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Mitigation of Methane Emission from Solid Waste Disposal Site in the Tropics by Vegetated Cover Soil

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Abstract: Development of a mitigation technique for methane emission from a solid waste disposal site using biological activity in cover soil was investigated. Methane emission rates through clay, sandy loam and vegetated sandy loam (with *Sporobolus virginicus*) cover soil laid on existing waste pile at a dumpsite in Thailand were studied by using closed flux chamber method. Over 275 days of monitoring, average methane emission rates measured through clay, sandy loam and vegetated sandy loam were 1.31, 1.79 and 0.95 $g/m^2/d$, respectively. Though methane emission rates fluctuated significantly with time, higher emission rates were detected during the dry period than the high intensity rainfall period. Significant reduction of methane emission was observed in cover soil employing vegetated sandy loam where methane oxidation reaction could be promoted. The application of leachate onto the vegetated cover soil could also enhance plant growth and methane oxidation. The results of this study suggest that methane emission from solid waste disposal sites could be mitigated through application of appropriate topsoil as a bio-filter.

Key words: Closed flux chamber, landfill vegetation, leachate irrigation, methane emission, methane oxidation, tropical climate.

Introduction

Methane is recognized as an important greenhouse gas since its global warming potential (GWP) is about 23 times higher than carbon dioxide. Normally, methane is generated naturally in places where anaerobic conditions predominate such as wetlands, rice fields etc. Solid waste disposal areas, such as landfill and open dumpsites, are also one of the major sources of global methane emission. This study focussed on the investigation of a mitigation technique to minimize the emission of methane gas from these waste disposal sites. Generally, methane emission can be minimized either by utilizing it as an energy source or converting it to carbon dioxide. In small waste disposal sites where the utilization of landfill gas is not economically feasible, the produced gas can be eliminated by using a gas flaring system or biological activity in cover soil referred to as methane oxidation. The occurrence of methane oxidation by methanotrophic bacteria is commonly found in the final cover of landfill under aerobic conditions (Whalen et al., 1990) in which methane is being oxidized to carbon dioxide. In this study, the closed flux chamber technique (Reinhart et al., 1992) was employed for the determination of methane emission rate through different types of cover soil (clay, sandy loam and vegetated sandy loam) laid on the existing waste pile at a waste disposal site in Thailand to examine the existence of methane oxidation in cover soil under ambient environmental conditions. The effect of leachate irrigation on these cover soils' performance was also investigated.

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Materials and Methods

Experimental System

The experiment was performed at the waste disposal site of Nonthanburi Province, Thailand. The site receives more than 800 tons of wastes daily and has been in operation for about 10 years. The cover soil was prepared in three experimental plots of 3 × 3 m laid on the top of the existing waste pile (5 m depth from original ground elevation). Clay, sandy loam (silt:sand of 1:2 on weight basis) and sandy loam with vegetation (*Sporobolus virginicus*) was filled into the first, second and third experimental plots respectively. The characteristics of soil used are presented in Table 1. In each plot, the cover soil of 30 cm depth was laid on top of a 5 cm layer of gravel (average size of 2-3 cm) and cement block layer (20 cm depth) provided to facilitate gas flow into the cover soil layer. The same amount of either groundwater or leachate (20 litres every two days) was irrigated onto each half of cover soil to provide sufficient moisture content for bacterial activities (12-15%) especially important during dry periods. The leachate was taken from the leachate-receiving ponds in waste disposal area. Leachate was diluted with groundwater (2.5 parts in 100 parts v/v) to obtain EC concentration of 1 dS/m before being applied onto the cover soils. Characteristics of concentrated leachate before dilution are shown in Table 2.

Table 1: Characteristics of Clay and Sandy Loam Used

Parameter	*Clay*	*Sandy loam*
Bulk density (kg/m^3)	1,303	1,243
S.G. of soil particles	2.58	2.46
Porosity (%)	53.05	43.71
pH	6.22	7.20
EC (dS/m)	1.45	0.08
TOC (%)	0.24	0.04
NH_4^+-N (mg/kg)	53.43	21.64
NO_3^--N (mg/kg)	0.51	0.29

Table 2: Characteristics of Leachate Used

Parameter	*Range*	*Average*
pH	8.1-8.2	8.2
EC (dS/m)	29.8-34.3	31.9
BOD (mg/l)	520-624	576
COD (mg/l)	12,620-15,220	14,070
NH_4^+-N (mg/l)	1,625-2,010	1,830
TKN (mg/l)	1,990-5,870	3,310
NO_3^--N (mg/l)	2.0-2.2	2.1
PO_4^{3-}-P (mg/l)	0.24	0.04
Cl^- (mg/l)	1,890-2,160	2,060

Determination of Methane Emission Rate by Closed Flux Chamber

Figure 1 shows a schematic diagram of the closed flux chamber used for the determination of methane emission rate (MER). Once the chamber had been installed on the cover soil, gas samples were collected from it at 15 minute intervals into a 10-mL vial by a gas-tight syringe. The gas component in the vial was then analyzed by using gas chromatography (Shimadzu GC-14B-FID; nitrogen carrier gas 10 mL/min; Unibeads A80/100 filled column). Simultaneously, the temperatures of soil, ambient air and solid waste were also measured.

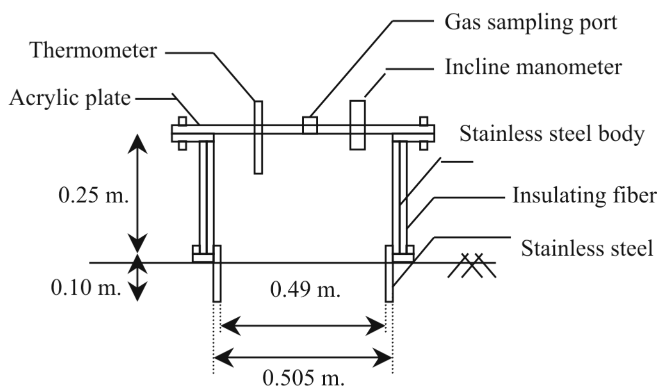

Figure 1: Schematic of closed-flux chamber.

Closed flux chambers operate by allowing the soil gas to accumulate in the chamber and withdrawing samples at timed intervals. The samples are later analyzed for the change of gas concentration, and the gas flux is found according to:

$$F = \frac{\rho V \Delta C}{A \Delta t} \quad (1)$$

where F = Flux of gas (g/m^2.s); ρ = Density of the gas (g/m^3); V = Volume of the chamber (m^3); A = Surface that are enclosed by the chamber (m^2); ΔC = Change of gas concentration (%); and Δt = Time interval over which the samples are taken (s).

Results and Discussion

Measurement of Methane Emission Rate by Closed Flux Chamber

Initially, the appropriate sampling time for determination of gas emission rate by closed flux chamber was investigated. The MER was directly related to the increasing rate of methane gas concentration in the chamber. During the measurement, methane concentration in the chamber increased and reached a plateau within 1-2 hours after installation of chamber on the cover soil. Therefore, the gas emission rate was obtained during the first 1-2 hours when methane concentration was linearly increasing with time.

The temperatures of cover soil (at 10 cm depth from soil surface) and ambient air (1 m from soil surface) were measured as shown in Figure 2. It was found that air temperature was higher than soil temperature by about 2 to 10 degrees. Their temperatures increased during 8:00 to 14:00 and the maximums were found at around 14:00. The soil temperature ranged from 25-35°C. The measurement of gas temperature inside the chamber showed less fluctuation and was slightly higher than soil temperature (about one degree on average). Ambient air temperature was not found to significantly affect the gas temperature in chamber and would not influence the measurement of methane emission rate.

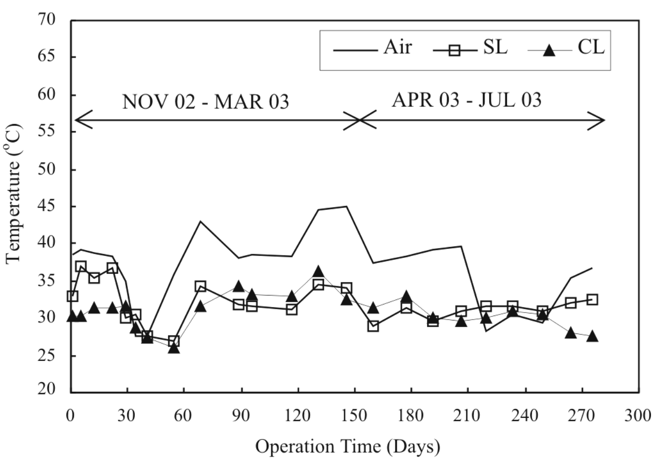

Figure 2: Variation in ambient air and soil temperature.

Methane Emission Rates through Different Cover Soils

The gas emission rate (methane and carbon dioxide) through different soil materials, i.e. clay, sandy loam and vegetated sandy loam (with *Sporobolus virginicus*) was determined for 275 days. Figure 3 shows the variation of daily rainfall during the monitoring period. The first 150 days (November 2002-March 2003) represented a dry period with average rainfall of 0.772 mm/day followed by rainy season (April-July 2003) where average daily rainfall increased to 3.577 mm. This rainfall variation also affected the moisture content of cover soil as shown in Figure 4. The moisture content of clay cover soil (CL) varied widely in a range between 15-30% whereas that of sandy loam (S+W: groundwater irrigation, S+L: leachate irrigation) and vegetated sandy loam (S+V+W, S+V+L) was maintained relatively constant at about 10% during the dry period and slightly increased to 13-15% during high intensity rainfall period. The cracking of clay cover soil was clearly observed over the entire monitoring period as its moisture content was maintained well below the shrinkage limit (Chiemchaisri et al., 2000).

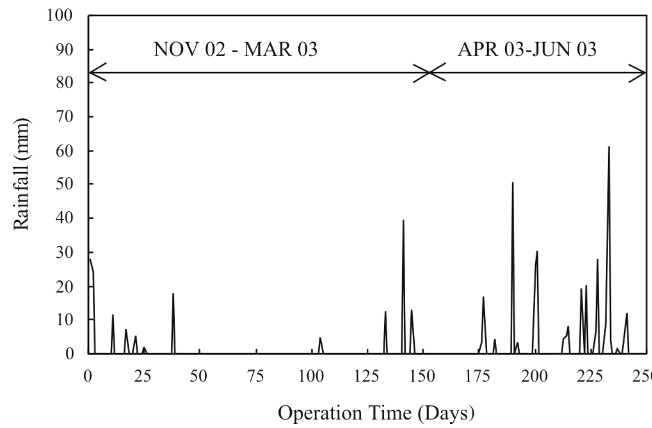

Figure 3: Daily rainfall intensity at waste disposal site.

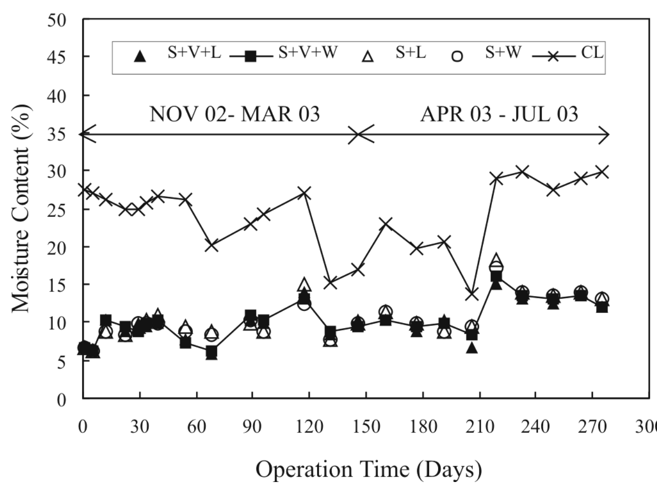

Figure 4: Variation in moisture content in cover soil.

Figure 5 shows the variation in methane and carbon dioxide emission rates through different types of cover soil. Over the 275 days of monitoring period, gas emission rates through the cover soils were found to vary significantly with time. The range and average emission rates of methane and carbon dioxide through clay, sandy loam and vegetated sandy loam are given in Table 3. In all experimental plots, higher MERs were detected during the dry period (day 0-150) than the high intensity rainfall period (day 150-275) as shown in Table 4. For clay cover soil, the MER fluctuated between 0.35 and 2.05 $g/m^2/d$ (average 1.30 $g/m^2/d$) during the dry period and between 0.59 and 1.65 $g/m^2/d$ (average 1.32 $g/m^2/d$) during the rainfall period. Comparatively, higher MER was found in the case of sandy loam soil with average rates of 2.31 and 1.11 $g/m^2/d$ during the same period of time. Higher porosity contained in sandy loam soil could explain their

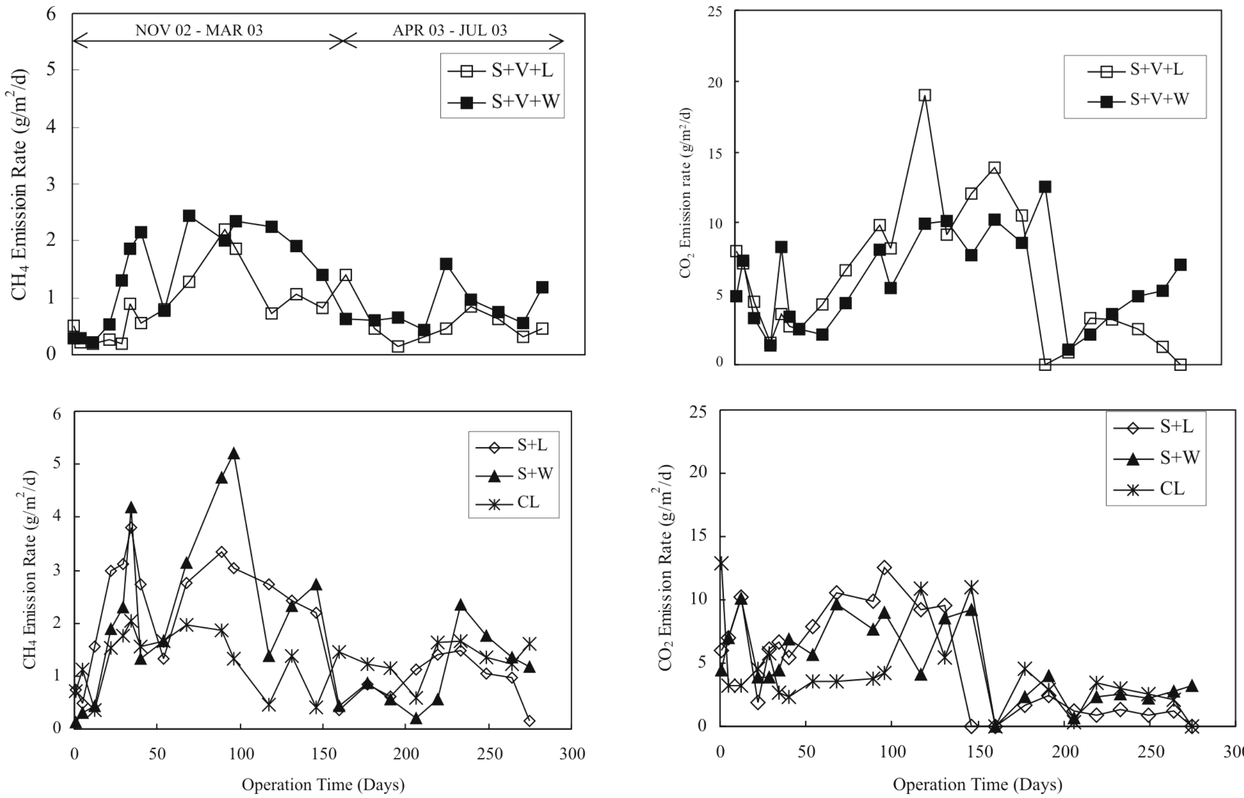

Figure 5: Variation in CH_4 and CO_2 emission rate through different cover soils.

higher emission rates. Nevertheless, a lower emission rate was found in the case of vegetated sandy loam cover soil especially when it was irrigated with leachate. Average MER of 0.82 and 0.56 $g/m^2/d$ were measured, respectively. For the whole monitoring period, average MER measured through the different cover soils of clay, sandy loam or vegetated sandy loam were 1.31, 1.79 and 0.95 $g/m^2/d$, respectively.

Table 3: CH_4 and CO_2 Emission Rates through Different Cover Soils

Cover soil	*CH_4 emission rate ($g/m^2/d$)*		*CO_2 emission rate ($g/m^2/d$)*	
	Range	*Average*	*Range*	*Average*
CL	0.35-2.05	1.31	ND-12.93	4.18
S+W	0.14-5.21	1.79	ND-10.13	4.99
S+L	0.16-3.82	1.79	ND-12.59	4.90
S+V+W	0.21-2.43	1.18	1.11-12.51	5.83
S+V+L	0.18-2.20	0.72	ND-19.04	5.86

Remark: ND = Not detected; CL = clay; S = sandy loam V = vegetation; W =groundwater; L = leachate

Lower MER detected through vegetated sandy loam cover soil could result from methane oxidation activity taking place in that layer. By comparing the figure with that detected at the bottom of the cover layer (average of 4.42 and 3.06 $g/m^2/d$), the reduction efficiency was found to be as high as 73.3-76.5%. For clay and sandy loam cover soils, the methane reduction efficiencies were 33% and 19%, respectively (Table 4). The irrigation of vegetated sandy loam soil yielded slightly higher methane reduction (76%) compared to groundwater irrigation (73%). This could be a beneficial effect of providing additional nutrients from leachate for plant growth and microbial activities. Figure 6 shows that the provision of leachate irrigation yielded higher growth of vegetation.

Table 4: Comparison of CH_4 Emission Rates between Dry and Wet Seasons

Cover soil	*Dry season (Nov.02-Mar.03), $g/m^2/d$*		*Wet season (Apr.03-Jul.03), $g/m^2/d$*	
	Range	*Average*	*Range*	*Average*
CL	0.35-2.05	1.30	0.59-1.65	1.32
S+W	0.14-5.21	2.27	0.22-2.36	1.03
S+L	0.47-3.82	2.38	0.16-1.47	0.89
S+V+W	0.21-2.43	1.41	0.44-1.59	0.82
S+V+L	0.18-2.20	0.82	0.31-1.40	0.56

Remark: CL = clay; S = sandy loam; V = vegetation; W = groundwater; L = leachate

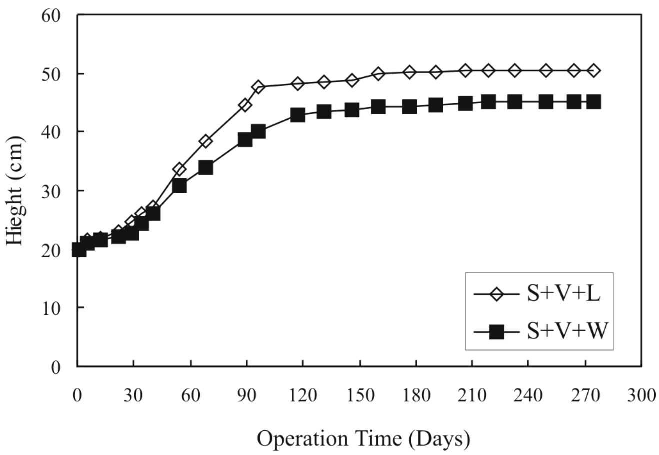

Figure 6: Growth of *S. virginicus* in groundwater and leachate irrigation conditions.

Soil moisture content also affects the microbial activity, and soil microorganisms can be inactivated in soil having moisture content lower than 5% (Glinski and Stepniewski, 1986). In this study, they could be maintained in the optimum range of 10-15% for sandy loam soil (Visvanathan et al., 1999). Sandy soil is a good soil texture for the enhancement of methane oxidation because air can diffuse through sandy soil much better than clay soil.

Table 5: Reduction of CH_4 Emission Rates in different Cover Soils

Cover soil	*CH_4 In ($g/m^2/d$)*		*CH_4 Out ($g/m^2/d$)*		*Average removal (%)*
	Range	*Average*	*Range*	*Average*	
CL	0.75-3.57	1.97	0.35-2.05	1.30	34.0
S+W	0.52-3.64	2.21	0.14-5.21	1.79	19.0
S+L	0.12-3.56	2.23	0.16-3.82	1.79	19.7
S+V+W	1.55-9.78	4.42	0.21-2.43	1.18	73.3
S+V+L	0.78-9.20	3.06	0.19-2.20	0.72	76.5

Remark: CL = clay; S = sandy loam; V = vegetation; W = groundwater; L = leachate

Conclusions

In this study, methane emission rate through different types of cover soil at a waste disposal site in Thailand was investigated by using closed flux chamber technique. Over 275 days of monitoring period, the measured methane emission rates were found to vary significantly with time and they were affected by the intensity of rainfall in the area. Higher emission rates were detected during the dry period compared to the high intensity rainfall period. Average MERs through cover soils of clay, sandy loam and vegetated sandy loam (with *Sporobolus virginicus*) were found to be 1.31, 1.79 and 0.95 $g/m^2/d$, respectively. Significant reduction of methane emission (about 75%) was observed in cover soil employing vegetated sandy loam where methane oxidation reaction could be promoted. In the case of clay and sandy loam cover soil, the reduction efficiencies were 33% and 19%, respectively. The application of leachate onto the vegetated cover soil could also enhance plant growth and slightly improved methane oxidation. Based on the results of this study, methane emission from a solid waste disposal site could be significantly reduced by the application of appropriate topsoil cover layer with high methane oxidation activity.

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