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Methane and carbon dioxide emissions from closed landfill in Taiwan

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Abstract

The atmospheric concentrations and emission rates of CH_4 and CO_2 were studied at three sites of the Fu-Der-Kan closed landfill and after as the multi-use recreational park in northern Taiwan. Atmospheric CH_4 and CO_2 concentrations of closed landfill were 1.7–4.6 and 324–409 ppm, respectively. CH_4 and CO_2 emission rates ranged from 8.8 to 163 mg m^{-2} h^{-1} and from 495 to 1531 mg $m^{-2}h^{-1}$, respectively. Diurnal variation was noted with higher values at night than those in daytime. After creation of the park, atmospheric CH_4 and CO_2 concentrations were 1.8–3.1 and 332–441 ppm, respectively. CH_4 and CO_2 emission rates ranged from −1.1 to 2.3 mg m^{-2} h^{-1} and from −135 to 301 mg m^{-2} h^{-1}, respectively. There were no notable diurnal variations in either atmospheric concentrations or emission rates.

Keywords: Landfill; Greenhouse gas; FTIR; Flux; Diurnal variation

1. Introduction

Landfills are accounting for about 10–19% of annual global CH_4 emissions (Kumar et al., 2004; USEPA, 2006). The global warming potential of CH_4 is 23 times higher than that of CO_2 (USEPA, 2002). The atmospheric CH_4 concentration has been increasing at a rate of −0.2–1% y^{-1} (Simpson et al., 2006). On a global scale, approximately 653 Tg y^{-1} of waste is landfilled, and annual global CH_4 emissions from landfills range from 16 to 223 Tg (Bogner and Matthews, 2003; Simpson et al., 2006).

Landfilling and incineration are the major methods of waste disposal in Taiwan. 89% of waste was disposed by landfills in 1989. This percentage dropped to 11.2% in 2006 as the result of increased incineration and the resource recycling policy (EPA/Taiwan, 2007). Landfills function as bioreactors due to the controlled and managed burial of biodegradable organic materials. These organic materials decompose via a complex series of microbial reactions under anaerobic conditions. Eventually, they are converted into CO_2, CH_4, N_2O and H_2O. Landfill CH_4 and CO_2 generations are controlled by landfill management, cover soil, composition, temperature, pressure, moisture content, water table level, wind induced ebullition and pH of the refuse (Bogner and Matthews, 2003; Hegde et al., 2003). Methanogenesis in landfills occurs when the pH of organic waste is between 6.8 and 7.4 and it is stimulated by increasing moisture content (Jang and Yang, 2001).

The Fu-Der-Kan landfill site was closed in 1995, and a multi-use recreational park was constructed from 1999 to 2003. The soil surface is covered with grass and small trees. Although the CH_4 and CO_2 emission rates of active landfills are well documented (Bogner et al., 1999; Czepiel et al., 2003; Meraz et al., 2004), emissions from closed sites and sites which have been converted to park have not been investigated in detail.

Atmospheric CH_4 and CO_2 concentrations and emission rates from an active landfill in northern Taiwan were described in a previous study (Hegde et al., 2003). Two main methods are used for such measurements. Gas-type open-path Fourier-transform infrared (FTIR) spectroscopy has the advantages of good precision, rapid and

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simultaneous measurement of different volatile compounds, and the ability to cover long-distance. Chamber techniques can be used to measure CH_4 and CO_2 emission rates from small areas, typically less than 1 m^2 (Yang and Chang, 1997). The advantages include simplicity, an appropriate scale for concurrent measurement of controlling variables, and the ability to determine the heterogeneity of surface emissions. Chamber techniques can also be easily compared to results from other studies because these methods have been widely employed in non-landfill settings for a variety of greenhouse gases (Rolston, 1986; Yang and Chang, 1998, 2001; Chang and Yang, 2003). In this study, FTIR was used successfully, along with gas chromatography (GC), to monitor atmospheric greenhouse gases. The atmospheric concentrations and emission rates of CH_4 and CO_2 were measured at Fu-Der-Kan closed landfill and after the construction of a multi-use recreational park in northern Taiwan.

2. Materials and methods

2.1. Site description

The Fu-Der-Kan landfill (25°01'53.9''N, 120°3'33.8''E) is located near Taipei City in northern Taiwan. This landfill was opened in 1985 for municipal solid waste (MSW) dumping, closed in 1995 and converted to a multi-use recreational park during 1999 to 2003. It covers 98 ha and 37 ha were used for landfilling of MSW. It received 3200 t of MSW every day during the operation period, with an average burial depth of 22.9 m. The landfill was covered by 1–2 m of waste landfill soil as surface material. Upon closing, the landfill was covered with another 1–1.5 m of loam-clay loam soil and reconstructed as a multi-use recreational park in 2001 (Fig. 1). The test areas cover about 32 ha of landfilling area including areas A, B, C, E, F, G and part of J around the testing areas. Site C is younger than sites A and B. Site C had received new MSW in 1999. During 1999-2000 testing period, site A (about 8 ha) included country activity area, lake, boating area and part of natural resource landscape; site B (about 12 ha) included Sun plaza, creation garden and part of natural resource landscape; site C (about 12 ha) included culture of indigenous people's area, grass skiing field and part of natural resource landscape. The testing area covers about 90% of landfilling except management center and wastewater treatment factory. The vegetations in the sites A, B, and C were grass and small trees during the testing periods 1999–2000. The major vegetations were Centipede grass (*Eremochlora ophiuroides*) and Carpet grass (*Axonopus affinis*) in sites A, B, and C during testing period 2006. There is a setup for CH_4 gas extraction system and each year recovered 3442 t of CH_4, which should equivalent to 79.2 Gg of CO_2, while the recovered CH_4 was burned and produced 10.2 Gg of CO_2 only. Soil samples were collected at 0–20 cm depth in different burial locations. Randomly three soil cores in each site were collected, sieved to 2 mm and stored at 4 °C before analysis. Each soil core was analyzed separately for moisture content, pH and organic carbon.

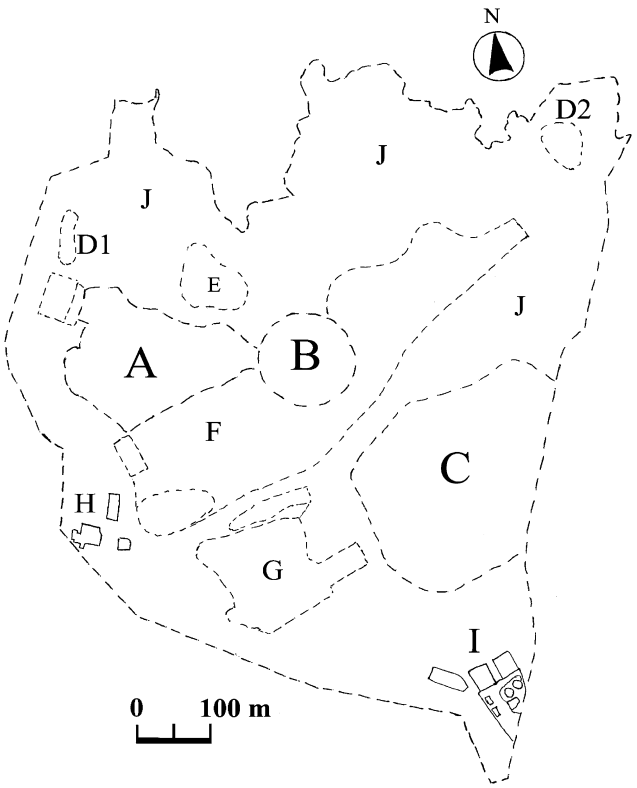

Fig. 1. Fu-Der-Kan closed landfill (37 ha) was reconstructed a multi-use recreational park: (A) country activity area (2.6 ha), (B) Sun plaza (1.4 ha), (C) culture of indigenous people's area (5 ha), (D1) and (D2) slightly lake, (E) boating area (0.8 ha), (F) creation garden (8 ha), (G) grass skiing field (2 ha), (H) management center, (I) wastewater treatment factory and (J) natural resource landscape (12 ha).

2.2. Gas-type open-path FTIR spectroscopy measurement

FTIR spectroscopy was used to measure the concentrations of atmospheric greenhouse gases at a height of 197 cm above ground with a scan number of 100 for 7 min. Absorbance was read at wavenumber of 2999 cm^{-1} for CH_4 and peak area from 2239 to 2393 cm^{-1} for CO_2. The distance between the light source and the reflecting mirror was 35 m (for four chambers) or 100 m (for nine chambers). The details of the experimental set-up adopted for the FTIR spectroscopy method have been described in a previous paper (Chang et al., 2000). Because the interferometer characteristics are dominated by a high spectral resolution up to 0.06 cm^{-1} and a configuration suitable for field measurements was needed, the MB-104 (BOMEM, Hartmann and Braun, Canada) was used for radiation emission as well as absorption measurements. The spectrum was observed on a PC screen and the mirror was adjusted to optimize the signal. The absorption peak areas and atmospheric concentrations of CH_4 and CO_2 have high correlation coefficients (0.998–0.999 and 0.996–0.997, respectively) with distance between 0 and 100 m. The accuracy of FTIR spectroscopy in CH_4 and CO_2 measurement is within 2% and 3%,

respectively. The atmospheric concentrations of greenhouse gases were determined from long-path measurements by differential absorption and a least squares fit of measurement, and were simulated by modeling air transmittances for various absorbed concentrations.

2.3. CH_4 and CO_2 emission rates

Gas samples were collected using a homemade closed acrylic chamber (length 40 cm, width 40 cm, height 65 cm, volume about 96 L) equipped with a fan, a thermometer, and a sampling hole. Either four or nine acrylic chambers were installed on the various landfill soils along a linear path. The chambers were inserted into the soil to a depth of 5 cm and allowed to equilibrate for 10 min before each measurement. Gas samples (35 ml) were collected from the headspace of each chamber and transferred to a 12.6 ml serum bottle sealed with a butyl rubber stopper and previously flushed with oxygen-free nitrogen gas (Yang and Chang, 1997). Gas samples were collected from chamber at 0.0, 0.5, and 1.0 h. Samples were taken again at 3.0, 3.5, and 4.0 h for comparison. CH_4 and CO_2 emission rates were calculated by performing a linear regression on the differences in CH_4 and CO_2 concentrations and adjusting for chamber volume and area covered. The following equation was used for the calculation (Rolston, 1986; Hegde et al., 2003):

$$f = \left(\frac{V}{A}\right)\left(\frac{\Delta C}{\Delta t}\right)$$

where, $f = CH_4$ or CO_2 emission rate (mg m^{-2} h^{-1}), $V =$ volume of chamber above the soil (m^3), $A =$ cross-section of chamber (m^2), $\Delta C =$ concentration difference between time zero and time t (mg m^{-3}), and $\Delta t =$ time duration between two sampling periods (h).

The ratios of atmospheric CH_4 and CO_2 concentrations measured with GC method to those measured with FTIR spectroscopy were analyzed. Gas samples were collected from the center of the FTIR spectrometer line at a height of 197 cm. CH_4 was analyzed by a Shimadzu 14A GC (Shimadzu Co., Japan) with a glass capillary column (0.26 mm × 2 m) packed with Porapak Q (80/100 mesh) and a flame ionization detector. The column temperature was set at 100 °C and the injection and the detector temperatures were set at 130 °C. CH_4 concentration was calculated with a standard curve from 0.1 to 100 ppm, with a detection limit of 0.01 ppm (Yang and Chang, 1997). For CO_2 analysis, a thermal conductivity detector was used. The column temperature was set at 150 °C and the injection and the detector temperatures were set at 200 °C. CO_2 concentration was calculated using a standard curve from 0.1 to 1000 ppm, with a detection limit of 0.05 ppm (Chang and Yang, 2003).

2.4. Analytical methods

Air and soil temperatures were determined on site either directly or under at 10 cm depth with a Hg-thermometer. Wind speed was measured with a weathercock (Weather link 4.0, USA). Light intensity was detected with a Toshiba SPI-5 photometer. Soil pH was determined using a pH meter directly in the soil or in a 1:1 (w/v) soil to water suspension. Moisture content was measured by drying the samples at 105 °C for 24 h until a constant weight was achieved. Total organic carbon (TOC) was estimated using a TOC-5000A analyzer (Code HI 8424C, Shimadzu, Japan). Experiments were carried out in quadruplicate; while nine experiments were used in the measurement of CH_4 and CO_2 emission rates on June 30, 2000. Data were subjected to coefficient of variance analysis and Duncan's multiple range tests ($p = 0.05$) using the Statistical Analysis System (SAS Institute, 2002).

3. Results

3.1. Properties of cover soils

The properties of cover soil at different burial locations are shown in Table 1. The cover soils were acidic (pH 5.6–6.0) in 1999 and 2000, and they were neutral (pH 7.4–7.7) after the construction of a multi-use recreational park in 2006. There were significant pH differences between 1999–2000 and 2006 ($p < 0.05$). The soil moisture, soil temperature and TOC in 2006 were lower than those in 1999–2000.

3.2. CH_4 and CO_2 concentrations and emission rates at site A

Air temperature, atmospheric concentrations of CH_4 and CO_2 at site A are presented in Fig. 2. Atmospheric concentrations of CH_4 and CO_2 on October 30, 1999 ranged from 1.7 to 2.7 ppm and from 324 to 390 ppm, respectively. Average values were 2.2 ± 0.3 and 366 ± 24 ppm, respectively. On November 24, 1999, atmospheric concentrations of CH_4 and CO_2 ranged from 1.9 to 4.6 ppm and from 373 to 409 ppm, respectively, with average values of 3.1 ± 0.9 and 386 ± 11 ppm, respectively. Atmospheric concentrations of CH_4 and CO_2 on October 30 were lower than those on November 24 and it might be due to the high wind velocity on October 30 (4.2 ± 0.7 m s^{-1}) (Table 1). Further, the total organic C content of cover soil on November 24, 1999 in site A was about 25% lower than that on October 30, 1999 might be due to the construction as a multi-use recreation park during this period, and some new cover materials with low organic C content were layered on the surface. Therefore, both the organic C content of cover soil and the CH_4 emission on November 24, 1999 were lower than those on October 30, 1999. CH_4 and CO_2 emission rates ranged from 8.8 ± 0.3 to 21.7 ± 4.3 mg m^{-2} h^{-1} and from 495 ± 31 to 1012 ± 43 mg m^{-2} h^{-1}, respectively (Table 1). CH_4 emission rate was higher on October 30, 1999 than those on November 24, 1999 because of high soil organic C and moisture content for active microbial reaction.

Table 1
Properties of cover soils in Fu-Der-Kan landfill and after as the multi-use recreational park

Sampling date	pH	Moisture content (%)	Soil temp. (°C)	Atmos. pressure (Pa)	Humidity (%)	Wind velocity ($m\ s^{-1}$)	Organic carbon (%)	CH_4 emission rate ($mg\ m^{-2}\ h^{-1}$)	CO_2 emission rate ($mg\ m^{-2}\ h^{-1}$)
Site A									
Oct. 30, 1999	$5.5–6.1^{b}$	31.1 ± 1.7^{a}	31.9 ± 1.0^{a}	1015 ± 1^{a}	74.4 ± 6.1^{a}	4.2 ± 0.7^{b}	20.8 ± 1.4^{a}	21.7 ± 2.4^{b}	1012 ± 14^{a}
Nov. 24, 1999	$5.5–6.2^{b}$	29.6 ± 1.8^{a}	30.9 ± 1.0^{a}	1014 ± 1^{a}	79.3 ± 7.8^{a}	2.3 ± 0.9^{a}	15.4 ± 1.0^{b}	8.8 ± 0.3^{c}	495 ± 11^{b}
Jan. 3, 2006	$7.6–7.7^{a}$	19.6 ± 2.2^{c}	20.5 ± 0.8^{c}	1018 ± 4^{a}	73.7 ± 6.4^{a}	3.0 ± 1.6^{a}	2.0 ± 0.2^{c}	0.7 ± 0.4^{d}	95 ± 6^{c}
Site B									
Oct. 30, 1999	$5.1–6.2^{b}$	24.0 ± 0.3^{b}	31.1 ± 1.0^{a}	1015 ± 1^{a}	74.4 ± 6.1^{a}	4.2 ± 0.7^{b}	14.7 ± 1.7^{b}	12.8 ± 0.2^{c}	901 ± 15^{a}
Nov. 24, 1999	$5.3–6.3^{b}$	29.3 ± 2.2^{a}	26.9 ± 0.6^{b}	1014 ± 1^{a}	79.3 ± 7.8^{a}	2.3 ± 0.9^{a}	19.3 ± 2.2^{a}	35.0 ± 3.1^{b}	813 ± 17^{a}
May 11-13, 2000	$5.3–6.4^{b}$	26.5 ± 3.0^{b}	29.5 ± 2.3^{a}	1007 ± 1^{b}	62.7 ± 6.5^{b}	2.4 ± 1.2^{a}	19.7 ± 3.0^{a}	18.4 ± 2.2^{b}	1531 ± 23^{a}
Jan. 4, 2006	$7.2–7.7^{a}$	17.5 ± 1.0^{c}	20.6 ± 0.7^{c}	1018 ± 4^{a}	73.7 ± 6.4^{a}	3.0 ± 1.6^{a}	2.3 ± 0.2^{c}	-0.1 ± 0.4^{d}	20 ± 5^{e}
Site C									
June 30, 2000	$5.6–6.3^{b}$	33.6 ± 2.9^{a}	33.6 ± 2.1^{a}	1007 ± 1^{b}	71.1 ± 7.4^{a}	1.5 ± 0.8^{a}	20.7 ± 4.0^{a}	$163.3 \pm 7.7^{*a}$	$1349 \pm 16^{*a}$
Jan. 5, 2006	$7.3–7.6^{a}$	22.5 ± 2.0^{c}	20.0 ± 0.9^{c}	1018 ± 4^{a}	73.7 ± 6.4^{a}	3.0 ± 1.6^{a}	2.6 ± 0.5^{c}	0.2 ± 0.2^{d}	-32 ± 7^{d}

Means $\pm$ SD ($n = 4$, $^{*}n = 9$). Emission rate was measured by chamber method. Values in the same column that do not share the same alphabetic superscript are significantly different at 5% level according to Duncan's multiple range tests.

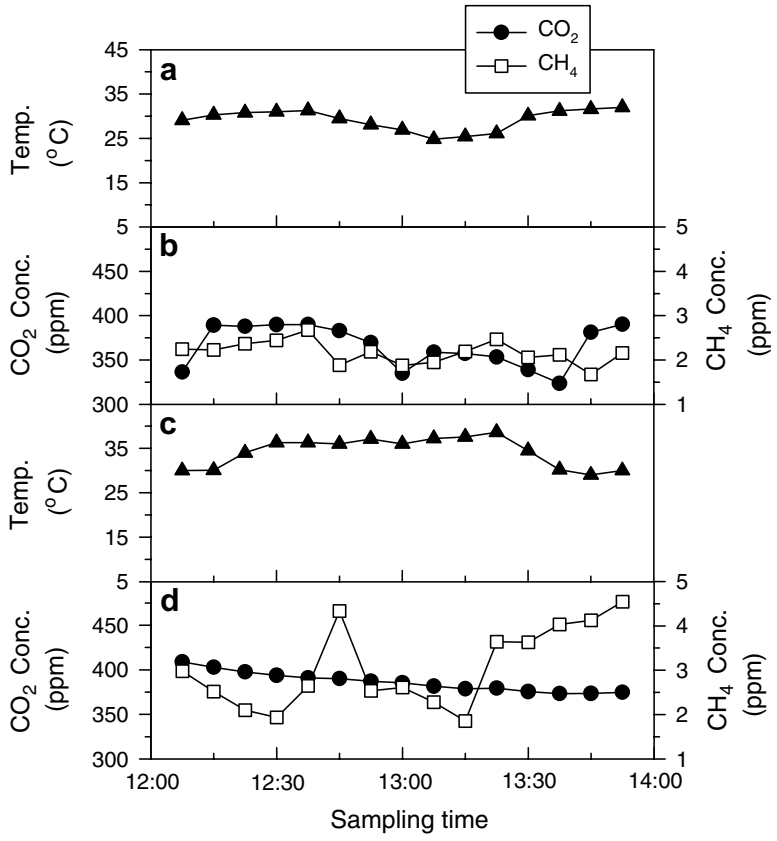

Fig. 2. Air temperature and atmospheric concentrations of CO_2 and CH_4 measured with FTIR spectroscopy at site A of the Fu-Der-Kan closed landfill. Data are presented for (a–b) October 30, 1999 and (c–d) November 24, 1999: (a) and (c) air temperature; (b) and (d) atmospheric concentrations of CO_2 and CH_4.

Site A was subsequently converted into a country activity area during the period from 1999 to 2003. Atmospheric concentrations of CH_4 on January 4, 2006 were between 1.8 and 3.1 ppm, with an average of 2.3 ± 0.5 ppm. CO_2 on that date ranged from 373 to 441 ppm, with an average of 396 ± 23 ppm. CH_4 and CO_2 emission rates were -0.4 ± 0.3 to $2.3 \pm 0.6\ mg\ m^{-2}\ h^{-1}$ and -72 ± 17 to $301 \pm 5\ mg\ m^{-2}\ h^{-1}$, respectively. Average CH_4 and CO_2 emission rate was 0.7 ± 0.4 and $95 \pm 6\ mg\ m^{-2}\ h^{-1}$, respectively (Fig. 3a–c). CH_4 and CO_2 emission rates in 2006 were lower than those in 1999 because of the more stable burial waste, low soil organic C and low moisture content.

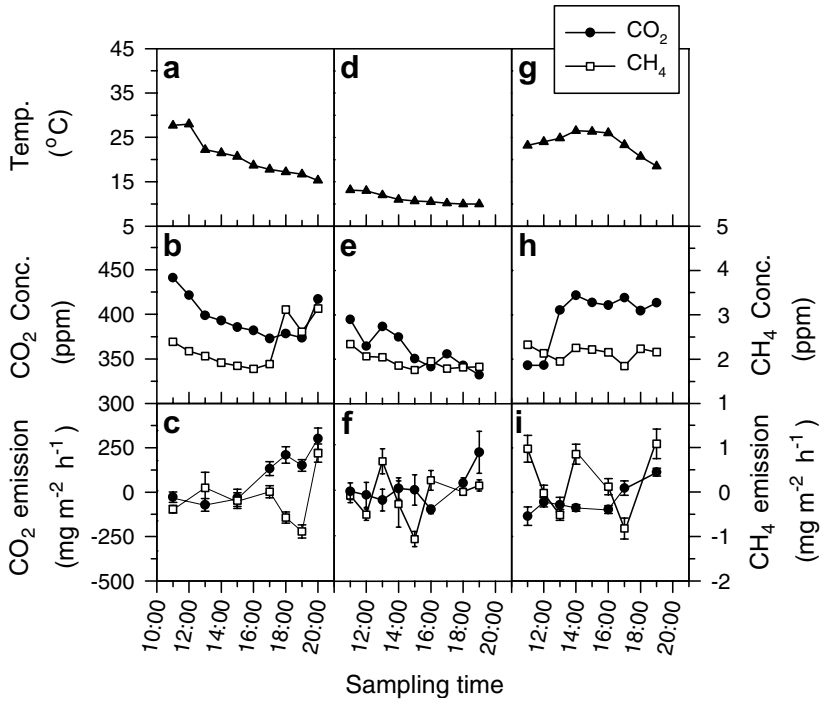

Fig. 3. Air temperature, atmospheric concentrations and emission rates of CO_2 and CH_4 of the Fu-Der-Kan landfill after as the multi-use recreational park. (a–c) country activity area on January 4, 2006. (d–f) Sun plaza on January 5, 2006. (g–i) culture of indigenous people's area on January 12, 2006. (a), (d) and (g) air temperature; (b), (e) and (h) atmospheric concentrations of CO_2 and CH_4; (c), (f) and (i) CO_2 and CH_4 emission rates.

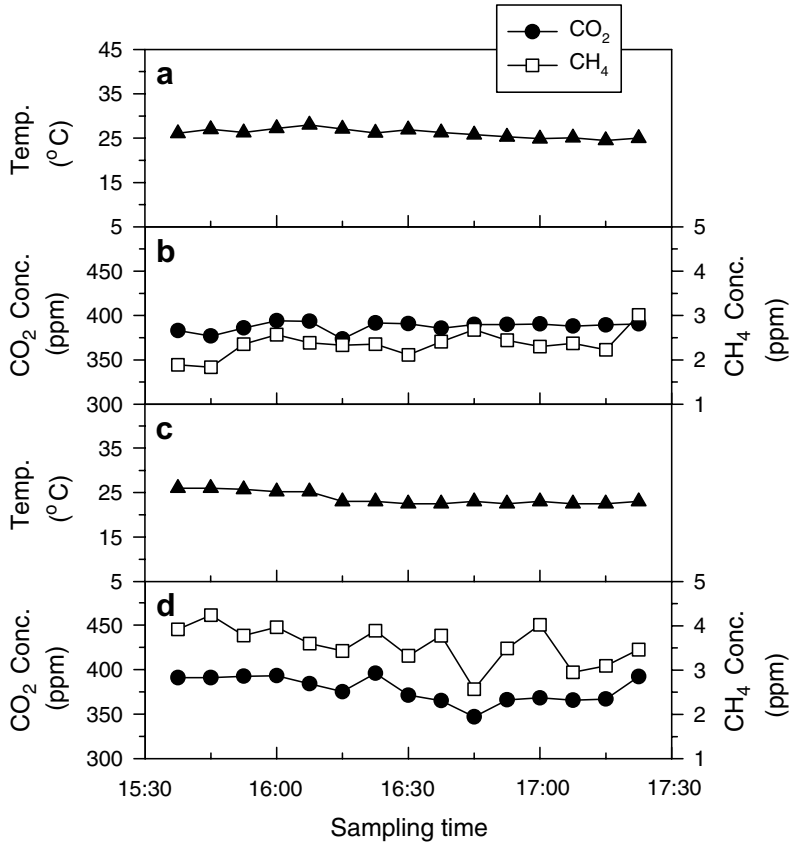

Fig. 4. Air temperature, and atmospheric concentrations of CO_2 and CH_4 measured with FTIR spectroscopy at site B of the Fu-Der-Kan closed landfill. Data are presented for (a–b) October 30, 1999 and (c–d) November 24, 1999: (a) and (c) air temperature; (b) and (d) atmospheric concentrations of CO_2 and CH_4.

3.3. CH_4 and CO_2 concentrations and emission rates at site B

Air temperature, atmospheric concentrations of CH_4 and CO_2 at site B are shown in Fig. 4. Atmospheric CH_4 concentrations on October 30, 1999 ranged from 1.8 to 3.0 ppm, with an average of 2.4 ± 0.3 ppm. CO_2 concentrations were between 373 and 394 ppm, with an average of 388 ± 6 ppm. On November 24, 1999, atmospheric CH_4 and CO_2 concentrations were ranged from 2.6 to 4.2 ppm, and from 347 to 397 ppm, respectively, with an average of 3.6 ± 0.5 and 378 ± 15 ppm, respectively. CH_4 and CO_2 emission rates were 12.8 ± 0.2 to 35.0 ± 3.1 mg m^{-2} h^{-1} and 813 ± 17 to 901 ± 15 mg m^{-2} h^{-1}, respectively (Table 1). Both the atmospheric concentration and emission rate of CH_4 were high on November 24, 1999, which may be partly attributed to high soil organic C and moisture content. Different situations, in contrast to site A, were found in site B on November 24, 1999. The new cover material used in site B on November 24, 1999 might contain high organic C. Therefore, both the organic C content of cover soil and the CH_4 emission in site B on November 24, 1999 were higher than those on October 30, 1999.

Sun plaza was constructed at site B during the years 1999 to 2003. Atmospheric CH_4 and CO_2 concentrations on January 5, 2006 ranged from 1.8 to 2.3 ppm and from 332 to 395 ppm, respectively. Average values were 1.9 ± 0.2 and 361 ± 12 ppm, respectively. CH_4 emission rate was -1.1 ± 0.5 to 0.6 ± 0.5 mg m^{-2} h^{-1} and CO_2 emission rate was -98 ± 11 to 224 ± 38 mg m^{-2} h^{-1}. Average CH_4 and CO_2 emission rates were -0.1 ± 0.4 and 20 ± 3 mg m^{-2} h^{-1}, respectively (Fig. 3d–f). These values were lower than those in 1999 because of the more stable buried refuse, low soil organic C and moisture content.

3.4. CH_4 and CO_2 concentrations and emission rates at site C

The CH_4 emission rate (163.3 ± 7.7 mg m^{-2} h^{-1}) and CO_2 emission rate (1349 ± 16 mg m^{-2} h^{-1}) at site C were the highest of the three sites and the variation among the nine installed chambers was also large (Table 1). The elevated CH_4 and CO_2 emission rates were due to new MSW was buried in this site during 1999.

Site C was converted into a culture of indigenous people's area during the years 2001 to 2003. Atmospheric CH_4 concentrations were 1.9 to 2.3 ppm, with an average of 2.1 ± 0.2 ppm on January 12, 2006. CO_2 concentrations ranged from 343 to 422 ppm with an average of 397 ± 13 ppm. CH_4 and CO_2 emission rates were -0.8 ± 0.7 to 1.1 ± 0.5 mg m^{-2} h^{-1} and -135 ± 8 to 113 ± 15 mg m^{-2} h^{-1}, respectively. Average CH_4 and CO_2 emission rates were 0.2 ± 0.2 and -32 ± 7 mg m^{-2} h^{-1}, respectively (Figs. 3 g–i). CH_4 emission rates were in the same level as those in sites A and B.

3.5. Diurnal variation of atmospheric CH_4 and CO_2 concentrations and emission rates at site B

Fig. 5 shows the diurnal variations in air temperature, atmospheric concentrations and emission rates of CH_4 and CO_2 from May 11 to 13, 2000 at site B. The atmospheric CH_4 concentrations ranged from 1.3 to 3.8 ppm with an average of 2.7 ± 0.8 ppm. The concentration of

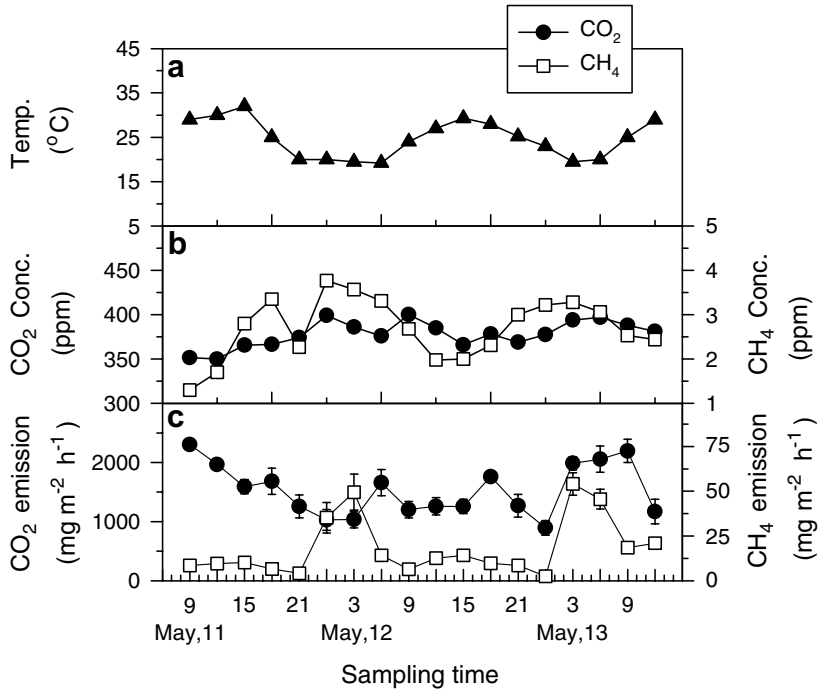

Fig. 5. Diurnal variation in the atmospheric concentrations and emission rates of CO_2 and CH_4 at site B in the Fu-Der-Kan closed landfill during May 11 to 13, 2000: (a) air temperature; (b) atmospheric concentrations of CO_2 and CH_4 measured with FTIR spectroscopy; (c) CO_2 and CH_4 emission rates.

CH_4 was high at night, which correlates with CH_4 emission rate. The atmospheric CO_2 concentration averaged at 374 ± 15 ppm and ranged from 350 to 399 ppm. The air temperature was the highest (31.7 °C) at noon on May 11 and the lowest (19.5 °C) at night on May 12.

The average CH_4 emission rate at site B was 18.4 ± 3.3 mg m^{-2} h^{-1} (Table 1). The maximum rate was 54.1 mg m^{-2} h^{-1} at 3 a.m. on May 13, and the minimum rate was 2.5 mg m^{-2} h^{-1} at midnight on May 12. The average CO_2 emission rate was 1531 ± 23 mg m^{-2} h^{-1}. The maximum rate was 2302 mg m^{-2} h^{-1} at 9 a.m. on May 11, and the minimum rate was 893 mg m^{-2} h^{-1} at midnight on May 12.

The diurnal variation in CO_2 emission was very consistent after completion of the recreational park for country activity area, Sun plaza and culture of indigenous people's area in January 2006. The CO_2 emission rates were high at night because of daytime photosynthetic activity by the grass and small trees. The diurnal variation of CH_4 emission was insignificant due to the low organic matter content and more stable burial waste.

4. Discussion

Compared to other terrestrial ecosystems, landfills are characterized by a high rate of CH_4 production and large CH_4 gradients from the deeper production zones to the soil–atmosphere interface. Bogner et al. (1999) found that CH_4 concentration was low at the surface and increased by about two orders of magnitude at 100 m depth. In paddy fields, the CH_4 emission rate has been found to be high at 11 a.m. to 2 p.m. and low in the early morning due to the shallow of rice root and the high effect of soil temperature (Yang and Chang, 1999, 2001). In contrast, the CH_4 emission rate at the closed Fu-Der-Kan landfill was the greatest at night for the collection of emission gases and CH_4 at daytime. A similar phenomenon was also observed at the Shan-Chu-Ku landfill during years 1–2, 2–3 and 5 (Hegde et al., 2003). However, no significant diurnal variation of emission rate was observed in the park constructed at the Fu-Der-Kan landfill. There was little fluctuation of soil temperature in the deeper zone of landfill.

CH_4 and CO_2 emission rates depend on soil pH, moisture content, pressure, total organic carbon, kind and age of the burial waste, gas extraction system, kind and depth of soil cover and methane oxidation. CH_4 and CO_2 emission rates were the highest in the site C because of new MSW was buried during 1999. CH_4 and CO_2 emission rates were higher in site A on October 30, 1999 than those on November 24, 1999 due to high organic C and moisture content for active microbial reaction.

CH_4 and CO_2 emissions in the park varied widely and included negative values. Negative CH_4 emission resulted from a net oxidation of atmospheric CH_4 by indigenous CH_4 oxidizing microbes. CO_2 emission was negative due to net photosynthetic use of CO_2 by grass and small trees. Atmospheric concentrations and emission rates of CH_4 and CO_2 were lower in 2006 than those in 1999 and 2000. This might be due to more stable buried refuse and low organic C content (2.0–2.6% in 2006 vs. 14.7–20.8% in 1999–2000). The fluctuation of CH_4 emission rates (-1.1 to 2.3 mg m^{-2} h^{-1}) was minor in 2006. The CO_2 emission rate was low in the daytime due to photosynthesis and it increased at night.

Hegde et al. (2003) measured the greenhouse gas concentrations in a homogenous grassland at the National Taiwan University campus, and found no major differences in the ratios of the concentrations measured with the GC method to those measured with FTIR spectroscopy (ratio is 1.10 in CH_4 and 1.02 in CO_2). However, the ratios of atmospheric CH_4 concentration measured with GC method to those measured with FTIR spectroscopy in the Shan-Chu-Ku landfill were 2.28–4.78, 2.82–8.05, and 1.72–7.57 at sites 1–2, 2–3, and 5 years old, respectively. The ratio decreased with the increasing of burial period. In this study, the ratios of atmospheric CH_4 concentration in the closed landfill during 1999–2000 were 1.08–1.55 at site A, 1.06–1.75 at site B, and 1.21–2.47 at site C. The ratios had decreased to 0.96–1.16, 0.97–1.15, and 0.99–1.25 in 2006 for the country activity area, Sun plaza and culture of indigenous people's area, respectively. These values were lower than those in the Shan-Chu-Ku landfill because of the more stable organic matter of buried refuse. Furthermore, the ratios at the reconstructed areas in 2006 were close to those in the campus grassland, which had the same level of soil organic C content. Therefore, the ratio of atmospheric CH_4 concentration measured with GC method to FTIR spectroscopy depends on the organic C content and could be used as a parameter to assess the stability of the buried refuse.

The presence of water vapor interfered with the CO_2 measurement by FTIR spectroscopy. CO_2 concentration was suddenly dropped at 16:45 p.m. on November 24, 1999 for the increase of relative humidity from 81 to 91%. While CO_2 concentration increased at afternoon on January 12, 2006 for the decrease of relative humidity from 88 to 67%. Therefore, the background of measurement and alignment are necessary to crosscheck the disturbances of relative humidity change on CO_2 concentration.

Due to low organic C content, both the atmospheric concentration and emission rate of CH_4 at the Fu-Der-Kan closed landfill were less than 10% of those at the Shan-Chu-Ku landfill (Hegde et al., 2003). The CH_4 emission rate at the reconstructed areas in 2006 was less than 2 mg m^{-2} h^{-1} which was less than 5% of that measured at the Fu-Der-Kan closed landfill site in 1999–2000. Again, this might be due to low organic C content and more stable organic matter of buried refuse.

In conclusion, both gas-type open-path FTIR spectroscopy and GC chamber method have been successfully used to measure atmospheric concentrations and emission rates of greenhouse gases in a closed and reconstructed landfill. The Fu-Der-Kan landfill closed in 1995 and was

reconstructed to form a multi-use recreational park during 1999 to 2003. Atmospheric concentrations and emission rates for CH_4 were higher at night than the daytime during 1999 to 2000. The CH_4 concentrations and emission rates in the closed landfill and reconstructed park were less than 10% and 1% of those in the active landfill, respectively. A systematic and continuous study of greenhouse gas emissions from closed landfills provides information about the field degradation of MSW, which in turn will help in the design of future landfills.

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