HISTORICAL TREND OF DIOXIN EMISSIONS FROM MUNICIPAL SOLID WASTE INCINERATORS IN JAPAN

TAKAOKA M[1], MATSUOKA A[2], KOYAMA T[2], MASUDA T[3]

[1] Department of Environmental Engineering, Graduate School of Engineering, Kyoto University, Kyoto, Japan, 615-8540, takaoka.masaki.4w@kyoto-u.ac.jp; [2] Environmental Regeneration and Material Cycles Bureau, Ministry of the Environment, Japan, Tokyo, Japan, 100-8975,[3] Tokyo Technology Research & Planning Department, TAKUMA Co., Ltd., Tokyo, Japan, 108-0023

Introduction

Municipal solid waste (MSW) incineration is a major source of dioxin emissions to the atmosphere. In Japan, a large proportion of MSW is incinerated for sanitary reasons, and because of a shortage of disposal sites. To prevent emissions, various countermeasures have been applied since dioxins were first discovered in MSW incinerator (MSWI) fly ash in Japan [1]. In 1990, the Ministry of Health and Welfare (MHW) issued Guidelines for Preventing the Emission of Dioxins from MSWI and examined potential solutions to the problem of these emissions [2]. However, because the guidelines were not regulatory and follow-up assessments were inadequate, it was difficult to determine whether the proposed solutions had the desired effect. In January 1997, the MHW produced the updated Guidelines for Preventing the Emission of Dioxins from MSWI—Program to Reduce Dioxins [3]. At almost the same time, high levels of soil contamination were found in Nose, Osaka [4]. After amending the ordinances in the Air Pollution Control and Waste Management and Public Cleansing Acts, the Act on Special Measures against Dioxins, the world's first legislation pertaining specifically to dioxins, was enacted on January 15, 2000.

Figure 1 shows the trend in total dioxin emissions to the atmosphere in Japan from 1997 to 2017. Over that 20-year period, dioxin emissions decreased dramatically, from 7,680–8,135 g toxic equivalent concentration (TEQ)/year in 1997 to 106–107 g-TEQ/year in 2017. The emissions from small-capacity waste incinerators, industrial waste incinerators and MSWIs all decreased remarkably. The ratio of waste incineration to total waste decreased from 94% in 1997 to 50% in 2017. MSWIs accounted for 65~69% of all waste incinerated in 1997, but this had decreased to 38% by 2017.

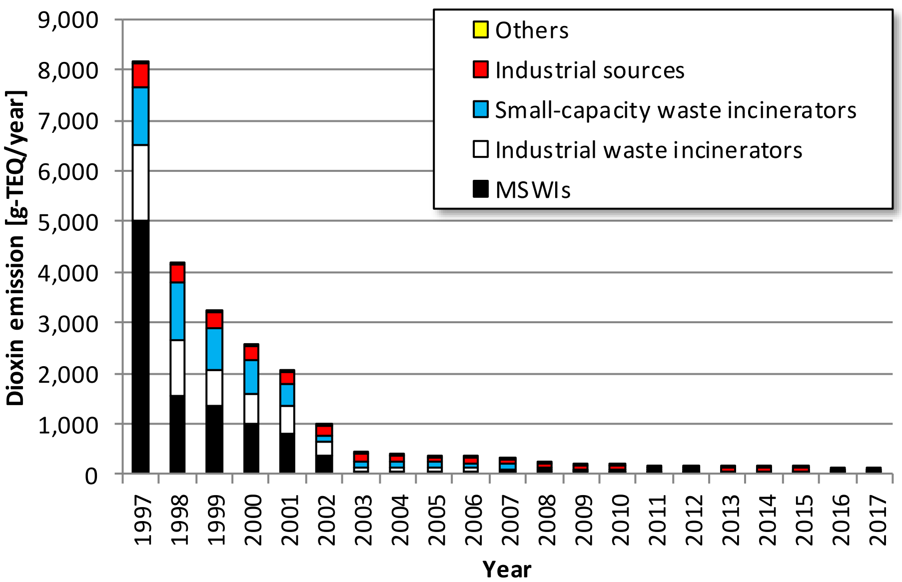

Figure 1 Total dioxin emissions to the air in Japan from 1997 to 2017.

Several papers have discussed the effectiveness of various measures for preventing dioxin emissions [3,5], and large reductions were observed following the improvement of combustion condition and introduction of bag filters and catalytic reactors. Although dioxin emissions from waste incineration decreased, Minomo reported that dioxins originating from combustion predominated in the atmosphere in Saitama Prefecture, Japan, and that the dioxin concentrations in rainfall still largely exceeded the environmental standard (1 pg-TEQ/L) [6].

To determine the effects of MSWIs on future dioxin levels, it is important to forecast changes in dioxin emissions from this source. The effects of renovating old MSWIs on dioxin emissions should be evaluated. MSWIs have recently been characterised as facilities for recovering energy from waste, and various technologies have been developed to achieve this [7]. These technologies can have positive or negative effects on dioxin formation and emissions from MSWIs. It is necessary to confirm that state-of-the-art MSWIs are effective in terms of both energy recovery and dioxin reduction.

Using national dioxin emissions data, this study evaluated the dioxin concentrations in exhaust gas and emissions to the air (ng-TEQ/ton of MSW incinerated) in the year of construction of MSWIs, to determine the effectiveness of the dioxin reduction and energy recovery policies. Future emissions were estimated according to renovation and renewal of MSWIs.

Materials and methods

The data used in this paper were collected by local governments and the Ministry of the Environment of Japan, as mandated by the Act on Special Measures against Dioxins of 2018. The data on dioxin concentrations in exhaust gas were analysed. Here, dioxins include polychlorinated dibenzodioxins (PCDDs), dibenzofurans (PCDFs) and dioxin-like polychlorinated biphenyls (PCBs). The emissions from each facility were calculated by multiplying the amount of MSW incinerated (tons /year) by the dioxin concentration in the exhaust gas (ng-TEQ/Nm^3), and by the amount of exhaust gas per ton of incinerated MSW (Nm^3/ton-MSW). However, due to data entry errors in the amount of exhaust gas data, we used only the amounts of exhaust gas ranging from 2,000 to 10,000 (Nm^3/ton-MSW).

Results and discussion

Concentration distribution of dioxin in exhaust gas

Figure 2 shows the dioxin concentrations in exhaust gas according to the year of construction of the MSWIs. In 60~70% of the MSWIs constructed up to 2000, the dioxin concentration was less than 0.1 ng-TEQ/Nm^3; it was 0.1–1 ng-TEQ/Nm^3 in 25~30% of the MSWIs and exceeded 1 ng-TEQ/Nm^3 in the remainder. The MSWIs constructed up to 2000are treated as existing facilities, such that the emission standard differs from that for facilities constructed after 2000, as shown in Table 1[8]. Overall, 20~30% of the MSWIs produced 0.1–1 ng-TEQ/Nm^3. All of the MSWIs complied with the emission standards after renovations had been completed.
For more than 90% of the MSWIs constructed after 2000, the dioxin concentration was less than 0.1 ng-TEQ/Nm^3; it was 0.1–1 ng-TEQ/Nm^3 in the remainder. None of the MSWIs produced more than 1 ng-TEQ/Nm^3 dioxin, which suggests that the various policies introduced were effective at reducing dioxin emissions.

The dioxin concentrations in exhaust gas decreased with increasing capacity of the MSWIs. Compared with MSWIs constructed up to 2000, dioxin concentrations were lower in those constructed after 2000, even in small facilities.

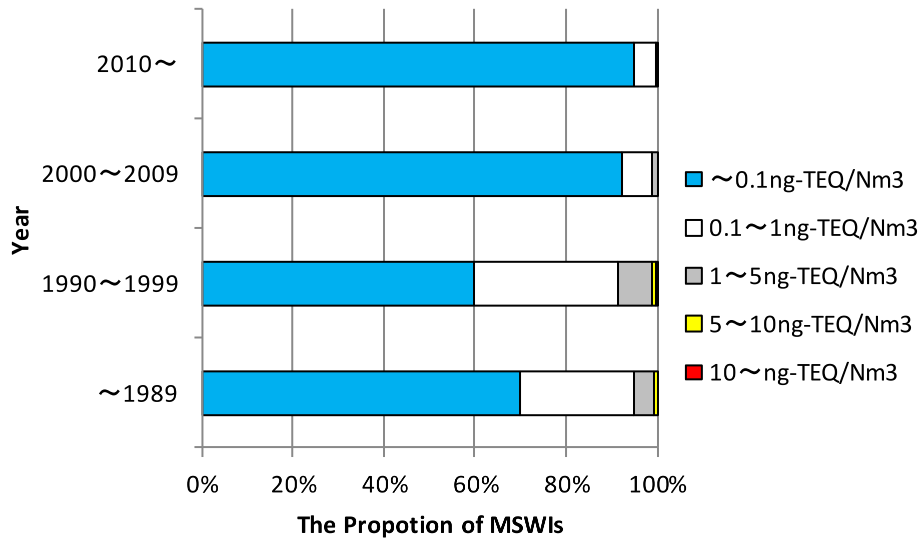

Figure 2 Dioxin concentration distribution in exhaust gas according to the year of construction of municipal solid waste incinerators (MSWIs)

Table 1 Dioxin emission standards for MSWI exhaust gas [8]

Source	Capacity (t/h)	Newly constructed facility ($ng\text{-}TEQ/Nm^3$)	Exsiting facility ($ng\text{-}TEQ/Nm^3$)
MSWIs	> 4	0.1	1
(grate area: > 0.5 m^2 or	2 to 4	1	5
capacity : >50 kg/h)	< 2	5	10

Dioxin emission factors

As mentioned above, there were errors in some of the exhaust gas volume data; these were removed from the analysis. However, 96.4% of the total available data were still included in the analysis, allowing major trends to be accurately determined. The total emissions amount, for all MSWIs combined, was 15.56 g-TEQ/year. This value was divided by the total waste incinerated yearly (32.6 million tons), to yield an average dioxin emissions per ton of incinerated waste of 476 ng-TEQ/ton of MSW incinerated. According to the PCDD/PCDF emission factors for a category 1a MSWI, as stated in article 5 of the Stockholm Convention on Persistent Organic Pollutants (POPs) pertaining to the identification and quantification of dioxins, furans, and other unintentional POPs, this value is roughly equivalent to the emission factor in class 4 "High technology combustion, sophisticated APCS": i.e. 500 ng-TEQ/ton of MSW incinerated [9]

Figure 3 shows the dioxin emissions to the air according to the year of construction of the MSWIs. The emissions from facilities constructed after 2000 were dramatically lower than those for facilities constructed up to 2000 (700~900 ng-TEQ/ton-MSW incinerated for the older MSWIs). There was variability in emission amounts among MSWIs constructed after 2000; the average emission amount was 50 (range: 10–120) ng-TEQ/ton of MSW incinerated, which is 1/10 of the lowest PCDD/PCDF emission factor for a category 1a MSWI according to article 5 of the Stockholm Convention on POPs.

The power-generation efficiency of MSWIs has recently improved. In 2009, the Ministry of the Environment of Japan produced a publication pertaining to the development of high-efficiency waste-based power plants. Energy recovery from flue gas can be improved by installing an economiser, instead of a cooling tower, before the air pollution control device, or lowering the operating temperature of (or removing) the denitrification reactor. Although these measures might increase dioxin emissions, this was not seen for recently constructed MSWIs, which suggests that there is no trade-off between dioxin emissions and energy recovery.

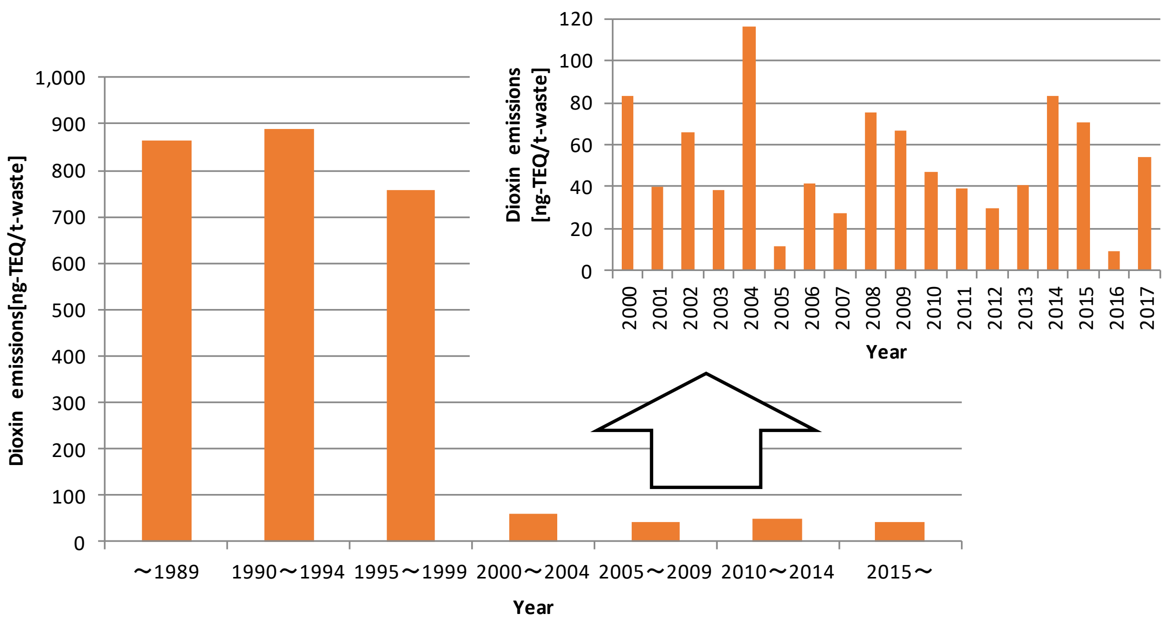

Figure 3 Dioxin emissions to the air according to year of construction of MSWIs

Future dioxin emissions from MSWIs

Figure 4 shows the number of MSWIs by years of operation. The service lifetime of an MSWI depends on maintenance efforts (in turn dependent on technological innovations therein and the budget of the local government), among other factors. The typical service lifetime of an MSWI is considered to be 40 years. Therefore, MSWIs constructed up to 2000 should be completely renovated by 2040, to achieve the levels of emissions of facilities constructed after 2000. The Japanese population is projected to decrease to 110.9 million by 2040.

Assuming that the amounts of MSW generated and MSW incineration rate remain the same, dioxin emissions from MSWIs will decrease to 2 g-TEQ/year by 2040, such that the contribution of MSWIs to total dioxin emissions will be reduced significantly.

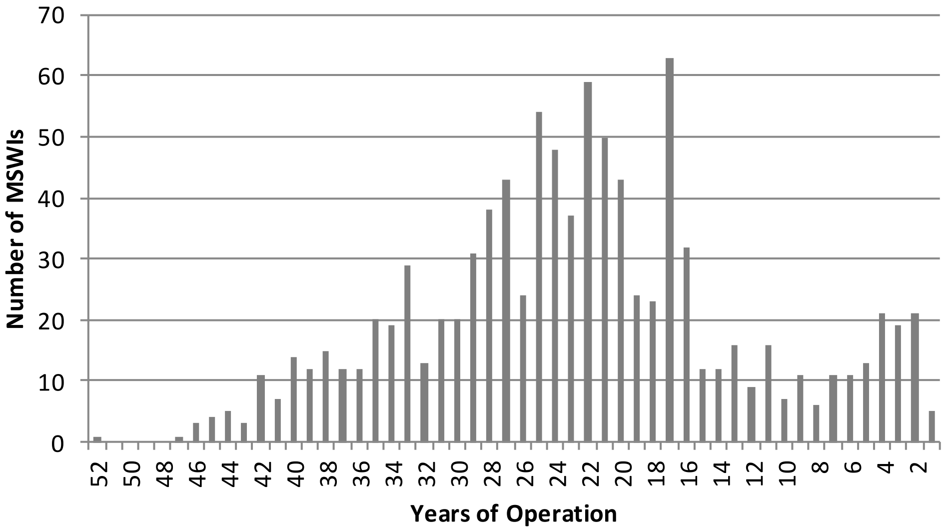

Figure 4 The number of MSWIs according to years in operation.

Conclusions

The dioxin emissions from MSWIs in Japan decreased dramatically from 1997 to 2017, with the introduction of various countermeasures. In all facilities, the dioxin concentration in exhaust gas complied with emission standards based on capacity and year of construction. The dioxins emissions to the air averaged 476 ng-TEQ/ton of MSW incinerated, which is equivalent to the lowest PCDD/PCDF emission factor for an MSWI according to article 5 of the Stockholm Convention on POPs. For MSWIs constructed after 2000, the average emission amount was 50 ng-TEQ/ton of MSW incinerated, or 1/10 of the lowest PCDD/PCDF emission factor for MSWIs of the Stockholm Convention. After 2000, various methods for increasing the power generation efficiency of MSWIs were introduced, none of which have influenced dioxin emissions. As the MSWIs constructed up to 2000 are renovated, dioxin emissions will decrease, and are projected to fall to 2 ng-TEQ/year by 2040. Herein, although dioxin emissions to the air from MSWIs were assessed, dioxins as incineration residues, such as fly ash and bottom ash, were not examined due to data limitations. Therefore, future studies should evaluate examine the total dioxin emissions from MSWIs.

Acknowledgements

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