SIMULATION OF ATMOSPHERIC DIFFUSION OF DIOXINS FROM MUNICIPAL WASTE INCINERATION PLANTS

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Introduction

In order to evaluate the contribution of dioxins emitted from municipal waste incineration plants, atmospheric diffusion and precipitation of dioxins around plants were simulated and compared with analytical data of atmospheric dust samples that precipitated on the ground. Plume and puff equations for diffusion were employed with the emission sources data and meteorological data of the same period for the simulation of the behavior of dioxins emitted from stacks. Comparison between measurement and simulation shows that the emission of the target plants explains only a small part of the measured precipitation. This means that there may be large contributions from unknown sources.

Methods

We selected two different incineration plants for the study. One has continuous-feed incinerators, and the other non-continuous feed incinerators. In order to obtain the actual amount of dioxins around the plants, we sampled precipitating dust for an analysis of dioxins, using several deposit gauges placed along the lines of the most frequent wind directions for one month. The measured spatial distribution of dioxins precipitation rate as an average for that period was thus determined.
The simulation is based on the plume and puff equations, which are analytical equations for atmospheric diffusion and are used for environmental assessment as standard equations[1,2]. In this study, however, we modified these equations in two ways: (1) Not only concentration of materials in the atmosphere, but also precipitation rate on to the ground is calculated. (2) Particulate matter is taken into consideration, since dioxins exist in the atmosphere as particulate as well as gaseous matter. The modified plume equation is

$$C_{pl}(x,y,z,i,j,k,id) = \frac{1}{\sqrt{2\pi}} \cdot \frac{Q_p}{\frac{\pi}{8} R \sigma_z u} \cdot \left[\exp\left\{ - \frac{(z - H_e + \frac{V_s R}{u})^2}{2\sigma_z^2} \right\} + \delta \cdot \exp\left\{ - \frac{(z + H_e - \frac{V_s R}{u})^2}{2\sigma_z^2} \right\} \right]$$

and the modified puff equation is

$$C_{pf}(x,y,z,j,id) = \frac{Q_p}{(2\pi)^{3/2}\gamma} \left\{ \frac{1}{R^2 + \frac{\alpha^2}{\gamma^2}(z - H_e + \frac{V_s R}{u})^2} + \frac{\delta}{R^2 + \frac{\alpha^2}{\gamma^2}(z + H_e - \frac{V_s R}{u})^2} \right\}$$

where C_{pl}, C_{pf}: concentration, x, y: horizontal coordinate, z: height from the ground, $R=(x^2+y^2)^{1/2}$, i: wind speed class, j: stability of atmosphere, k=k(x,y): wind direction, id: particle diameter class, Q_p: intensity of emission, H_e: effective stack height, u: wind speed, σ_z: diffusion width in vertical direction by Pasquill-Gifford, V_s: gravity settling velocity, α, γ: diffusion parameter, $\delta=\delta(V_d)$, V_d:

dry deposition velocity.

At normal conditions we used the CONCAWE equation as typical to calculate the effective stack height. But when the ratio of gas speed to the wind speed is small enough, downwash takes place. So we used Briggs' equation to obtain the effective stack height for downwash.

Meteorological data were collected at hourly intervals throughout the measurement period. They include wind direction, wind speed, solar radiation flux, and cloud index. Pasquill's stability of atmosphere is determined from these data.

Results and Discussion

1. Continuous feed incinerator

This type of incinerator is operated for 24 hours a day and seven days a week with relatively constant combustion conditions. Emission characteristics are, therefore, basically constant. In addition, its exhaust gas volume tends to be large enough, which results in few chances of downwash.

We set deposit gauges on the ground along the lines that were expected to be the main wind directions. Precipitating dust was collected for one month. Results of GC-MS analysis of the samples are shown in terms of precipitation rate of dioxins in Table 1.

Table 1 Precipitation rate of dioxins around the continuous incineration plant (3/15~4/16/1999)

Item \ Location		Windward (km)		Leeward (SE) (km)		
		4.5(N)	1.0(NW)	1.0	2.0	3.5
$pg/m^2 \cdot d$	PCDDs	980	2100	990	5300	500
	PCDFs	340	620	380	700	86
	Total	1300	2700	1400	6000	590
$pg\text{-}TEQ/m^2 \cdot d$	PCDDs	0.89	4.9	1.2	8.2	0.62
	PCDFs	5.2	12	3.9	9.3	0.36
	Total	6.1	17	5.1	17	0.98

Two incinerators out of three installed in this plant were in operation. Emission characteristics of the two incinerators are shown in Table 2.

Table 2 Emission characteristics of the continuous incineration plant (3/15~4/16/1999)

Dioxins concentration in stack ($ng\text{-}TEQ/m^3_N$)	Flow rate of exhaust gas (m^3_N-wet/h) *	Temperature of exhaust gas (_)	Particle density (g/cm^3)	Particle size (μm)	Stack height (m)	Stack diameter (m)
5.14	119 600	230	2.6	0.1~40	80.0	1.15

* Sum of the two incinerators

The wind direction distribution of this area throughout the test period is shown in Fig. 1. There was no calm time in this period.

Calculated precipitation rate over the surrounding area is shown in 3D contours in Fig. 2. We can see the peaks of precipitation rate on the leeward of main wind directions. Measured and calculated precipitation rates are compared in Fig. 3. Most measured values are several times as high as calculated. Some unknown sources as well as the background are considered to have contributed to the measured values. Effect of wet deposition, which we did not incorporate into this calculation, should also be considered. Dioxins isomers that are presumably attributed to agricultural chemicals were detected, but their contribution to the toxicity equivalents are very little.

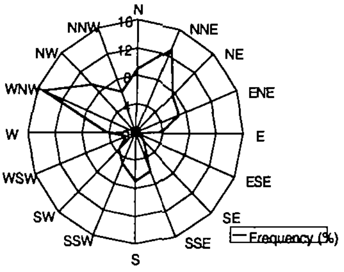

Fig. 1 Wind direction distribution of the continuous incineration plant area

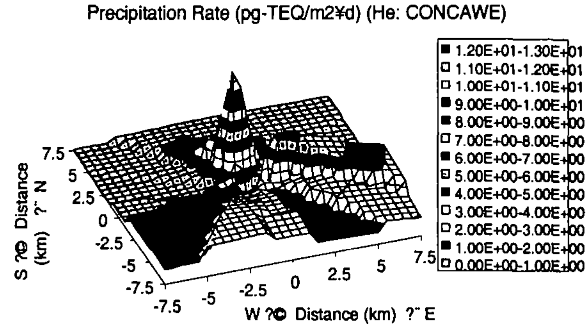

Fig. 2 Calculated precipitation rate (3D contours) around the continuous incineration plant

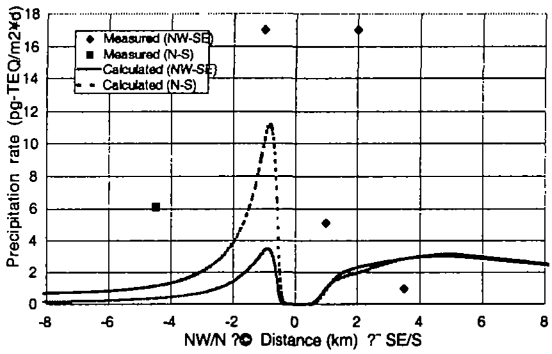

Fig. 3 Precipitation rate along the main wind directions

2. Non-continuous feed incinerator

This type of incinerators usually start up and shut down every weekday. Emission characteristics change according to the operation modes, which are reflected to input data for simulation. Precipitating dust was collected by deposit gauges along the line of an expected main wind direction for one month. Results of GC-MS analysis of the samples are shown in terms of precipitation rate of dioxins in Table 3.

Table 3 Precipitation rate of dioxins around the non-continuous incineration plant (1/21~2/22/1999)

Item \ Location		Windward (NNW) (km)		Leeward (SSE) (km)							
		2.0	0.5	0.05	0.2	0.5	0.8	1.3	2.0	3.0	4.0
$pg/m^2 \cdot d$	PCDDs	1200	1100	2800	1300	1100	920	640	660	1200	2400
	PCDFs	840	640	860	700	500	430	300	280	480	750
	Total	2000	1700	3600	2000	1600	1300	940	940	1700	3200
$pg\text{-}TEQ/m^2 \cdot d$	PCDDs	3.3	1.1	17	5.1	4.3	1.0	0.81	0.83	1.5	5.7
	PCDFs	16	11	17	13	8.7	6.0	7.2	4.4	6.1	15
	Total	19	12	34	18	13	7.0	8.0	5.2	7.6	20

Two incinerators are installed in this plant. They start up and shut down each day, and are suspended at every weekend. Their emission characteristics and operation time ratio in the test period is shown in Table 4. Stack height is 59.0 m and stack diameter is 1.05 m.

Table 4 Emission characteristics of the non-continuous incineration plant (1/21~2/22/1999)

Incinerator operated	Combustion stage	Dioxins concentration in stack (ng-TEQ/m^3_N)	Flow rate of exhaust gas (m^3_N-wet/h)	Temperature of exhaust gas ( )	Particle density and size (g/cm^3, μm) *	Time ratio (%)
Both No.1 and No. 2	Start-up	9.85	56 800	253.1	2.6, 0.1~40	3.01
	Steady	6.44	71 400	253.1	2.6, 0.1~40	28.00
	Shut-down	7.39	50 400	252.8	2.6, 0.1~40	2.38
No. 1 only	Start-up	8.71	28 200	255.5	2.6, 0.1~40	0.33
	Steady	5.81	35 800	255.5	2.6, 0.1~40	3.54
	Shut-down	5.48	21 700	255.5	2.6, 0.1~40	0.33
No. 2 only	Start-up	11.0	28 600	250.7	2.6, 0.1~40	0.13
	Steady	7.07	35 600	250.7	2.6, 0.1~40	0.39
	Shut-down	8.84	28 700	250.7	2.6, 0.1~40	0.20
None	Suspension	0	0			61.70

* Particle data measured at the continuous incineration plant were applied.

The wind direction distribution of this area throughout the test period is shown in Fig. 4.

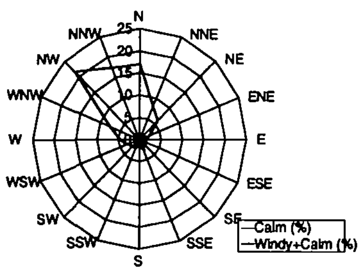

Fig. 4 Wind direction distribution of the non-continuous incineration plant area

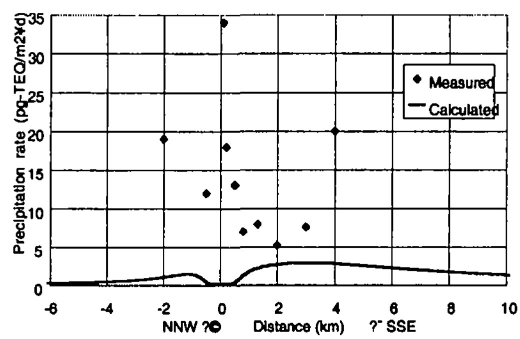

Fig. 5 Precipitation rate along the main wind direction (Sum of contribution of all operation modes)

Since the ratio of exhaust gas speed to wind speed changed widely, downwash condition was frequently met and incorporated in the calculation automatically. Nine sets of calculation corresponding to the operation modes were carried out, and the results were summed up with the weight of each time ratio. The result is shown in Fig. 5. Contribution from unknown sources on dioxins level in the precipitation dust seems to be very large.

Acknowledgments

We thank Sendai City and Waste Research and Information Center of Chiba Prefecture for giving opportunity to take operation data of the incineration plants. This study was partly funded by the Japanese Environment Agency.

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1. Japanese Environment Agency (1995) Manual for areawide total pollutant load control of nitrogen oxide (revised edition)
2. Japanese Environment Agency (1997) Manual for prediction of pollution by suspended particulate matter