B-2. 1 A Quantitative Study on Greenhouse Gases Emitted from Solid Waste Disposal Facilities

Contact Person Masaru Tanaka
Director
Department of Waste Management Engineering,
The Institute of Public Health
Shiroganedai 4–6–1, Minato-ku, Tokyo, 108 JAPAN
Phone +81–3–3441–7111 (Ext. 373), Fax +81–3–3446–4314

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Abstract In order to estimate the amount of greenhouse gases from waste treatment and disposal facilities in Japan and the world, the emission behaviors and fluxes of methane (CH_4) and nitrous oxide (N_2O) were observed at municipal solid waste (MSW) incineration plants, night soil treatment plants, Gappei-shori Johkasous (domestic waste water plants) and MSW landfill sites. The emission factor (EF), amount of emission gas per amount of waste, of CH_4 in MSW incinerators and night soil treatment plants were ranged 29.7–742 g-CH_4 ton^{-1} and 4.0-6.0 g-CH_4·kL^{-1}, respectively, depending on the type of facilities. The EF of N_2O of them were also determined as 115–144 g-N_2O·ton^{-1} and <0.01-630 g-N_2O·kL^{-1}, respectively. In order to predict amount of CH_4 emission from MSW landfill sites, the gasification models and published data were used. Estimated CH_4 emissions in 1990 were 130–520 Gg-CH_4·yr^{-1} in Japan, and 54 Tg-CH_4·yr^{-1} in the world. In the current conclusion, total yearly emissions of CH_4 and N_2O from waste treatment and disposal facilities in Japan was estimated as 390–770 Gg-CH_4·yr^{-1} (include emission from landfill) and 4.7–5.3 Gg-N_2O·yr^{-1} (not include emission from landfill), respectively, in 1990.

Key Words global warming, methane, nitrous oxide, emission analysis, solid waste disposal facilities

1. Introduction

Methane (CH_4) and nitrous oxide (N_2O) are also produced from some processes of waste disposal. The CH_4 emission rate from the landfill of municipal solid waste (MSW) has been estimated to be 20–70 Tg-CH_4·yr^{-1}, which is 3–10 % of total amount of CH_4 emissions [1], but is in wide range. CH_4 and N_2O from other sources, such as MSW incinerators and night soil treatment plants, are more unclear. Thus, the field studies at various sources are needed to quantify the magnitude of these emissions precisely.

The purpose of this study is to measure quantitatively emission fluxes of CH_4 and N_2O in various waste treatment and disposal facilities and to estimate emission amounts of both gases in Japan and worldwide. We have carried out field observations at MSW incineration plants, night soil treatment plants, the Gappei-shori Johkasous (domestic waste water plants) and MSW landfill sites. CH_4 emission from MSW landfill sites were also surveyed in some southeast Asian countries. Using results of these observations and published data, we estimated yearly emission amount of CH_4 and N_2O on each and total facilities.

2. CH_4 and N_2O emissions from MSW incineration plants

(1) Developments of the sampling and analytical methods

Carbon dioxide (CO_2), coexisting in flue gas at high concentration, seriously affects the N_2O sensitivity in GC-ECD, as well as oxygen (O_2). Thus, the GC-ECD method with carrier gas doping technique was developed for N_2O in flue gas. In this method, the sensitivity of ECD to N_2O was increased about five times, and the influence of CO_2 or O_2 concentration in sample gas to the determination of N_2O could be minimized.

(2) Estimation of emission factor and amount

In mechanical batch type incinerators, CH_4 and N_2O concentrations were widely varied with operation step, such as start up and cool down (**Fig. 1**). And it is often difficult to obtain the weight of MSW in furnaces corresponding with sampling time. Thus, we introduced the following equation for the emission factor (EF) at MSW incinerators and can estimate instantaneous values of EF_x;

$EF_x\ (g \cdot ton^{-1}) = M_x \cdot C_x\ (ppm) \cdot R_c \cdot 100 / C_{CO2}\ (\%) / 12$

where M_x is molecular weight of concerned gas x, C_x is concentration of concerned gas in sample, R_c is organic carbon content in MSW (20–25% in Japan), C_{CO2} is concentration of CO_2 in sample and 12 means atomic weight of carbon. This equation is based on assumptions that the organic carbon in MSW is completely changed to CO_2 and CH_4, and that the amount of CO_2 greatly exceeds the amount of CH_4.

The EF of CH_4 and N_2O emitted from the several types of MSW incineration plants were estimated and listed in **Table 1** with other facilities. The values were ranged 29.7–742 g-$CH_4 \cdot .ton^{-1}$ and 115–144 g-$N_2O \cdot ton^{-1}$ depending on the type of facilities. **Table 1** is also listed estimates of yearly (1990) total amount of CH_4 and N_2O from MSW incineration plants in Japan. These were calculated using EF and published data about amounts of MSW generation and processing[2].

3. CH_4 and N_2O emissions from night soil treatment plants

The emission concentrations of CH_4 and N_2O were in the order of 10^2 ppmv and 10 ppmv, respectively, at night soil treatment plants with conventional denitrification process (treatment capacity; 130 $kL \cdot day^{-1}$) . While, at plants with high loading denitrification process (treatment capacity; 40 $kL \cdot day^{-1}$), relatively high concentrations of N_2O, which were sometimes higher than 1000 ppmv, were observed (**Fig.2**). In both systems, CH_4 and N_2O emissions were mainly occurred at tank that subjected under anaerobic conditions.

The EF of CH_4 and N_2O emitted from the several types of night soil treatment plants were estimated and listed in **Table 1** with other facilities. The values were ranged 4.6–6.0 g-$CH_4 \cdot .ton^{-1}$ and <0.01–630 g-$N_2O \cdot .ton^{-1}$ depending on the type of facilities. **Table 1** is also listed estimates of yearly (1990) total amount of CH_4 and N_2O from night soil treatment plants in Japan. These were calculated using EF and published data about amounts of night soil generation and processing[2].

4. CH_4 and N_2O emissions from Gappei-shori Johkasous

(1) CH_4 emission from Gappei-shori Johkasous

The plants surveyed include various treatment processes (anaerobic filter and aeration, separation and contact aeration) and population discharging (6-410 persons). Daily CH_4 emissions trend to be widely varied with observation site and season (10.6–1774 $ppmv \cdot hr^{-1}$). However, non-dimensional value of influent rate (Q_i/Q_{avg}) and emission rate (C_i/C_{avg}) shows

that hourly emissions of CH_4 were increased with influent rate (**Fig. 3**). It is suggested one emission mechanism that CH_4 generated in anaerobic chamber will be transferred to aeration chamber and emit with aeration.

(2) N_2O emission from Gappei-shori Johkasous

The plants surveyed include various treatment processes (anaerobic filter and aeration, separation and contact aeration, extend aeration, total aeration) and population discharging (5–1900 persons). N_2O was mainly emitted from contact aeration chamber (0–0.14 ppmv·hr^{-1}), and N_2O dissolved in water (0–0.06 mL·L^{-1}) were almost higher than theoretical concentration (with Henry low: ca. 0.0002 mL·L^{-1}). These suggest the transfer of dissolved gas same as mentioned in CH_4.

5. CH_4 emissions from MSW landfill sites

(1) CH_4 flux from MSW landfill sites in Japan and southeast Asian countries

CH_4 fluxes from soil surface were measured at 0.6–5.91L·day^{-1}·m^{-2} and that from gas removal pipe were 0–50%. The CH_4 ratio;

$[CH_4, \%]/\{[CH_4, \%]\cdot[CO_2, \%]\}$,

was almost constant at 60% in the region of % CH_4. (**Fig. 4**). The ratio, however, in the region of ppmv CH_4 was low and increased with CH_4 concentration. The data plotted in former region were mainly obtained from gas removal pipes and in the latter region from soil surface. **Fig. 5** shows the vertical distribution of CH_4 oxidation bacterium in the cover soil of landfill site. This kinds of microbes existed through wide range of depth in the cover soil. Then, It is suggested that CH_4 oxidation in the cover soil could considerably alter the CH_4 flux in MSW landfill sites.

CH_4 fluxes from MSW landfill sites in southeast Asian countries (Onnut Site, Thailand and Bantar Gebang Site, Indonesia) were also measured. In Onnut Site, a open dumping site, the CH_4 ratio ranged from 8% to 60%, but the ratio in the region that CH_4 concentration was above 5% is constantly at ca. 55% (**Fig. 6**). In Bantar Gebang Site, sanitary landfill site, CH_4 fluxes from soil surface were measured at 7.0–610L·day^{-1}·m^{-2} and that from gas removal pipe were 6.1–2300 L·day^{-1}·pipe^{-1}. The average CH_4 ratios were 62% and 54% at soil surface and gas removal pipe, respectively. These value of CH_4 ratio, 50–60%, were similarly in Japan.

(2) Amount of CH_4 emission from MSW land fill site in Japan and the world.

The method of prediction of CH_4 emission from MSW land fill site is illustrated in **Fig. 7**. Data which input are yearly amount of MSW generation and landfill, composition of MSW, carbon content of each component of MSW. For the worldwide prediction, amount of MSW generation of each country was estimated using a liner regression vs. economical index (GNP or GDP [3–5]). And other requirements were obtained from published data [2, 3, 68]. The gasification models used in this study are Sheldon Areta model and Palos Verdes model [9]. With respect to mass balance of carbon, amount of waste and gas were treated as carbon weight in these models.

In Japan, amount of CH_4 emission from MSW land fill site was predicted as 130–520 Gg-CH_4·yr^{-1} in 1990 (**Table 1**). **Fig. 8** shows future changes of CH_4 emission in both models. Models predicts that emission will be declined in future. In the world, amount of CH_4 emission from MSW land fill site was predicted as 54 Tg- CH_4·yr^{-1} in 1990 (**Table 2**). In this table, emission from OECD countries is 71% of total emission, however, amount of waste in these countries consist of only 9% in the world. This result would be reflected by the difference of the MSW composition among the countries.

6. CH_4 and N_2O emissions from waste treatment and disposal facilities in Japan

Emission factors and amounts CH_4 and N_2O estimated in this study are summarized in **Table 1** (in 1990). CH_4 is almost emitted from MSW land fill sites (97–99 % of total emission). N_2O emission mainly originated from MSW incineration plants (87–100%), but, in this table, contribution of MSW land fill sites has not been estimated. In the further study, accumulating the emission data from this and other facilities, more precise and complete estimation will be done.

7. Conclusion

In order to estimate the amount of greenhouse gases from waste treatment and disposal facilities in Japan and the world, the emission behaviors and fluxes of CH_4 N_2O were observed at MSW incineration plants, night soil treatment plants, Gappei-shori Johkasous (domestic waste water plants) and MSW landfill sites.

(1) The sampling and analytical methods for flue gas from MSW incinerator were developed. The emission factor of CH_4 and N_2O were estimated using mass balance of carbon between waste and gas. Emission factors of MSW incineration plants were ranged 29.7–742 $g\text{-}CH_4 \cdot ton^{-1}$ for CH_4 and 115–144 $g\text{-}N_2O \cdot ton^{-1}$ for N_2O.

(2) Relatively high concentrations of N_2O (above 1000 ppmv) were observed in a night soil treatment plant with high loading denitrofication process. The emission factor of night soil treatment plants were ranged 4.0-6.0 $g\text{-}CH_4 \cdot kL^{-1}$ for CH_4 and <0.01-630 $g\text{-}N_2O \cdot kL^{-1}$ for N_2O.

(3) Emission rates of Gappei-shori Johkasous were observed in terms of various treatment processes and population discharging. Daily CH_4 and N_2O emission rates were 10.6–1774 $ppmv \cdot hr^{-1}$ and 0–0.14 $ppmv \cdot hr^{-1}$. These emissions tended to change with influent rate.

(4) The CH_4 ratio; $[CH_4, \%]/\{[CH_4, \%] \cdot [CO_2, \%]\}$, was almost constant at 50-60% in the region of % CH_4, mainly data from gas removal pipes, in Japan and southeast Asian countries. The ratio, however, at soil surface was often low. In order to predict amount of CH_4 emission, the gasification models and published data were used and estimated CH_4 emissions from MSW landfill sites in 1990 were 130–520 $Gg\text{-}CH_4 \cdot yr^{-1}$ in Japan, and 54 $Tg\text{-}CH_4 \cdot yr^{-1}$.

(5) Total yearly emissions of CH_4 and N_2O from waste treatment and disposal facilities in Japan was estimated as 390–770 $Gg\text{-}CH_4 \cdot yr^{-1}$ (include emission from landfill) and 4.7–5.3 $Gg\text{-}N_2O \cdot yr^{-1}$ (not include emission from landfill), respectively, in 1990.

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Table 1 Amount of CH_4 and N_2O emissions from waste treatment and disposal facilities in Japan

Facilities	Emission Factor Average (Min–Max)		Amount of Treatment and Disopsal	Amount of Emission	
	CH_4	N_2O	(billon ton·yr^{-1})	CH_4	N_2O
MSW Incineration Plants	(g·ton^{-1})			7.1	4.7
Full Continuous Feed Type	29.7 (-2.15–114)	144 (28.7–293)	251	0.7	3.6
Semi Continuous Feed Type	617 (258–975)	128 (97.4–145)	28	1.7	0.35
Mechanical Batch Type	742 (41-230)	115 (58.5–187)	58	4.3	0.67
Fixed Grate Batch Type	same above	same above	5	0.4	0.06
Night Soil Treatment Plants	(g·L^{-1})			0.04	0.002–0.6
With Conventioanl Denitrification Process	5.9	<0.01	49	0.03	<0.0005
With High Loading Denitrification Process	4.0–6.0	2–630	14	0.006–0.008	0.002–0.6
AnearobicTreatment	—	—	1,100	5.4	—
MSW Land Fill Sites	—	—	—	130–520	—
TOTAL				149–539	4.7–5.3

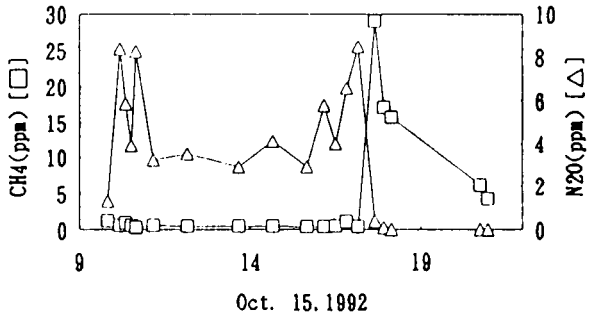

Fig. 1 CH_4 and N_2O emissions from a mechanical batch type incinerator

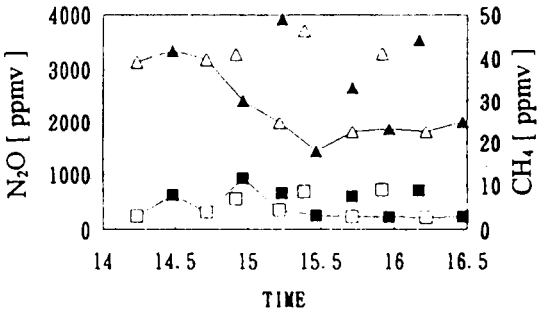

Fig. 2 CH_4 and N_2O concentrations at a night soil treatment plant with high loading denitrification process

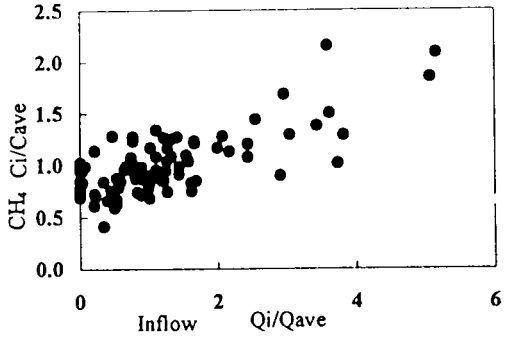

Fig. 3 Relationship between CH_4 emission and inflow rate

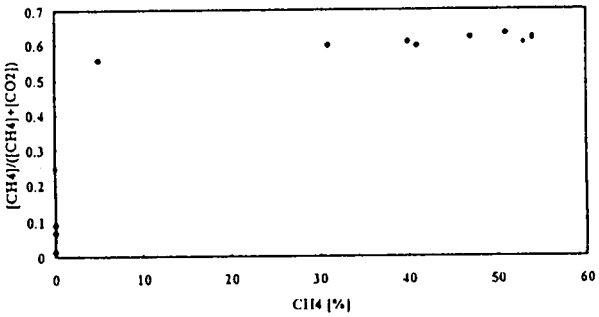

Fig. 4 Relationship betwen CH_4 concentration and ratio of CH_4 in Japan

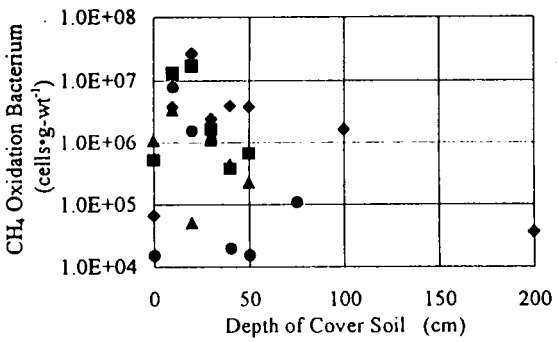

Fig. 5 Distribution of CH_4 oxidation bacterium in cover soil on a MSW landfill site

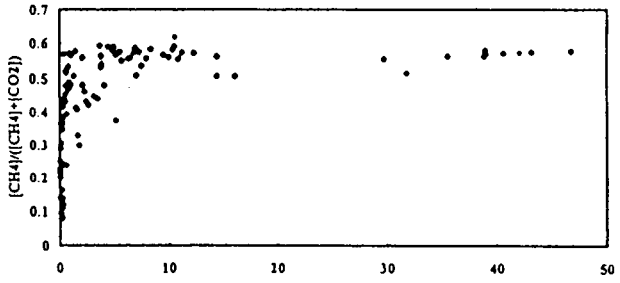

Fig. 6 Relationship betwen CH_4 concentration and ratio of CH_4 in open dumping site

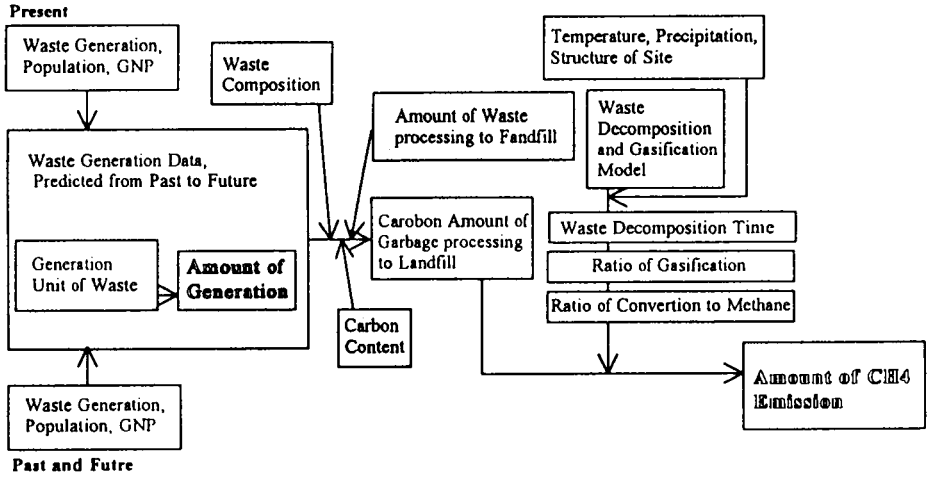

Fig. 7 Scheme of prediction of CH_4 emission from MSW landfill sites

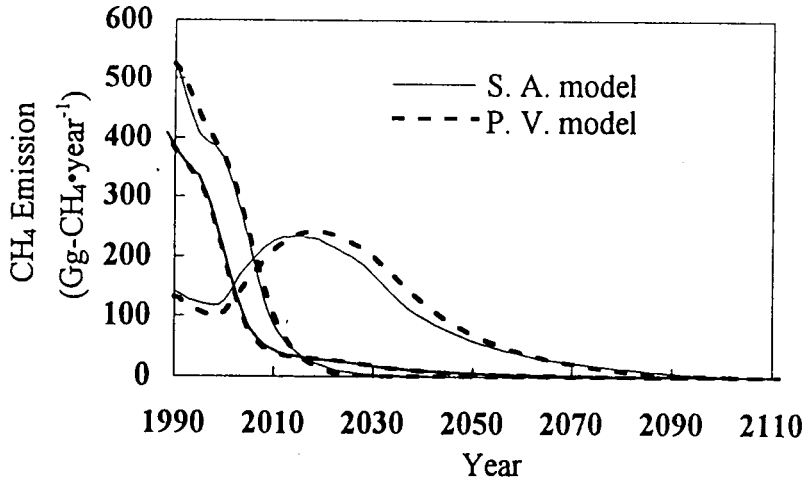

Fig. 8 Changes of estimated CH_4 emission from MSW landfill sites in Japan

Table 2 Amount of CH4 emission from MSW landfill sites in the world

	Units	except OECD Countries						OECD Countries	TOTAL
		Africa	Central America	South America	Asia	Europe	Oceania		
Population	billon·persons	641	146	296	2902	429	5.0	781	5200
Waste Generation	billion ton·yr^{-1}	138	33.1	68.3	626	122	1.09	236	1220
CH_4 Emission	Tg·yr^{-1}	2.66	1.04	2.13	4.71	5.02	0.03	38.6	54.2