## TABLE OF CONTENTS

# Page

TABLE OF CONTENTS	i
LIST OF TABLES	ii
LIST OF FIGURES	iv
LIST OF ABBREVIATIONS	vii
INTRODUCTION	1
LITERATURE REVIEW	4
MATERIALS AND METHOD	35
RESULT AND DISCUSSION	47
CONCLUSIONS AND RECOMMENDATIONS	101
LITERATURE CITED	103
APPENDICES	112
Appendix A Calculations	113
Appendix B Data of Gas Concentrations in Column Experiment	119
Appendix C Data of Landfill Cover Materials in Column Experiment	147
Appendix D Data of Plant Growth in Column Experiment	159
Appendix E Data of Effluents in Column Experiment	163
Appendix F Data of Methanotrophic Activity Study in Batch Experiment	173

## LIST OF TABLES

Table		Page
1	Global atmospheric concentration (ppm), rate of concentration change (ppb/yr), atmospheric life time (years) and global warming potential (GWP) of greenhouse gasses	5
2	Estimation of the global source and sink of methane emission	6
3	Typical constituents found in MSW landfill and their characteristics	8
4	Methane production rate from various landfills	11
5	Details of general components of final cover systems	13
6	Effect of ammonium $(NH_4^+)$ and nitrate $(NO_3^-)$ additions on methane oxidation	18
7	Summary of methane oxidation studies in actual landfill cover soil	21
8	Summary of methane oxidation studies in landfill cover soil columns	22
9	Characteristic of landfill cover materials	36
10	Field capacity and evaporation of landfill cover materials	37
11	Characteristics of leachate	38
12	Nitrogen contents in cover materials after amendment with nutrient solution	44
13	Organic carbon contents in various mixtures of sandy loam and compost	44
14	Methane oxidation rate in batch experiment of three cover materials collected from column experiment with rainwater and leachate	
	applications	58
15	Respiration rate of landfill cover materials with rainwater and leachate	
16	irrigations	61
16	Methane oxidation in the active period of column experiment with rainwater and leachate irrigations	63
17	Effect of NH <sub>4</sub> <sup>+</sup> amendment on methane oxidation rate in three landfill covers	64
18	Effect of NO <sub>3</sub> <sup>-</sup> amendment on methane oxidation rate in three landfill covers	65
19	Effect of different ratios of organic compost amendment on methane	05
	oxidation rate	67
20	Methane oxidation rate in batch experiment of vegetated cover compost collected from column experiment with rainwater and leachate	
	applications	78
21	Numbers of methanotrophs detected by FISH technique in relation to the total DAPI counts in vegetated column experiment with rainwater and	
	leachate applications	81
22	Quantities of water balance components for landfill cover systems under	-
	wet and dry conditions	88
23	Methane oxidation rate (MOR) in different cover materials (sandy loam,	00
	SL and compost, C) and vegetated cover layer (S. virginicus and P. repens)	
	during wet and dry seasons	95
24	Methane oxidation rate in batch experiment of vegetated and non-	
- ·	vegetated cover materials collected from column experiment without	
	irrigation	98

# LIST OF TABLES (Cont'd)

Table		Page
25	Numbers of methanotrophs detected by FISH technique in relation to the total DAPI counts in vegetated and non-vegetated column experiment without irrigation	99

#### LIST OF FIGURES

Figure

Page
------

1	Phenomena of greenhouse effect	4
2	Biodegradation processes under anaerobic condition	9
3	Generalized phases in the generation of landfill gases	10
4	Typical layers used for final landfill cover	12
5	Pathways for methane oxidation and assimilation of formaldehyde	15
6	Methane oxidation rate as function of soil temperature	16
7	Methane oxidation rate as function of soil moisture	17
8	Methane oxidation rate as function of soil moisture and temperature	17
9	Effect of compost application on (a) soil porosity and (b) soil pore size	
	distribution	24
10	Effect of compost application at different rates (0, 50, 200 and 500 ton/ha	)
	on soil bulk density	25
11	Effect of compost additions on soil water retention	26
12	Effect of compost application on soil water content	26
13	Methane oxidation rates observed in three biofilters over 340 days	28
14	Bermuda grass (Cynodon dactylon): (a) spikelet, and (b) ligule	30
15	Star grass (Cynodon plectostachyus): (a) inflorescence, and (b) spikelet	31
16	Dixie grass (Sporobolus virginicus)	32
17	Torpedo grass (Panicum repens)	32
18	Production, oxidation and transfer of methane to the atmosphere	33
19	Biochemical mechanisms in landfill	34
20	Schematic of laboratory soil column	35
21	Tropical grasses and their roots used in vegetated cover systems:	
	(a) S. virginicus and (b) P. repens	37
22	Overall experimental investigation plan	39
23	Schematic of experimental system	40
24	Variation of moisture content of sandy loam at different irrigation patterns	5
	and operations (a) with and (b) without synthetic landfill gas upflow	48
25	Variation of moisture content of sandy loam/compost mixture at 200	
	mL/4days irrigation with and without operation of synthetic landfill	
	gas upflow	49
26	Variation of moisture content of compost at 200 mL/4days irrigation	
	with and without operation of synthetic landfill gas upflow	49
27	Variation of total methane oxidation rate (MOR) in landfill cover	
	materials with (a) rainwater and (b) leachate irrigations	51
28	Methane oxidation rate (MOR) throughout the depth profile of landfill	
	cover materials with rainwater and leachate irrigations	52
29	Gas concentration profiles during leachate application as a function of	
	depth in sandy loam after (a) 50 days and (b) 150 days; mixture of sandy	
	loam and compost after (c) 50 days and (d) 150 days; and compost after	
	(e) 50 days and (f) 150 days of experiment	54

iv

#### LIST OF FIGURES (Cont'd)

Figure		Page
30	Comparison of methane oxidation rate (MOR) between rainwater and leachate irrigations in (a) sandy loam, (b) sandy loam/compost mixture, and (c) compost	55
31	Nitrogen content, (a) TKN and (b) $NH_4^+$ -N, of irrigated leachate and effluents from column experiments operated with leachate	55
32	EPS (expressed as mg C/g dry soil) profiles as a function of depth in landfill cover materials at the end of experiment: (a) rainwater and	
33	<ul><li>(b) leachate irrigations</li><li>Methane consumption in batch experiment of three cover materials:</li><li>(a), (b) sandy loam; (c), (d) sandy loam/compost mixture; and</li></ul>	57
34	(e), (f) compost with rainwater and leachate applications, respectively Methane concentration in headspace over time in batch $NH_4^+$ and $NO_3^-$ amendment of three landfill covers: sandy loam added (a) $NH_4^+$ and (d) $NO_3^-$ ; sandy loam/compost mixture added (b) $NH_4^+$ and (c) $NO_3^-$ ;	59
35	and compost added (c) $NH_4^+$ and (f) $NO_3^-$ Methane concentration in headspace over time in batch organic compost addition	62 67
36	Variation of total methane oxidation rate (MOR) in vegetated landfill cover compost with (a) rainwater and (b) leachate irrigations	69
37	Methane oxidation rate (MOR) throughout the depth profile of vegetated landfill cover compost with rainwater and leachate irrigations	71
38	Changes in height (a), (b); and number (c), (d) of <i>S. virginicus</i> and <i>P. repens</i> during a period of vegetated column experiment operated with rainwater and leachate	72
39	Changes in leaf width (a), (b); leaf length (c), (d); and number of leaves (e), (f) of <i>S. virginicus</i> and <i>P. repens</i> during a period of vegetated column	
40	experiment operated with rainwater and leachate Comparison of methane oxidation rate (MOR) between rainwater and leachate irrigations in (a) compost, (b) compost with <i>S. virginicus</i> , and	/4
41	(c) compost with <i>P. repens</i> Nitrogen content, (a) TKN and (b) $NH_4^+$ -N, of irrigated leachate and	75
42	effluents from vegetated column experiment operated with leachate EPS (expressed as mg C/g dry soil) profiles as a function of depth in vegetated landfill cover compost at the end of experiment: (a) rainwater	76
43	and (b) leachate irrigations Methane consumption in batch experiment of vegetated cover compost: (a) (b) compost: (c) (d) compost with S, wire in inverse and (c) (f) compost	77
44	(a), (b) compost; (c), (d) compost with <i>S. virginicus</i> ; and (e), (f) compost with <i>P. repens</i> irrigated with rainwater and leachate, respectively Photomicrographs of <i>in situ</i> hybridization with (a) $M\gamma 84 + M\gamma 705$ and	79
	(c) Mα450 probes for detecting type I and type II methanotrophs, respectively; and (b), (d) corresponding DAPI stained cells	82
45	Variation of moisture contents on vegetated and non-vegetated sandy loam and compost under wet and dry conditions	84

#### LIST OF FIGURES (Cont'd)

Figure		Page
46	Components of water balance in vegetated and non-vegetated landfill	
	cover systems under wet and dry conditions	86
47	Variation of total methane oxidation rate (MOR) in vegetated and	
	non-vegetated landfill cover materials without irrigation	89
48	Methane oxidation rate (MOR) throughout the depth profile of vegetated	
	and non-vegetated landfill cover materials without irrigation	90
49	Gas concentration profiles during dry condition (day 0-160) and	
	re-irrigation (after day 160) as a functions of depth in (a) sandy loam;	
	(b), (c) sandy loam with <i>P. repens</i> ; (d), (e) compost; and (f), (g) compost	
	with P. repens, respectively	91
50	Oxygen penetrations in vegetated and non-vegetated cover materials	
	without synthetic landfill gas upflow	92
51	Variation of total methane oxidation rate (MOR) in vegetated and	
	non-vegetated landfill cover materials without irrigation compared to	
	rainwater and leachate irrigations: (a) sandy loam and sandy loam with	
	<i>P. repens</i> ; (b) compost; and (c) compost with <i>P. repens</i>	93
52	EPS (expressed as mg C/g dry soil) profiles as a function of depth in	
	vegetated and non-vegetated landfill cover materials at the end of	
	experiment without irrigation	96
53	Methane consumption in batch experiment of vegetated and non-vegetate	d
	cover materials (no irrigation): sandy loam (b) with and (a) without	
	P. repens; and compost (d) with and (c) without P. repens	97

# LIST OF ABBREVIATIONS

BOD CEC	mg/L cmol <sub>c</sub> /kg	Biochemical Oxygen Demand Cation Exchange Capacity
COD	mg/L	Chemical Oxygen Demand
DM	-	Dry Matter
d.w.	-	dry weight
EC	dS/m	Electrical Conductivity
EPS	mg C/g dry soil	Extracellular Polysaccharide
FC	% d.w.	Field Capacity
FISH	-	Fluorescence in situ hybridization
GC	-	Gas Chromatography
GWP	-	Global Warming Potential
MO	-	Methane Oxidation
MOR	mol CH <sub>4</sub> /m <sup>3</sup> .d	Methane Oxidation Rate
MSW	-	Municipal Solid Waste
n.a.	-	not analyzed
n.d.	-	not detected
ppb	-	part per billion
ppm	-	part per million
ppt	-	part per trillion (million million)
TN	mg/kg	Total Nitrogen
TKN	mg/L	Total Kjeldahl Nitrogen
VOCs	-	Volatile Organic Compounds
WPR	$cm^3 H_2O/cm^2.d$	Water Production Rate