Asian Journal of Water, Environment and Pollution, Vol. 7, No. 1, pp. 107-112.

Influence of Solid Waste Disposal Conditions on Organic Pollutants Discharged from Tropical Landfill

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Received February 25, 2009; revised and accepted December 7, 2009

Abstract: This research was carried out to determine the influence of landfill design and operating conditions on organic loading from leachate of municipal solid waste landfill operating in the tropics. Several factors were investigated including waste composition, compaction density, rainfall intensity, leachate re-circulation and accumulation of leachate in the waste cell. Laboratory scale lysimeters filled with urban wastes in Thailand were used to represent typical landfill conditions in Asian developing countries. Tropical condition was simulated by adding rainwater to the lysimeters where the precipitation rate was varied between 35 and 100% of maximum rainfall intensity. The collected leachate samples were determined for chemical characteristics. Leachate re-circulation was practiced to investigate incremental leaching of pollutants along the waste depth. Other lysimeters were operated with internal storage (saturation) condition. The experimental results revealed that the organic pollutant load increased with increasing rainfall intensity and substantially decreased from low compaction density (220 kg/m^3) in open dumping to high compaction density (450 kg/m^3) in sanitary landfill condition. Total organic pollutant load in water storage condition was considerably higher than conventional operation, but it was completely retained within the waste cell.

Key words: Landfill, leachate, monsoon, solid wastes, organic pollutant, tropical climate.

Introduction

Landfill plays an important role in integrated solid waste management. The current landfilling situation in Asia constitutes various problems related to geographical and climatic differences, along with the waste composition and improper waste management. The significant environmental impacts of landfill create detrimental effects to air, water, and soil environment (Kolsch and Ziehmann, 2004). The generation tendency of MSW in Asian countries is also increasing with time (ARRPET, 2004). If such condition is recklessly unattended, it may lead to environmental conflicts. Nevertheless, when solid waste management conditions reach critical position, there is often a tendency to implement a typical western approach to overcome the existing problem in waste management. This approach is generally applied uncritically and rapidly resulting in the malfunctioning and inefficient management of waste treatment and disposal facilities (Bodelius and Rydberg, 2000). Importantly, geographic and climatic differences need to be considered in improving landfill design and operation. The urgent transition from traditional landfill (open dump approach) to engineered sanitary landfills has to be successfully managed in Asian context. Therefore, the design of an appropriate landfill technology demands for a comprehensive approach, followed by an optimized design and the adaptation of cost effective locally available technologies (Visvanathan et al., 2002).

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When considering leachate generation and its characteristic in a landfill, the influence of the climate conditions on leachate formation is complex. In tropical climate, the formation leachate production after intense precipitation is generally huge and it is even greater when the waste is not well compacted (Lema et al., 1988). Consequently, it is significant to understand the effect of leachate generation and its characteristics due to local climate conditions in the region where the landfill is to be designed and operated.

In this research, several landfill design and operation factors affecting leachate characteristics were considered. Various solid waste disposal conditions such as open dumping and sanitary landfill of fresh wastes, landfilling of pre-treated (composted) wastes under leachate re-circulation or water accumulation within the waste cell were evaluated in terms of leachate quantity, organic pollutant leaching and waste characteristics.

Methodology

Experimental System

The experiment was conducted in the laboratory scale lysimeters of 1 m in height and 0.2 m in diameter. In Run I, five lysimeters were used in which different rainwater infiltration rates were applied. The rainfall intensity in each lysimeter was varied at different percentage of maximum intensity obtained from the historical rainfall data in Thailand. All lysimeters were operated with leachate recirculation once a week except one lysimeter with internal storage. All lysimeters were filled with open dump fresh wastes. The schematic diagram of this experiment is shown in Figure 1 and the experimental conditions are described in Table 1.

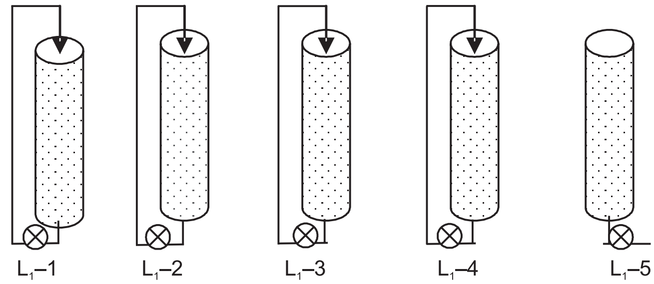

Figure 1: Schematic of lysimeter operation in Run I.

Table 1: Experimental condition in Run I

Lysimeter No.	*Operating condition*	*Re-circulation rate (% of max. rainfall)*
L_1-1	Re-circulation	100
L_1-2	Re-circulation	75
L_1-3	Re-circulation	50
L_1-4	Re-circulation	35
L_1-5	Internal storage	

The second experiment was carried out to examine the effect of waste characteristics. There were six lysimeters in which two were fed with pre-treated wastes and another two with sanitary landfill wastes. These four lysimeters were operated at two different rates of maximum rainfall intensity with leachate re-circulation. The remaining lysimeters were operated with sanitary landfill wastes without plastic component and sanitary landfill wastes with internal storage. The schematic diagram of this experiment is shown in Figure 2 and the experimental conditions are described in Table 2.

Solid Wastes

Solid wastes from urban community in Thailand were shredded to about 2.5-5 cm before being placed in the lysimeters. For pre-treated wastes, solid waste was composted using windrow system for about two months. The bulk densities of open dump wastes, sanitary landfill wastes and pre-treated wastes in the lysimeters were set at 220, 440 and 650 kg/m^3 while having same physical composition. The physical and chemical characteristics of solid wastes used in this study are illustrated in Table 3.

The bulk density, porosity, field capacity (FC), moisture content (MC), total solids (TS), volatile solids

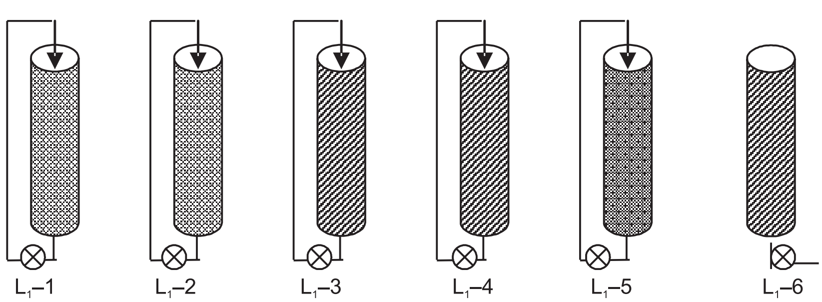

Figure 2: Schematic of lysimeter operation in Run II.

Table 2: Experimental condition in Run II

Lysimeter No.	*Type of wastes*	*Operating condition*	*Re-circulation rate (% of max. rainfall)*
L_2-1	Pre-treated wastes	Re-circulation	100
L_2-2		Re-circulation	35
L_2-3	Sanitary landfill wastes	Re-circulation	100
L_2-4		Re-circulation	35
L_2-5	Sanitary landfill wastes without plastic	Re-circulation	100
L_2-6	Sanitary landfill wastes internal storage		

Table 3: Physical and chemical characteristics of solid wastes

Parameter	*Open dump wastes*	*Pre-treated wastes*	*Sanitary landfill wastes*	*Sanitary landfill wastes w/o plastic*
Density (kg/m^3)	221	650	437	437
Porosity (-)	0.71	0.41	0.46	0.45
FC (mm/m)	744	737	694	669
TS (%)	35.72	30.36	35.72	33.46
MC (%)	64.28	69.64	64.28	66.54
Ash (%)	4.65	14.10	4.65	9.40
VS (%)	31.07	16.26	31.07	24.05
TKN (mg/kg)	25,200	34,253	25,200	17,220

(VS), ash and nitrogen (TKN) content were determined at beginning and end of the experiment (60 days period). Leachate characteristics including pH, BOD, soluble (GF/C filtered) COD, total (non-filtered) COD, NH_3 and TKN were analyzed on weekly basis. All analyses were performed according to Standard Methods for the Examination of Water and Wastewater (18th Edition).

The pollutant load from the lysimeters is determined by multiplying organic concentrations with leachate quantity. In the lysimeters with leachate re-circulation, summation of first flush pollutant load with incremental load from each re-circulation (once a week) during the entire experimental period (60 days) is used to determine total pollutant load. In submerged type lysimeter, the pollutant concentration in retaining water at the end of experimental period was multiplied by total water volume to determine total pollutant load. For comparison purpose, specific pollutant load expressed in terms of total pollutant per weight of dry waste mass was used.

Results and Discussion

Effect of Leachate Re-circulation Rate on Pollutant Load

Figure 3 illustrates the variation of pollutant concentrations with time. It was found that the pollutant concentration increased along the experimental period and became relatively constant towards the end of experiment for COD, NH_3 and TKN. Meanwhile, BOD concentration reached a plateau after 3-5 weeks and reduced afterwards. pH in leachate from the lysimeters was found varied between 5.3 and 7.0 except in L_1-5 where it maintained relatively constant at 5.3-5.4. The concentrations of BOD, COD, NH_3 and TKN in L_1-1 to L_1-4 were found to be in the same order but significantly higher than those of L_1-5. These results suggest that the rainfall intensity did not affect the concentrations of pollutant in leachate. Nevertheless, when the wastes were allowed to submerge under stagnant water, the organic concentration in leachate was lower than those in leachate re-circulation case.

Cumulative BOD, soluble COD, total COD, NH_3 and TKN loading from the lysimeters during the experimental period were calculated as shown in Table 4. The results reveal that the higher the re-circulation rate, higher the pollutants discharged from the lysimeters. This was mainly due to higher water flow rate which helped increasing hydrolysis rate and leaching of organic substances from the waste matrix into water soluble form. Even though the concentration of pollutants was found lower in internal storage condition, the total pollutants load was much higher than all the re-circulation cases because of largest amount of leachate produced. Nevertheless, these organic pollutants will not be discharged off the site but retained within the waste cells if total storage capacity in the waste cell was not

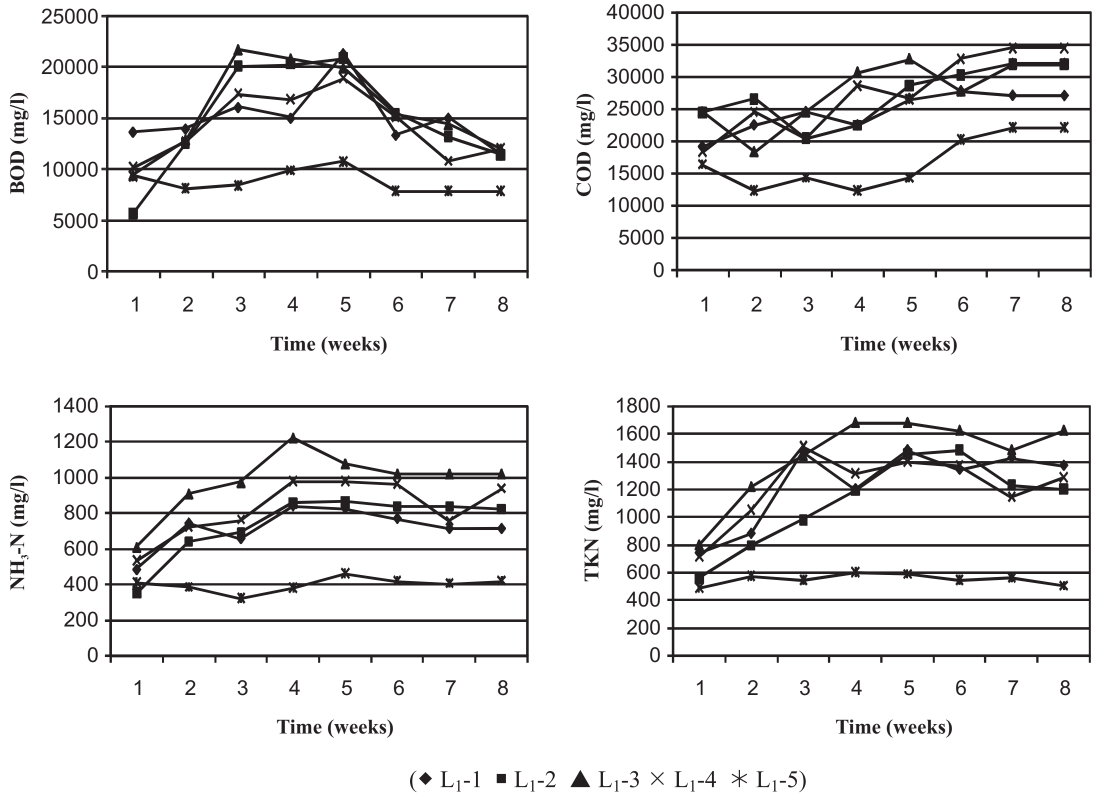

Figure 3: Pollutant concentrations in leachate from the lysimeters.

Table 4: Total pollutant load from lysimeters over 60-days operation in Run I

Lysimeter No.	*Leachate amount (% of inflow)*	*Specific pollutant load (g/kg dry waste mass)*				
		BOD	*sCOD*	*COD*	*NH_3*	*TKN*
L_1-1	24	13.20	21.24	25.77	0.70	1.35
L_1-2	20	10.32	16.43	21.26	0.58	0.85
L_1-3	13	7.50	11.45	15.65	0.53	0.80
L_1-4	12	6.82	9.62	14.56	0.43	0.64
L_1-5	88	79.9	126.1	227.0	2.30	2.33

Table 5: Physical and chemical characteristics of solid wastes after 60 days in Run I

Parameter	*L_1-1*	*L_1-2*	*L_1-3*	*L_1-4*	*L_1-5*
Density (kg/m^3)	403	377	375	349	450
Porosity (-)	0.41	0.45	0.45	0.47	0.38
FC (mm/m)	757	745	795	776	730
TS (%)	24.49	28.18	22.9	24.04	26.99
MC (%)	75.51	67.92	77.1	75.96	73.01
Ash (%)	3.4	4.05	4.47	3.76	4.08
VS (%)	21.09	21.34	18.43	20.28	22.91

exceeded. The determination of leachate quantity from the lysimeters suggested that 12-24% of rainfall input was transformed into leachate in conventional landfill but as high as 88% was generated during internal storage operation.

Table 5 reveals that moisture content in solid wastes at the end of experiment increased when compared to its initial value. Substantial increase in density was also observed along leachate re-circulation and internal storage operations. The porosity in waste matrix decreased with increasing leachate recirculation rate and the lowest value was recorded under internal storage condition. But there was slight increase in field capacity when compared with its initial value in all lysimeters except under internal storage condition.

Effect of Waste Characteristics on Pollutant Loading

From the experimental results obtained from lysimeter with leachate re-circulation, pollutant concentration was found highest in sanitary landfill wastes with 100% re-circulation rate (L_2-3) followed by sanitary landfill wastes without plastic (L_2-5) and sanitary landfill wastes with 35% recirculation (L_2-4) respectively. Similar to the first experiment, the pollutant load was found highest under internal storage condition (L_2-6) as water quantity drained from the lysimeter was largest. It was also noticed that the pollutant concentration gradually increased and reached plateau in those lysimeters while pH in leachate was maintained relatively constant (5.4-5.6). In case of pre-treated wastes, a decreasing trend of BOD and COD concentration was observed while pH was ranging 7.3-7.8. No effect of leachate re-circulation rate on BOD and COD concentration was clearly observed in this pre-treated wastes cases. For internal storage condition, pollutant concentration maintained relative constant along the experiment and pH was maintained between 5.2 and 5.4.

Cumulative BOD, COD, NH_3 and TKN loading from the lysimeters along the experimental period are shown in Table 6. Lowest pollutant load was obtained from lysimeters filled with pre-treated wastes. This observation is in accordance with previous studies (Leikam and Stegmann, 1999; Tränkler et al., 2005). Higher leachate re-circulation rate yielded higher pollutant load. Higher specific pollutant load was obtained in open dump wastes (L_1) as compared to sanitary landfill wastes (L_2) mainly due to the production of larger leachate volume. Lower pollutant loading was observed from sanitary wastes without plastic as compared to the mixed wastes at 100% leachate re-circulation rate even though larger quantity of leachate was formed when the wastes did not contain plastic content. Among all experimental conditions in Run II, highest loading was observed under internal storage condition. However, the pollutants were contained within the waste cells and not discharged off the site.

Water balance determination suggested that 10-31% of rainfall input was transformed into leachate for pre-treated wastes, 5-15% for sanitary landfill wastes, 19% for sanitary landfill waste without plastic and 67% for internal storage conditions respectively. Comparing between low compaction (open dump) and high compaction (sanitary landfill) wastes, it was found that considerably less amount of leachate was formed in sanitary landfill due to low permeability properties of the waste layer.

Table 7 shows that moisture content in solid wastes increased when compared to initial value for sanitary landfill wastes with and without plastic and pre-treated

Table 6: Total pollutant load from lysimeters over 60-days operation in Run II

Lysimeter No.	*Leachate amount (% of inflow)*	*Specific pollutant load (g/kg dry waste mass)*				
		BOD	*sCOD*	*COD*	*NH_3*	*TKN*
L_2-1	31	0.01	0.40	0.58	0.002	0.007
L_2-2	10	0.02	0.54	0.77	0.008	0.012
L_2-3	15	8.90	16.02	18.65	0.69	0.87
L_2-4	5	6.58	12.77	13.78	0.45	0.61
L_2-5	19	7.51	13.05	14.61	0.58	0.71
L_2-6	67	37.46	47.35	52.61	4.30	5.16

Table 7: Physical and chemical characteristics of solid wastes after 60 days in Run II

Parameter	*L_2-1*	*L_2-2*	*L_2-3*	*L_2-4*	*L_2-5*	*L_2-6*
Density (kg/m^3)	697	698	565	561	552	627
Porosity (-)	0.38	0.4	0.32	0.35	0.42	0.32
FC (mm/m)	760	765	775	794	740	726
TS (%)	26.59	27.24	31.34	26.06	26.97	25.65
MC (%)	73.41	72.76	68.66	73.94	73.03	74.35
Ash (%)	12.73	12.51	6.2	6.86	8.67	4.38
VS (%)	13.85	14.73	25.13	19.21	18.3	21.28

waste. Highest moisture content was recorded under submerged condition. Substantial increment in waste density along the operation was observed in most lysimeters except for pre-treated wastes. The porosity decreased with time and lowest under internal storage condition. Field capacity of all wastes was found increasing when compared to its initial value.

Conclusion

From the experimental results obtained, the following conclusions can be drawn:

1. Landfill design and operating conditions had significant influence on organic pollutant discharge through leachate. Rainfall intensity and leachate re-circulation rate did not significantly affect organic concentration in leachate but influenced leachate quantity and total pollutant loading from wastes.
2. Leachate re-circulation practice can help enhancing the degree of waste degradation in landfills but also increasing pollutant load discharged from the waste cell. Internal storage condition yielded highest total pollutant load but it could be well retained within the waste cells.
3. Pollutant leaching from sanitary landfill wastes was found less than open dump wastes due to less amount of leachate formed under high compaction density. Nevertheless, the pre-treated wastes with highest compaction density yielded lowest pollutant load as majority of organic substances in wastes has already been stabilized. The separation of plastic component from wastes prior to landfill also reduced total pollutant load from the waste cell.

Acknowledgement

This research work was carried out under Asian Regional Research Programme on Environmental Technology, funded by Swedish International Development Cooperation Agency (SIDA).

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