Iranica Journal of Energy & Environment 3 (Special Issue on Environmental Technology): 50-59, 2012
ISSN 2079-2115
IJEE an Official Peer Reviewed Journal of Babol Noshirvani University of Technology
DOI: 10.5829/idosi.ijee.2012.03.05.09

BUT

Influence of Landfill Operation and Tropical Seasonal Variation on Leachate Characteristics: Results from Lysimeter Experiment

*Islam M. Rafizul** *and Muhammed Alamgir*

Department of Civil Engineering, Khulna University of Engineering & Technology (KUET),
Khulna-9203, Bangladesh

Abstract: This study demonstrates the influence of lysimeter operational condition and tropical seasonal variation of leachate characteristics generated from municipal solid waste (MSW) deposited in landfill lysimeter at KUET campus, Bangladesh. Three different situations of landfill were considered here as well as both the open dump lysimeter-A having a base liner and sanitary landfill lysimeter-B and C at two different types of cap liner were simulated. The leachate characteristics, leachate generation and climatic influence parameter had been continually monitored, from June 2008 to May 2010. This period covers both dry and rainy season. The leachate generation followed the rainfall pattern and the open dump lysimeter-A without top cover was recorded to have the highest leachate generation. Moreover, the open dump lysimeter-A had lower concentration and load of total kjeldahl nitrogen (TKN), ammonia nitrogen (NH_4-N) and dissolved organic carbon (DOC), while chemical oxygen demand (COD) and biological oxygen demand (BOD_5) concentration were higher compared with sanitary lysimeter-B and C. On the other hand, sanitary lysimeter-B, not only had lowest leachate generation, but also produced reasonably low COD and BOD_5 concentration compared with open dump lysimeter-A. Based on evaluated results, it was also concluded that metal concentrations which were comparatively higher in leachate of open dump lysimeter were Ca and K, however, the heavy metal concentrations of Cd, Cu, Zn and Mn, and those apparently lower were metals of Na, Mg and Fe as well as heavy metals of Cr, Pb and Ni. However, significant release of heavy metals under open dump lysimeter was observed compared to sanitary lysimeter. Moreover, meaningful correlation between DOC and leaching of Cu and Pb was observed. Result reveals that lysimeter operational mode had direct effect on leachate quality. Finally, it can be concluded that the knowledge of leachate quality will be useful in planning and providing remedial measures of proper liner system in landfill design and leachate treatment.

Key words: Climatic Condition; Landfill Lysimeter; Landfill Operation; Leachate Characteristics; Municipal Solid Waste.

INTRODUCTION

The term 'landfill' can be treated as synonymous to 'sanitary landfill' of MSW, only if the latter is designed on the principle of waste containment and is characterized by the presence of a liner and leachate collection system to prevent ground water contamination [1, 2]. Sanitary landfill is one of the secure and safe facilities for the disposal of MSW; however, it needs high standard of environment protection in the operation of landfill [3]. Lysimeter is a simulated form of sanitary landfill in the sense of control device. The word lysimeter is a combination of two Greek words *"Lusis" means "Solution"* and *"Metron" means "Measure"* and the original aim is to measure soil leaching [4]. Most of the landfill in developing countries does not have any liners at the base or proper top covers, which results in the potential problems of ground water/surface water contamination due to the leachate generated from solid waste landfill [5]. Landfill leachate is considered as one of the highly contaminated resources from physical, chemical and biological point of view and it may pose a severe pollution threat to ground water [6].

Chemically contaminated leachate is one of the byproducts in landfill degradation reactions. One of the severe problems associated with the open dumping of MSW is percolation of leachate into the surrounding environment, subsequent contamination of land and water bodies [7]. El-Fadel et al. [8] reported that composition of leachate can exhibit considerable spatial and temporal variations depending on the site, management practices, refuse characteristics and internal landfill processes.

Corresponding Author: Islam M. Rafizul, Department of Civil Engineering,
Khulna University of Engineering & Technology (KUET),
Khulna -9203, Bangladesh. Phone: +880-41-769468-75 Ext 295 (Off),
Fax: +880-41-774780, E-mail: imrafizul@yahoo.com

Morever, the variation of leachate quality in terms of organic and inorganic compounds as well as metal and heavy metal concentrations can be attributed to many interacting factors such as composition and depth of MSW; decomposition and age; degree of compaction; landfill design and operation; liner design; filling procedures; availability of moisture content and landfill gas (LFG); rate of water movement and temperature [4].

In addition, leachate quality may vary from time to time and site to site due to the variables of waste composition, temperature, moisture content and climatic changes. To these endeavor, the present study aimed to evaluate the influence of lysimeter operational mode as well as tropical seasonal variation on leachate characteristics from open dump and sanitary landfill lysimeter.

EXPERIMNETAL SET UP AND METHODOLOGY

Experimental set up of landfill lysimeter: Three landfill lysimeter designated as A, B and C were designed and constructed at KUET campus, Bangladesh based on a reference cell shown in Fig. 1, showing all the design components in details. The operational condition, liner specifications, simulation behavior and the total weight of MSW deposited in each lysimeter are presented in Table 1. The MSW deposited in lysimeter was collected from Khulna city and the average composition and moderate compaction density was maintained during the deposition of MSW in each lysimeter. The MSW deposited in lysimeter mainly consisted of 93 (w/w) organic (food and vegetables), 3 (w/w) of plastic/polythene and 2 (w/w) of leather/rubber, 1 (w/w) of animal bone and rubber/leather as well as 1 (w/w) of rope/straw and egg pill. However, the organic and moisture content of MSW were found 52% and 65%, respectively, and the total volume was 2.80 m^3 (height 1.6 m) with a manual compaction to achieve the unit weight of 1,064 kg/m^3. At the bottom of each lysimeter, a concrete layer of 125 mm thickness was provided then the lysimeter was filled with stone chips (diameter 5-20 mm) and coarse sand (diameter 0.05-0.4 mm) to the height of 15 cm of each to ensure uniform and uninterrupted drainage. At the base of each lysimeter after placing the perforated leachate collection pipe, a geo-textile sheet having 0.60 m wide and 1.65 m length was placed to avoid rapid clogging by the sediments.

Landfill lysimeter-A (Open Dump): The type and volume of MSW deposited in open dump lysimeter-A was exactly the same as deposited in the reference cell. In open dump lysimeter-A, a compacted clay liner (CCL) of 400 mm thickness was placed as the base liner and a layer of compost of 150 mm thick was used as the top cover to simulate the behaviour of present practice of open dumping in Bangladesh shown in Fig.

2. In this lysimeter the MSW was not covered by a top cover system to pervert the movement of air, water and landfill gas (LFG). Moreover, the thickness of MSW in lysimeter-A is such that it is expected the atmospheric air can move in the entire MSW deposited in this cell with negligible inference. Due to the mentioned practical situations, lysimeter-A, represents an open dump landfill condition comparing the counterparts i.e. sanitary landfill lysimeter-B and C.

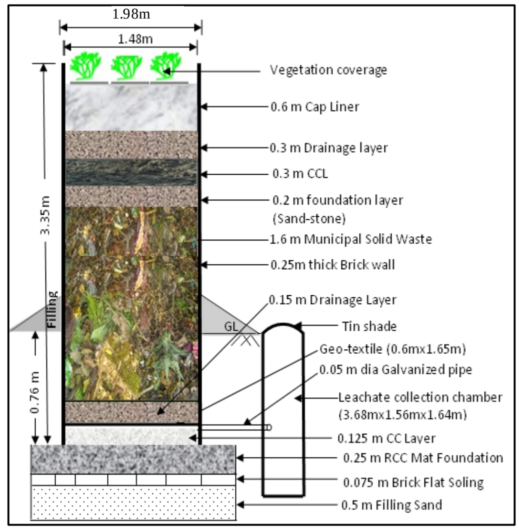

Fig. 1: Schematic diagram of reference cell for landfill lysimeter design

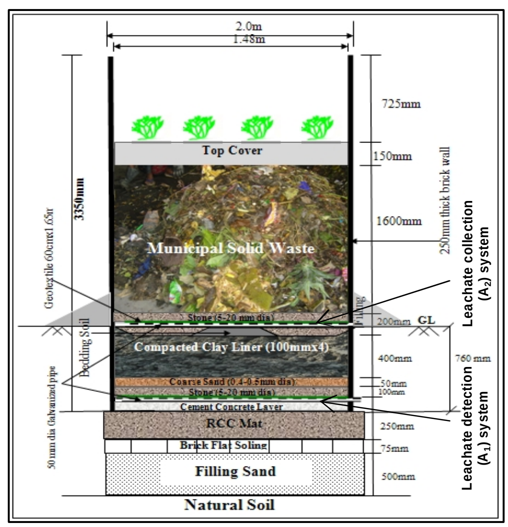

Fig. 2: Schematic diagram of open dump lysimeter-A with detection and collection system

Sanitary landfill lysimeter-B (Cap liner I): In sanitary lysimeter-B, the characteristics and volume of deposited MSW was similar to that of the open dump lysimeter-A. However, it differs with open dump lysimeter-A, by a top cover and without a base liner, because this cell aims to examine the applicability of the designed top cover to simulate the sanitary landfill condition. The top cover consisted of stone chips (diameter 5-20 mm) and coarse sand (diameter 0.05-0.4 mm) layer each of 100 mm thickness, then a 300 mm CCL was provided.

Table 1: Operational conditions of lysimeter to simulate different landfill conditions

lysimeter	*Operating condition*	*Refuse (kg)*	*Liner specification*	*Simulation*
A	Open dump lysimeter with leachate detection (A_1) system	2860	400 mm thick CCL as a barrier between leachate detection and collection system of lysimeter-A	present practice of open dumping
	Open dump lysimeter with leachate collection (A_2) system			
B	Sanitary landfill lysimeter with gas collection and leachate recirculation system	2985	Cap liner-I (300 mm thick CCL)	applicability of designed top cover

On the CCL, there were 150 mm thick coarse sand (diameter 0.05-0.4 mm) and 150 mm thick stone chips (diameter 5-20 mm), which was followed by 600 mm thick top soil (Table 1). Due to the above mentioned practical situations, lysimeter-B represents a sanitary landfill condition comparing with open dump lysimeter-A as well as sanitary lysimeter-B acts as a control device from where, the flow rate and the composition LFG is possible to measure and monitor. In sanitary lysimeter-B, 38 mm diameter of gas collection and 25 mm diameter of leachate recirculation pipe were installed.

Stationary landfill lysimeter-C (Cap liner II): In sanitary landfill lysimeter-C, there was also no base liner and the provided top cover was different from that of sanitary landfill lysimeter-B. In this lysimeter no CCL was used; however, 900 mm thick natural topsoil was used instead of 300 mm thick CCL and 600 mm thick top soil (Table 1). Moreover, the drainage and gas collection layers were remained same as the sanitary landfill lysimeter-B. In sanitary lysimeter-C, 38 mm diameter of gas collection and 25 mm diameter of leachate recirculation pipe were also installed. Designated compaction of the CCL in the lysimeter means the degree of compaction which was provided in the pilot scale sanitary landfill (PSSL) at Rajbandh, Khulna. To achieve the designated compaction at the CCL of lysimeter, locally manufactured hammer similar to that used in the PSSL was employed.

Characterization of clay and MSW used in this study: In the laboratory through ASTM standard [9] soil moisture content, plastic limit, liquid limit, plasticity index and shrinkage limit of clay soil used as CCL were found 22%, 22%, 43%, 21%, and 16%, respectively. In addition, the percentages of soil constituents were found as sand, silt and clay of 10, 56.6% and 33.4%, respectively. Then the value of soil pH, optimum moisture content, maximum dry density and coefficient of permeability were found 6.7%, 18%, 16 kN/m^3 and $1.90x10^{-7}$ cm/sec, respectively. In contrary, the mineralogical compositions of clay such as Non-clay minerals in terms of Quartz, Feldspars and Carbonates of 19, <1 and <1% (depth of sample 0-7 m) as well as 17, <1 and <1% (depth of sample 13-23 m), respectively. The Non-swelling clay minerals in terms of Illite, Kaolinite and Chlorite of ~50, ~10 and <1% (depth of sample 0-7 m) as well as ~50, ~10 and 1-2% (depth of sample 13-23 m), respectively, while, the Swelling clay minerals of Smectite was found as 20% (depth of sample 0-7 m) and 19% (depth of sample 13-23 m). The mineralogical compositions of clay used as CCL was measured in the laboratory of the Department of Applied Geology, Karlsruhe University, Germany [10]. In contrary, the MSW deposited in lysimeter consists of pH, volatile solids (VS), and ash residue and bulk density of 7.79%, 58%, 46% and 1000-1066 kg/m^3, respectively. In addition, the percent finer of MSW was 100% in 300 mm and 200 mm sieve openings, whereas the values were found as 76.25%, 63.72%, 45.22%, and 24.34% for the opening of 100 mm, 76.2 mm, 38.2 mm, and 19.1 mm, respectively. Moreover, the chemical characteristics in terms of carbon (C), nitrate (N) potassium (K), phosphorous (P) and C/N ration was found as 25.63%, 1.84%, 1.37%, 0.41%, and 13.92%, respectively. The detailed procedure for measuring the moisture and organic content, physical and chemical composition of MSW can be obtained in Austrian Standard (S 2023) [11].

Analytical Methods for the Assessment of Leachate: The leachate samples were collected at a regular interval of time and analyzed in the laboratory. pH by pH meter (HACH, Model No. Sens ion 156), chloride by potentiometric titration method using silver nitrate solution, alkalinity by titration method, hardness by EDTA titrimetric method, COD by closed reflexive method and BOD_5 by BOD meter (HACH, Model No. HQ40d) as per the standard method [12]. Moreover, total solid (TS) dried at 103-105°C, total dissolved solid (TDS) dried at 180°C, total suspended solid (TSS) dried at 103-105°C and conductivity by conductivity meter (HACH, Model No. Sension 5) were measured in the laboratory. In addition, ammonia nitrogen (NH_4-N) by nesslerization standard method and total kjeldahl nitrogen (TKN) by macro-kjeldahl method as per the standard method [12] were determined. Moreover, the sulfate (SO_4^{2-}) by Sulfa Ver 4 method using spectrophotometer (HACH, DR/2500) and dissolved organic carbon (DOC) were measured by combustion (NPOC) with a Shimadzu TOC-5000 instrument as per the standard method [12]. Moreover, Na, K, Ca and Mg using flame atomic absorption spectrophotometer (VARIAN; AA/2400) as well as Fe, Cd, Cu, Cr, Ni, Pb, Zn and Mn using spectrophotometer (HACH; DR/2400) as per the standard method [12] were determined and presented in Table 2.

RESULTS AND DISCUSSION

The behavior of leachate concentration in relation to the increasing of elapsed period, lysimeter operational condition as well as changes of climatic condition are presented and hence discussed in followings.

Behavior of leachate parameter: The behavior of COD against LFG; TKN, NH_4-N, DOC, Cd, Cu, SO_4^{2-}/Cl^- and pH as well as behavior of Cu and Pb with DOC at varying elapsed period are discussed in followings.

Behavior of COD concentration and landfill gas: The highest concentration of CH_4 occurred after 50 days of sanitary lysimeter-B operation shown in Fig. 3 and the COD decreased rapidly up to the 95 day (Fig. 4). Here, it is demonstrated that biological activity may occur in sanitary lysimeter-B and it is revealed by the rapid production of LFG up to 70 day of operation. However, the rapid increase of CH_4 at the initial stage suggests that a significant portion of leachate was organic and that biodegradation contributes to produce the high level of COD [10]. Moreover, Fig. 3 depicts that after 3 day of lysimeter-B operation, CH_4 was comparatively higher (45.7%) which led the higher COD at the initial stage. However, Fig. 4 reveals that COD levels remained steady at approximately 500 mg/L, this indicates that a significant proportion of degradable organics were still present in leachate of lysimeter-B. COD did not further reach high levels after the onset of methanogenesis as in other investigations [13]. Furthermore, there was a negligible acidic inhibition evident in the early stages of degradation process, as was found in other studies [14]. This may be attributed to the large proportion of slowly degradable material presents in lysimeter in this study.

Behavior of TKN and NH_4-N: The variation TKN and NH_4-N of entire lysimeter operation is provided in Figs. 5 and 6, respectively. The higher TKN was recorded for the collection system of sanitary lysimeter-B against the other counterparts i.e. collection system of sanitary lysimeter-C as well as the detection (A_1) and collection (A_2) system of open dump lysimeter-A (Fig. 5). Both the A_1 and A_2 system of lysimeter-A produced low TKN by reason of dilution of pollutant due to its top cover design enhance rainfall percolation and similar trend was also observed by [1].
In sanitary lysimeter-C, TKN increased up to 1860 mg/L by the 90th day and then started to decrease whereas for the collection system of lysimeter-A and lysimeter-B, TKN decreased and then remain almost constant throughout this study (Fig.5).

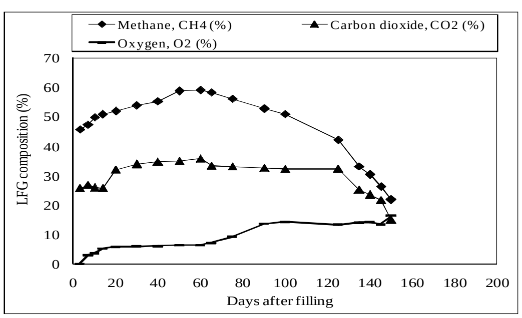

Fig. 3: Biogas concentrations in sanitary lysimeter-B

In contrast, the higher NH_4-N was recorded for the collection system of lysimeter-B and C than that of A_1 and A_2 system of lysimeter-A shown in Fig. 6. At the end of the study period, both the nitrogenous compounds reached a minimum level of TKN (178 mg/L, 125 mg/L, 165 mg/L, and 176 mg/L) as well as NH_4-N (154 mg/L, 232 mg/L, 298 mg/L, and 306 mg/L) during the 970th day for the A_1 and A_2 system of open dump lysimeter-A as well as collection system of sanitary lysimeter-B and C, respectively.

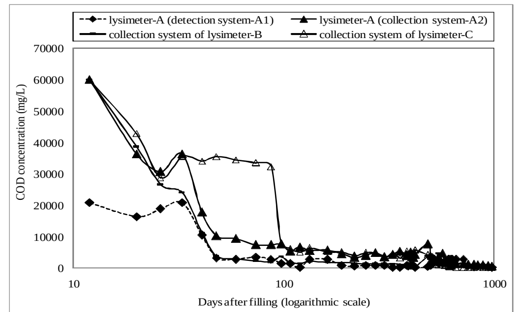

Fig. 4: Leaching behavior of COD concentration in leachate of lysimeter at varying operational

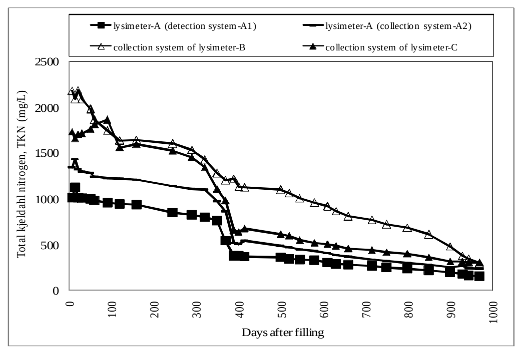

Fig. 5: Leaching behavior of TKN in leachate of lysimeter at varying operational condition

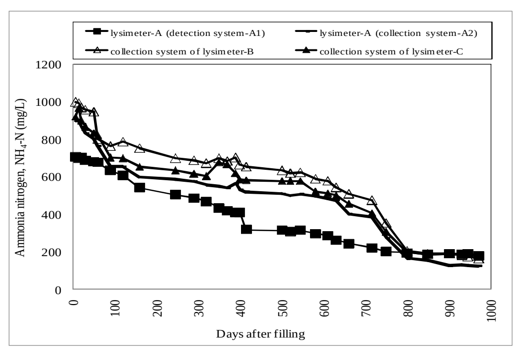

Fig. 6: Leaching behavior of NH_4-N in leachate of lysimeter at varying operational condition

However, the maximum concentrations of TKN (1120 mg/L, 1430 mg/L, 2187 mg/L, and 1860 mg/L) and NH_4-N (705 mg/L, 901.3 mg/L, 997 mg/L, and 965.7 mg/L) were recorded within 90th day of lysimeter operation of A_1 and A_2 system of lysimeter-A as well as the collection system of lysimeter-B and C, respectively. Ammonia was released from the waste by the decomposition of proteins and there is no mechanism for its degradation under methanogenenic condition. So, only leaching can decrease the NH_4-N [13]. Here, it can be established that variation of TKN and NH_4-N in A_1 and A_2 system of open dump lysimeter-A may be occurred due to the providing of 400 mm thick CCL as a barrier between the detection and collection system of lysimeter-A. As the A_2 system of lysimeter-A was provided just below the MSW deposited in lysimeter-A and the followed A_1 system was separated with the 400 mm thick CCL and this operational mode may be considered for the variation of TKN and NH_4-N between these two systems. Moreover, the variation of TKN and NH_4-N for the collection system of lysimeter-A and B may be occurred due to the simulation behavior of open dumping and providing the base liner in open dump lysimeter-A as well as sanitary landfill and providing the cap liner in lysimeter-B. In contrast, TKN and NH_4-N for the collection system of sanitary landfill lysimeter-B and C may be occurred due to the difference of landfill lysimeter-B and C in terms of thickness and compaction conditions of cap liner.

Behavior of DOC: DOC values in leachate of sanitary lysimeter-B were relatively high (up to 3760 mg/L), and rapid reduction in DOC levels in A_1 and A_2 system of open dump lysimeter-A compared to collection system of sanitary lysimeter-B and C clearly showed the acceleration of bio-stabilization in open dump lysimeter-A shown in Fig. 7. However, the maximum concentrations of DOC (2707 mg/L, 2890 mg/L, 3760 mg/L, and 3500 mg/L) were recorded within 20^{th} day of lysimeter operation of A_1 and A_2 system of lysimeter-A as well as the collection system of lysimeter-B and C, respectively. In anaerobic cells, DOC decreased mainly due to dilution [15]. However, it is very clear that DOC reduction in both the system of lysimeter-A is larger and caused by dilution, since initial concentrations were very close in both the sanitary and open dump lysimeter as well as pH, chloride and EC indicated rather higher dilution in sanitary lysimeter-B and C (data not shown). BOD_5 in leachate showed distinctly different pattern between three landfill lysimeter (Table 2). Moreover, BOD_5 of A_2 system of lysimeter-A has decreased faster than DOC and became 450 mg/L after around day 900 (data not shown).

Behavior of metal concentrations with elapsed period: The main processes for the low metal concentrations in leachate are sorption and precipitation [16]. Solid wastes contain soils and organic matter, which have a significant sorptive capacity, especially at neutral to high pH prevailing in methonegenic leachate [17]. However, the solubility of the metals with sulfides and carbonates is low and sulfide precipitation is often cited as an explanation for low concentrations of heavy metal in leachate. Sulfides and carbonates are capable of forming precipitates with heavy metals of Cd, Ni, Zn, Cu and Pb. The metal concentration viz. Ca, Na, K and Mg as well as heavy metals concentrations viz., Cu, Cr, Cd, Ni, Pb, Mn, Fe and Zn were measured (Table 2). Based on evaluated results, it can be depicted that metal concentrations which were comparatively higher in leachate of open dump lysimeter-A were Ca and K, however, the heavy metal concentrations of Cd, Cu, Zn and Mn, and those apparently lower were metals of Na, Mg and Fe as well as heavy metals of Cr, Pb and Ni. A study conducted by Bulent et al [15] and investigated no excessive release of heavy metals under open dump (aerobic) conditions was observed compared to sanitary (anaerobic) and control cells. Hantsch et al. [18] have reported no noticeable increase in heavy metal in leachate of open dump (aerobic) lysimeter compared to sanitary (anaerobic) lysimeter. Moreover, the variation of Cd and Cu with elapsed period and the relation of Cu and Cd with DOC are discussed here. The variation of Cd with elapsed period for A_1 and A_2 system of lysimeter-A as well as the collection system of sanitary lysimeter-B and C is provided in Fig. 8. At the beginning of lysimeter-A, Cd was found 0.265 mg/L and 0.168 mg/L, and after 120 day, it decreased markedly 0.078 mg/L and 0.097 mg/L, for A_1 and A_2, respectively. From the day of 660 to until the end of this study, there was no significance change of Cd for both the system of lysimeter-A.

In contrast, at the beginning of lysimeter-A, Cu was found at 0.04 mg/L and 0.04 mg/L, and after 100 days operation, it increased rapidly up to day 500, at 0.98 mg/L and 0.97 mg/L, for A_1 and A_2, respectively (Fig. 9). From day 630 and 775 to until the end of this study, it decreased rapidly for both cases of open dump lysimeter-A. Both the Cd and Cu concentrations in lysimeter-B and C were found to follow almost similar trend of lysimeter-A operation, although the values of Cd and Cu for lysimeter-A was higher than that of lysimeter-B and C. Similar trend was also observed by Jensen et al. [19].

Moreover, the only study by Cossu et al. [14] which investigated the impact of aerobic conditions in lab-scale lysimeter and postulated that among the heavy metals monitored, Cr and Cu only have slightly increased with start of aeration after 52 days under anaerobic conditions. Moreover, the present study reveals that Cu had comparatively higher concentrations in leachate of open dump lysimeter-A. This could be due to two factors: higher initial amounts of these metals in open dump lysimeter or enhanced leaching under aerobic conditions. However, it should be noted that observed mean Cu (below 0.437 mg/L) in this study are far below the state discharge limit of 3.0 mg/L.

Behavior of Cu and Pb with DOC: It seems that DOC had more influence on Cu and Pb leaching from lysimeter at varying operational condition can be seen from Figs. 10 and 11, respectively. Heavy metal leaching, especially for Cu and Pb have been suggested to be strongly dominated by interaction with particulate matter and DOC [15]. However, Figs. 10 and 11 reveal approval correlation between DOC levels and Cu and Pb leaching was observed in this study. This indicates that leaching of these heavy metals was being controlled dominantly by DOC in lysimeter. Rather, it was controlled mainly by simple dissolution into water phase from the solid matrix at this early stage of landfilling.

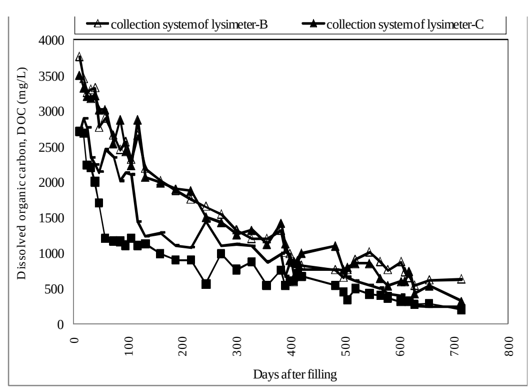

Fig. 7: Leaching behavior of DOC in leachate of lysimeter at varying operational condition

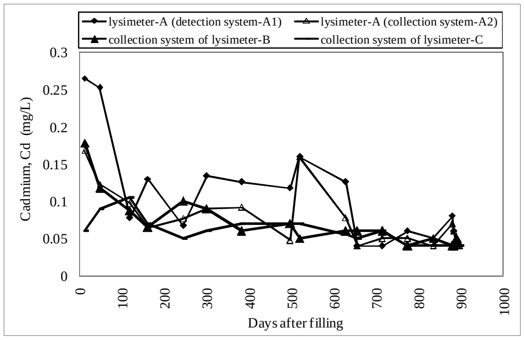

Fig. 8: Leaching behavior of Cd in leachate of lysimeter at varying operational condition

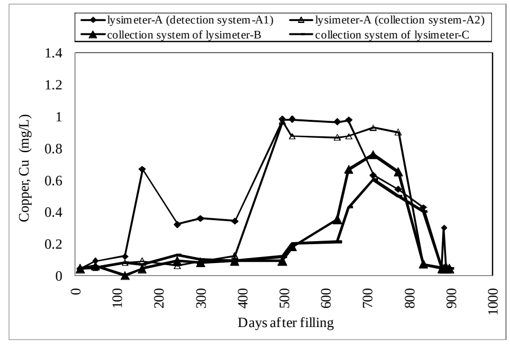

Fig. 9: Leaching behavior of Cu in leachate of lysimeter at varying operational condition

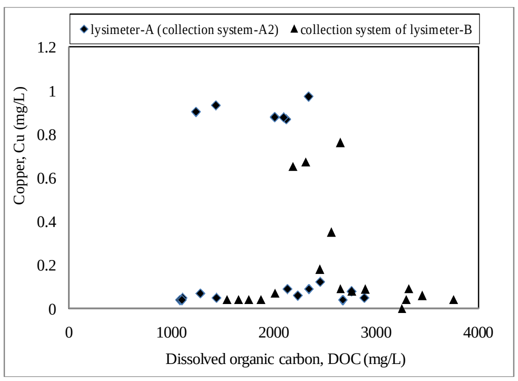

Fig. 10: Relationship between Cu and DOC in leachate of lysimeter at varying operational condition

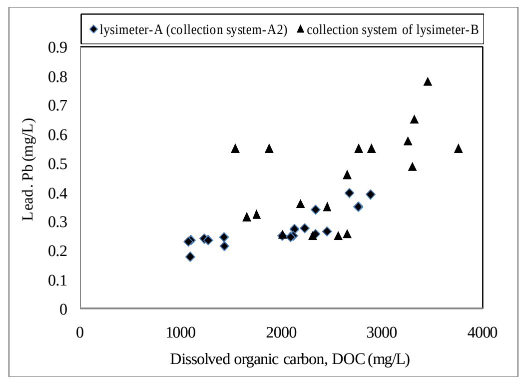

Fig. 11: Relationship between Pb and DOC in leachate of lysimeter at varying operational condition

Table 2: Characteristics of leachate generated from MSW in landfill lysimeter

Parameter	*Operating condition of landfill lysimeter*			
	A_1	*A_2*	*B*	*C*
Organic and Inorganic compound				
pH	5.98-8.17 (6.78)	6.14-8.02 (7.27)	6.40-8.61 (7.38)	6.30-8.38 (7.44)
Chloride	970-3097 (2182)	1155-3572 (2419)	510-1870 (1066)	110-1810 (1183)
TS	280-10400 (6026)	5019-36690(13244)	2920-14770(10919)	500-27280 (14047)
TDS	210-9930 (5720)	140-35810 (12507)	1800-29980(9786)	420-26000 (13132)
TSS	70-1080 (306)	17-1380 (736)	90-2540 (1133)	47-2340 (915)
TKN	154-1120 (554)	232-1430 (735)	298-2187 (1216)	306-1860 (948)
NH_4-N	178-705 (405.67)	125-901 (508.27)	165-997 (608.46)	176-965.7 (559.62)
Hardness	129.8-3241(2103.60)	986-10000 (2198.81)	1165-14000 (2783.16)	1043-10000 (2337.73)
Alkalinity	400-5550 (1100)	980-10000 (2930)	1000-8770 (4805)	900-9435 (4642)
BOD_5	83-6750 (2310.43)	143-20420 (5176.50)	437-12358 (3308.70)	490-16733 (4428.30)
COD	160-20800 (3258)	654-60000 (7458)	543-60000 (5034)	265-60000 (9723)
DOC	201-2707 (919.70)	250-2890 (1221)	543-3760 (1640)	321-3500 (1622.73)
Conductivity	5.3-17.7 (7.30)	3.1-24.7 (9.38)	5.2-16.5 (7.70)	3.7-21.7 (11.26)
Sulfate	-	100-1180 (607.50)	110-1110 (543)	-
Metal Concentrations				
Ca	254-790 (414.63)	218- 664 (388,99)	153-578 (355.78)	140-664 (406.53)
K	856-1967 (1429.91)	1102-2589 (2067.79)	1009-1764 (1447.45)	567-1957 (1247.28)
Na	1268-2425 (2052.93)	1252-2370 (2046.57)	1256-2764 (2214.91)	1012-2409 (1657.34)
Mg	147-590 (381.17)	127-564 (349.85)	228-606 (412.57)	156-594 (359.44)
Fe	1.8-70 (19.53)	3.4-83 (24.22)	3.6-91 (27.94)	1.4-72 (6.30)
Heavy Metal Concentrations				
Cd	0.04-0.265 (0.104)	0.04-0.168 (0.078)	0.04-0.178 (0.073)	0.04-0.105 (0.058)
Ni	0.04-0.075 (0.054)	0.04-0.055 (0.045)	0.045-0.09 (0.066)	0.04-0.07 (0.050)
Zn	0.25-1.27 (0.757)	0.15-0.97 (0.537)	0.10-0.55 (0.312)	0.10-0.576 (0.212)
Cu	0.04-0.98 (0.437)	0.04-0.97 (0.344)	0.04-0.76 (0.196)	0.04-0.60 (0.177)
Cr	0.01-0.07 (0.045)	0.01-0.056 (0.038)	0.023-0.03 (0.060)	0.01-0.025 (0.044)
Mn	0.80-6.0 (3.922)	2.5-21.2 (7.422)	0.50-19.3 (6.833)	0.80-8.0 (4.283)
Pb	0.12-0.32 (0.205)	0.179-0.40 (0.271)	0.25-0.78 (0.448)	0.10-0.476 (0.292)

TS=total solid, TDS=total dissolve solid, TSS=total suspended solid, TKN=total kjeldahl nitrogen, NH_4-N=ammonia nitrogen, BOD_5= biological oxygen demand, COD=chemical oxygen demand, DOC= dissolved organic carbon, Ca=calcium, K=potassium, Na=sodium, Mg=magnissium, Fe=iron, Cd=cadmium, Ni=Nickel, Zn=Zinc, Cu=copper, Cr=chromium, Mn=manganese and Pb=lead. All values in mg/L, except pH and conductivity (mS/cm). Range is given for the minimum and maximum values, while the value of parenthesis indicates the mean values.

Behaviour of sulfate-chloride ratio and pH: Fig. 12 represents the relationship of SO_4^{2-}/Cl^- and pH with the increasing of elapsed period of open dump lysimeter-A (Fig. 12 a) and sanitary lysimeter-B (Fig. 12 b). Here, it is interesting to note that SO_4^{2-}/Cl- decreased with elapsed period for lysimeter-B, while, it increased up to the 80^{th} day of lysimeter operation and then decreased for the A_2 system of lysimeter-A. However, the predicted SO_4^{2-}/Cl^- was found higher for lysimeter-B than that of lysimeter-A. Based on Fig. 12, it can be concluded that for both the lysimeter, pH increases with increasing SO_4^{2-}/Cl^-. Here, it is interesting to note that for lysimeter-B, the reduction of SO_4^{2-}/Cl^- is only a biological process and the reduction of SO_4^{2-} has a higher energy benefit for organism than methane production [6]. The value of pH is greatly influenced by the SO_4^{2-}/Cl^- [20]. There the SO_4^{2-} degradation is the first phase before intensive methane production. Moreover, the rapid decreased of sulfate is a result of predominately anaerobic condition in waste landfill under which sulfate is reduced to sulfide.

Influence of tropical seasonal variations on lysimeter operation: To investigate the variation of leachate quality against rainfall as well as COD, BOD_5, TKN load and pH in relation to the changes of tropical condition, periodic monitoring of leachate quantity at varying operational condition of lysimeter was carried out and hence discussed in followings.

Variation of leachate generation: The amount of rainfall and cumulative leachate generation from A_1 and A_2 system of lysimeter-A as well as the collection system of sanitary lysimeter-B and C is provided in Fig. 13, for the period from July 2008 to August 2010. During the first rainy season (July to August 2008), high amount of leachate was generated from the A_2 of lysimeter-A. After 135 days of lysimeter operation, leachate generation from A_2 of lysimeter-A was about 41.0 times and 19.0 times more than that of the collection system of lysimeter-B and C, respectively. The leachate generation was found as lower in the A_1 than the other system. In lysimeter-B and C, the leachate generation was found lower than that in lysimeter-A, although the amount of rainfall was same because the provided cap liner in lysimeter-B and C, played an important role to reduce the percolating of rainwater in lysimeter-B and C and similar trend was followed by [21]. It was advocated that for open cell, without a CCL, rain water was percolated rapidly into the lysimeter and hence produces relatively higher quantity of leachate, whereas, due to the providing a CLL having high compaction density expected to produce relatively low leachate, especially during the dry season. However, considering about 65% of moisture content and 52% of organic composition of MSW in lysimeter, the amount of leachate generation was found to be strongly related to rainfall and cover system [4]. During second rainy season (July to Sep. 2009), high amount of leachate was again generated from A_2 of lysimeter-A and it was about 51.0 times and 22.0 times more than that in lysimeter-B and lysimeter-C, respectively. After 450 days of entire lysimeter operation, leachate generation was also increased steady than the successively rainy season.

Variation of leachate characteristics: The characteristic of leachate depends on type and composition of MSW and the top cover design in landfill. The effect of seasonal variations on COD, BOD_5, TKN load and pH had been observed and discussed in followings.

Organic content in leachate: The organic content of landfill leachate was measured as COD and BOD. Fig. 14 and Fig. 15 shown the relationship between the quantity of leachate, COD and BOD of open dump lysimeter-A and sanitary lysimeter-B, respectively. Fig. 14 and Fig. 15 reveals at the day around 50 day to up the 135 day of lysimeter operation, during the rainy season COD was found higher for both the lysimeter. At the beginning of dry season period (after day 135), both the lysimeter did not generated much leachate and the concentration of COD was stable for both the lysimeter because few leachate flows was produced and similar trend was followed by Trankler et al. [2] and Visvanathan et al. [21] and advocated that COD of open cell was higher than those of closed cell. The high organic content in landfill lysimeter in the beginning stage of decomposition cause the high COD and BOD values [1, 22].

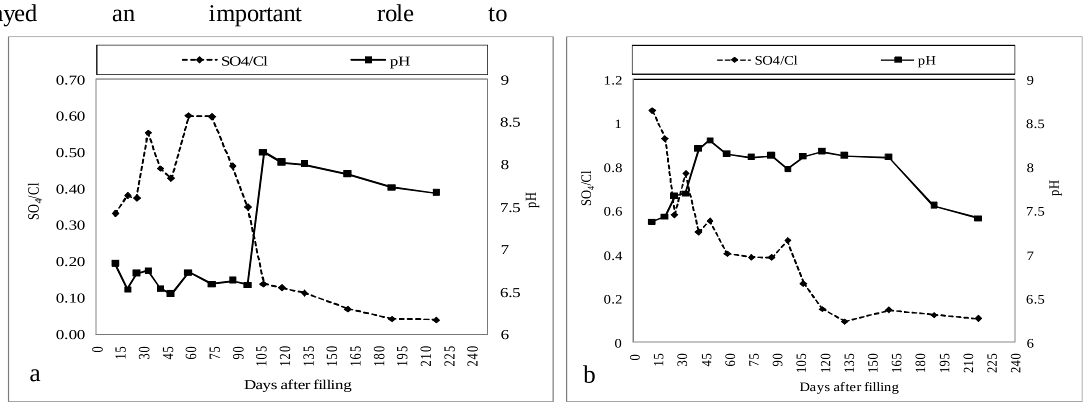

Fig. 12: Co-relation of SO_4/Cl^- and pH with elapsed period in (a) open dump lysimeter-A and (b) sanitary landfill lysimeter-B.

Nitrogen load in leachate: Fig. 16, the distribution of cumulative TKN load, shows a clear seasonal pattern characterized by low load in dry season and high load in rainy season. Fig. 16 illustrates the cumulative load of TKN for the collection system of open dump lysimeter-A as well as sanitary landfill lysimeter-B and C. Result reveals that during the rainy season (50-135 day of lysimeter operation), TKN load was increased rapidly with the ranging from 0.50 to 146 mg/ kg, 1 to 155 mg/ kg, and 1 to 161 mg/ kg solid waste in relation to the increasing of elapsed period from waste deposition, for the collection system of lysimeter-A, B and C, respectively. The cumulative TKN of landfill lysimeter leachate has somewhat increased from initial until end of dry season. During rainy season, the cumulative TKN of three lysimeter has quickly increased from initial until end of rainy season. Although the leachate generation for lysimeter-A is comparatively higher than lysimeter-B and C, but due to the lower TKN, the cumulative TKN load of lysimeter-A was lower compared with other counterparts i.e. lysimeter-B and C.

pH in leachate: The variation of pH against the changes of climatic condition regarding to the entire lysimeter operation is evident in Fig. 17. Fig. 17 depicts that for the operated system A_1 and A_2 of open dump lysimeter-A as well as sanitary landfill lysimeter-C, the leachate was acidic (pH below 7.0) at the initial stage during the dry season and it was remained stable until 20 days of operating period. It was shifted to alkaline (pH above 7.0) for the entire lysimeter within the operating period of 50 days in the dry season. Moreover, after 50 days in the rainy season, due to the percolating of rain water into the open dump lysimeter-A and sanitary landfill lysimeter-C for their looser conditions of cap liner as well as the higher rate of leachate production than that of sanitary landfill lysimeter-B, pH was shifted to acidic (pH below 7.0). The rainfall in this site is acidic and this change may indicate the decomposition of organic fraction of MSW in lysimeter. Very low pH (~6.14) was recorded at 95 days of A_2 system of lysimeter-A during the rainy season, indicating that lysimeter-A is in active acid forming phase. On the other side, leachate of lysimeter-B was alkaline initially (~7.38). A drop in pH was observed after 50 days, followed by also a decrease until 310 days for entire lysimeter system. Although the MSW in lysimeter-B, produced leachate of alkaline nature, after rainfall and at 290 days, neutral activity occurs reducing the pH equal to 7.0, then, stimulated acidogenic activity reducing the pH below 7.0. Chian and Dewalle [7, 24] have reported that pH in leachate increases with time due to the decrease of VFA in the system.

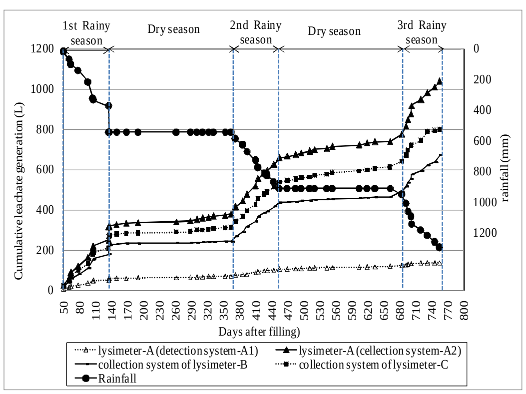

Fig. 13: Relationship between rainfall and cumulative leachate production from landfill lysimeter.

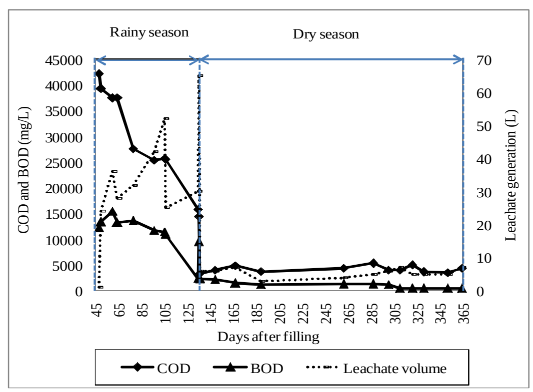

Fig. 14: Relationship between leachate quantity, COD and BOD of open dump lysimeter-A.

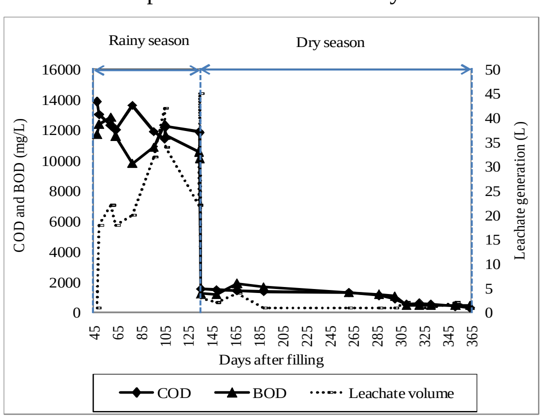

Fig. 15: Relationship between leachate quantity, COD and BOD of sanitary lysimeter-B.

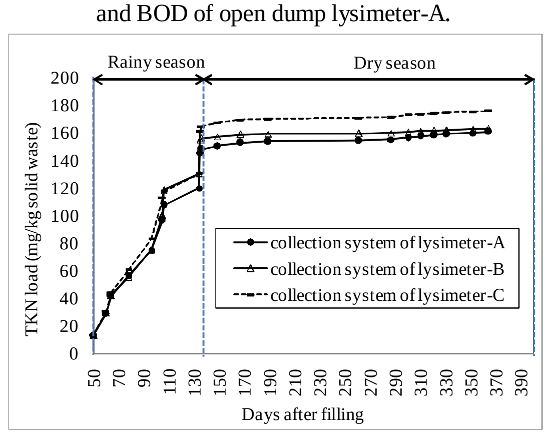

Fig. 16: The cumulative TKN of open and sanitary landfill lysimeter

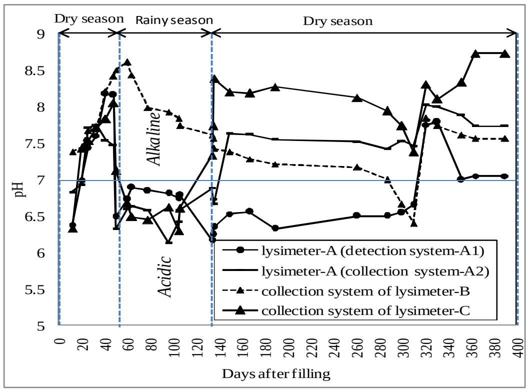

Fig. 17: Temporal variation of pH in leachate of open and sanitary landfill lysimeter

CONCLUSION

Open dump lysimeter had the lowest TKN concentration and load, NH_4-N and DOC while COD and BOD_5 concentration was higher compared with sanitary landfill lysimeter. Result reveals that metal concentrations which were comparatively higher in leachate of open dump lysimeter were Ca and K, however, the heavy metal concentrations of Cd, Cu, Zn and Mn, and those apparently lower were metals of Na, Mg and Fe as well as heavy metals of Cr, Pb and Ni. The highest degradation of MSW occurred during the rainy season and lowest during the dry season due to lack of moisture in lysimeter. Low leaching actions during dry season resulted in a smaller volume but high-strength leachate quality. Finally, it can be concluded that the knowledge of leachate quality will be useful in planning and providing remedial measures of proper liner system in sanitary landfill design and leachate treatment.

ACKNOWLEDGEMENT

The author gratefully acknowledged the financial support provided by European Commission through the project of EU-Asia Pro Eco II Programme (ASIE/2006/122-432) for the project of Waste Safe II.

REFERENCES

1. Tubtimthai, O., 2003. Landfill lysimeter studies for leachate characterization and top cover methane oxidation. Master Thesis, AIT, School of Env., Resources and Development, Thailand, pp 4-5.
2. Tränkler, J., C. Visvanathan, P. Kuruparan, and O. Tubtimthai, 2005. Influence of tropical seasonal variations on landfill leachate characteristics-Results from lysimeter studies. Waste Management, 25(10): 1013–1020.
3. Davis, M.L. and D.A.Cornwell, 1998. Introduction to environmental engineering: 3rd ed. New York, McFraw-Hill International, ISBN 0-07-115237-4.
4. Rafizul, I.M., M. Alamgir, E. Kraft, and G. Haedrich, 2009. Characterization of leachate generated from MSW in landfill lysimeter, Proc. of Sardinia 2009, 12th Int. WM and Landfill Symp., Cagliari, Italy.
5. Horing, K., I. Kruempelbeck, and H.J. Ehrig, 1999. Long term emission behaviour of mechanical-biological pretreated MSW. Conf. Proc. SARDINIA 99, 7th Int. Landfill Symp., Cagliari, Italy.
6. Rafizul, I.M., M. Alamgir, and M.M.Islam, 2011. Evaluation of contamination potential of landfill lysimeter using LPI. 13th Int. Waste Manag. and Landfill Symp., SARDINIA 2011, Cagliari, Italy.
7. Chian, E.S.K. and F.B. DeWalle, 1976. Sanitary landfill leachate and their treatment. Journal of the Environmental Engineering Division, 102(2): 411-431.
8. El-Fadel, M., E. Bou-Zeid, W. Chahine, and B. Alayli, 2002. Temporal variation of leachate quality from pre-sorted and baled MSW with high organic and moisture content. Waste Management. 22: 269–282.
9. ASTM, 2004. Annual Book of ASTM Standard: Soil and Rock (1). D420-D49; 14.V04.08-04.09, Section 4.
10. Roehl, K.E., 2007. Internal report of external experts of WasteSafe II project. EU- Asia Pro Eco II Programme of EC, Dept. of CE, KUET.
11. Austrian Standard (S 2023). Analytical methods and quality control for waste compost, composting technical standards committee 199 and also standard groups S 3 and US 2.
12. APHA, 1998. Standard methods for examination of water and wastewater, 19th ed., Prepared and published jointly by APHA, AWWA and WEFP, Washington, DC.
13. Robinson, H.D., K.B.D. Knox, and A. Picken, 2005. Leachate quality from landfill MBT waste. Waste Management, 25: 383-391.
14. Cossu, R. and R.D. Rossetti, 2003. The PAF Model: an integrated approach for landfill sustainability. Waste Management, 23: 37–44.
15. Bulent, I., I. Yuzo, Y. Masato, O. Yusaku, and N. Masanao, 2007. Heavy metal leaching from aerobic and anaerobic landfill bioreactors of co-disposed municipal solid waste incineration bottom ash and shredded low-organic residues. Journal of Hazardous Materials, 141: 793–802.
16. Reinhart, D.R. and C.J. Grosh, 1998. Analysis of Florida MSW landfill leachate quality. Florida Center of Solid and Haz.Waste Mag. Gainesville, FL.

17. Bozkurt, S., L. Moreno, and I. Neretnieks, 1999. Long term fate of organics in waste and its effect on metal release. Science of the Total Environment, 228(2): 135-152.
18. Hantsch, S., B. Michalzik, and B. Bilitewski, 2003. Different intensities of aeration and their effect on contaminant emission via the leachate pathway from old landfill waste: a laboratory study, in: Proceedings of the Ninth International Symposium on Waste Management and Landfill, Cagliari, Italy.
19. Jensen, D.L. and T.H. Christensen, 1999. Colloidal and dissolved metals in leachates from four danish landfills. Water Research, 33(9): 2139–2147.
20. Bilgili, M.S., A. Demir, M. Ince, and B. Ozkaya, 2007. Metal concentrations to simulated aerobic and anaerobic pilot scale landfill reactors. Journal of Hazardous Materials, 145: 186-194.
21. Visvanathan, C., J. Trankler, P. Kuruparan, and Q. Xiaoning, 2002. Influence of landfill operation and waste composition on leachate control: lysimeter experiments under tropical conditions. 2^{nd} Asian Pacific Landfill Sym., Seoul Korea, Session: 4.
22. Robinson, H.D. 1989. Development of methanogenic conditions within landfills. Conf. Proc. SARDINIA 89, 2^{nd} Int. Landfill Symp., Cagliari, Italy.
23. Kjeldsen, P., M. Barlaz, A. Rooker, A. Baun, A. Ledin, and T.H. Christensen, 2002. Present and long term composition of MSW landfill leachate: A Review. Critical Reviews in Environmental Science and Technology, 32(4): 297-336.