collector less than 20 mg/m^3.

If combustion is not complete, both carbon monoxide and dioxins and dibenzofurans are present in the effluent gas. Carbon monoxide concentration can be taken as a measure of

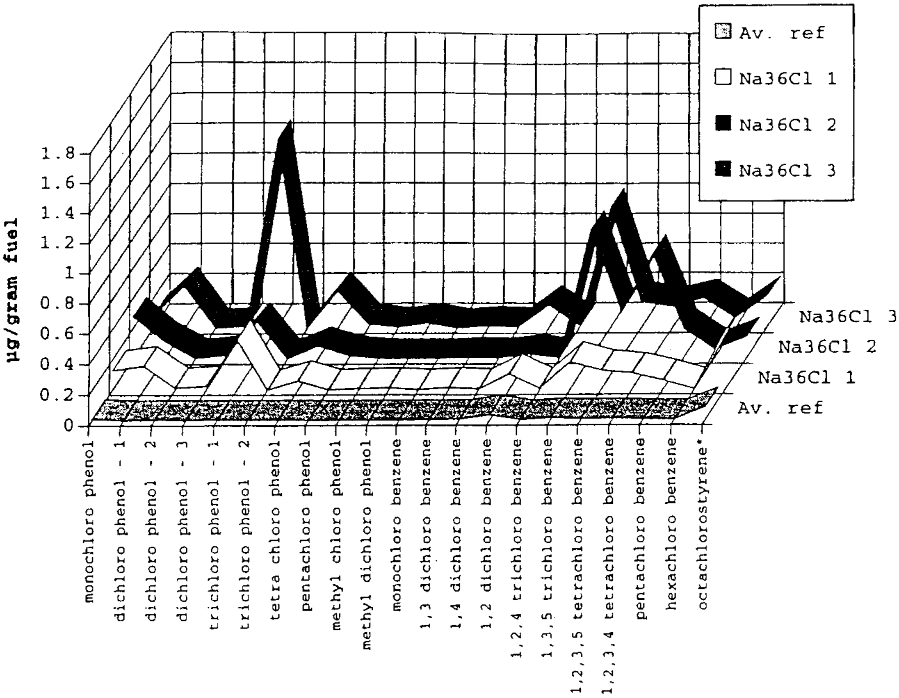

Fig. 4: Average amounts of chloroorganics from the reference biomass combustions and total amounts of chloroorganic compounds identified by GC-MS in the flue gas from three $Na^{36}Cl$ combustions

the degree of combustion. Since some old incinerators are not efficient enough for complete combustion, the problem of reforming incinerators into those capable of burning wastes completely has been studied. With proper reforming of the incinerator, quite large cuts in the concentrations of effluent CO, dioxins and dibenzofurans are achieved.[5,6] The fundamental concepts for reforming furnaces are: (1) combustion at high temperature, say higher than 800°C, should be attained, (2) high turbulence in furnaces should be brought about to assure good gas mixing and to suppress formation of reducing atmosphere, and (3) sufficient gas residence time, say 2 s, in the furnace should be realized for effluent gas to be oxidized completely. Gas mixing in the combustion chamber is accomplished by both change in the furnace inner form and change in the supply of secondary air.

For continuously-operated incinerators with a boiler for gas cooling, proper operating conditions can suppress dioxin and dibenzofuran concentrations to very low values. [7) By operating incinerator carefully and realizing complete combustion with effluent CO concentration of about 3 ppm, the concentration of dioxins and dibenzofurans will become 1 to 2 ng TEQ/m^3. (Here, TEQ stands for 2,3,7,8-tetrachlorodibenzo-1,4-dioxin toxicity equivalent.) A method using the highly toxic 2,3,7,8-tetrachlorodibenzo-1,4-dioxin isomer as a reference to evaluate other isomers is employed as a comprehensive toxicity evaluation method. Automatic control of steam generation and oxygen concentration at the exit of the dust collector by operating stoker grate velocity and primary and secondary air amounts stabilizes combustion satisfactorily. Between the incinerator and dust collector a quenching reactor may be installed. Spraying slaked lime slurry in the quenching reactor and lowering temperature of dust collector-entering gas lowers dioxins concentration.

Widely employed electrostatic precipitators should be operated at relatively low temperatures as stated before. Recently, reacting bag filters were preferably employed. The reacting bag filter is formed when unreacted slaked lime is deposited on the bag filter. It is reported that the reacting bag filter working at 150°C reduced dioxins from 2 to 3 ng TEQ/m^3 at the inlet to 0.01ng TEQ/m^3 at the exit.[8)] Dioxins moved to fly ash and electrostatic precipitator ash can be decomposed by hot melting at 1300°C. In the United States, the trend is towards the use of dry scrubber and fabric filter for acid gas and particulate control.

Combustion of Waste Plastics

A recent German report[9] on energy recovery experiment through co-combustion of mixed waste plastics and municipal solid waste shows interesting positive effects of polymers in the combustion of municipal solid residues. The Municipal Solid Waste incinerator Würzburg was employed to test the effects of plastics under real operating conditions. The plant has the widely used reverse acting grate type from MARTIN, an economic emission control system, the so-called dry scrubbing system, a sufficiently long residence time furnace and the energy recovery system for electricity and district heating use. For scrubbing, two types of neutralization additives: lime without carbon and with 3 wt % carbon were used. Three different feed conditions, A = normal basic case (waste plastics content 7 wt %), B = medium polymer case (14.5 wt % waste plastics) and C = high polymer case (24 wt % waste plastics) were tested for several weeks. Mean clean gas data under the conditions A, B, and C are shown in Table 3. The addition of waste plastics did not lead to any significant change in CO concentration and dust. The combustion was more stable with waste plastics. The concentrations PCDD/PCDF in the crude gas showed no increase with addition of waste plastics. Expressed in toxic equivalents, the mean values of PCDD/PCDF concentrations were 3.7, 3.7 and 2.9 ng TEQ/m^3 for the cases A, B, and C, respectively. The results of emission measurements of PCDD/PCDF are shown in Fig. 5. The carbon-containing

Tab.3. Mean Clean Gas Data for Conditions A,B and C

	A basic case	B medium case	C high-polymer case
CO, mg/m^3	19	18	7
HCl, mg/m^3	23.5	22.4	21.4
SO_2, mg/m^3	19	9.0	<5
NO_2, mg/m^3	405	385	410
Dust, mg/m^3	2.4	<2.0	2.4
Furnace, °C	890	892	894

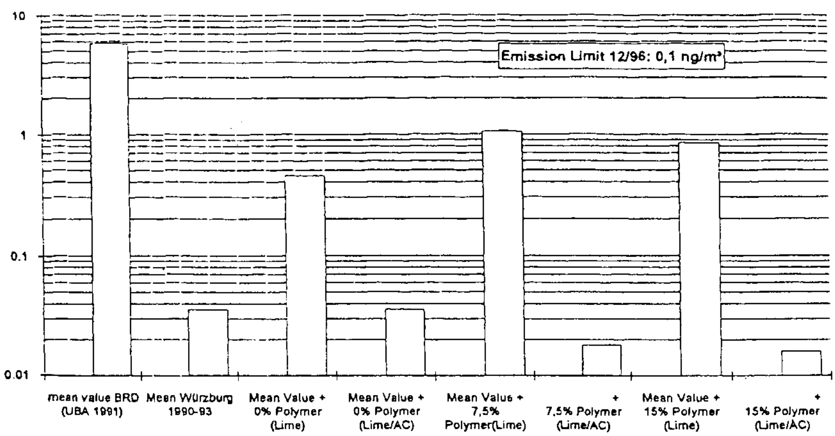

Fig. 5: PCDD/PCDF clean gas data

lime was required for neutralization to meet the new German limit.

Industrial wastes containing waste plastics are also incinerated in fluidized-bed type incinerators. Mixed wastes of plastic dusts and scraps, sludges, waste oil, paint dusts, paper and woods, polisher dusts, and carbon dusts in automobile manufacturing plants are often disposed in fluidized-bed incinerators.[10] Combustion is essentially complete, with effluent CO of 1 to 5 ppm under proper conditions.

Used tires can be burned in a fluidized-bed incinerator and to give additional energy to cooling gas of a cement kiln to which used tires have also been fed. The fluidized combustion is complete with effluent CO concentration of 7 to 10 ppm.

A few incineration cases of plastic waste have been reported. Polyethylene and poly(vinyl chloride) pellets, with the amount of PVC of up to 10 %, are burned in fluidized-bed incinerator with the CO concentration in the exit gas about 2 ppm, and of dioxins 1.6 ng TEQ/m^3.[11] The combustion conditions are: gas temperature 930°C, air ratio 0.4 for primary suppressed combustion and 0.8 to 1.0 for secondary combustion in a freeboard of the fluidized-bed incinerator.

Public concerns with health risks associated with dioxin emission from MSW incinerators frequently cause delays in the construction of incineration facilities. A health risk assessment has been recently made for an MSW incinerator.[12] Using a dispersion model, air concentrations of dioxins at the ground level were predicted and compared with the data from actual stack measurement of dioxins emission from existing old incinerators: dioxins concentration was 1.3 to 12 ng TEQ/m^3 and their mass emission 1 to 9 mg TEQ/day. The incidence of adverse effects was calculated for the exposure through inhalation, ingestion, and dermal absorption. The estimated cancer risk associated with dioxins did not exceed $5x10^{-7}$, which is lower than the virtually safe level of 10^{-6}. The estimated daily exposure was 0.041 pg/kg/day which is 4 % of the acceptable daily intake 1pg/kg/day. If the existing incinerators are reformed as described above, dioxins emission would become about one hundredth of the present amount and therefore the future impact would be very much lower than the present one.

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