

## **Tropical Climatic Influence on Municipal Solid Waste Landfill Dynamics -Lysimeter Studies**

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**ABSTRACT.** *Lack of base data and guidelines for designing of appropriate MSW landfills and their monitoring are some of the main problems, which are being faced by most of the Local Authorities in Sri Lanka. Therefore a lysimeter study was conducted to generate data for designing and understanding of landfill dynamics as a preliminary tool for developing sanitary landfills with appropriate Municipal Solid Waste(MSW) landfill guidelines.*

*Three pilot-scale lysimeters have been constructed and used for the study. Lysimeters were filled with MSW focusing on different simulation studies of tropical climatic influence on MSW landfills. Data obtained through the leachate and settlement were used to verify the climatic influence on MSW landfills.*

*The results show that the data generated through the lysimeter studies are very useful to understand climatic influence and MSW landfill dynamics under the tropical climatic conditions. The compaction density, status of moisture and pre-treatments are some of the critical parameters influencing the water balance of the MSW landfill. The stabilization of MSW landfill under tropical climatic conditions is comparatively higher than reported values of other regions. After three and half months of operation of open dump lysimeter, the BOD<sub>5</sub> concentration has fallen to 2500mg/l. The degree of compaction, moisture content and nature of the MSW are the controlling factors on physical settlement. Loosely compacted landfill lysimeter gave greater settlement (22.18%) after 175 days of operation. Pre-treatment and high compaction can reduce post-closure settlement of MSW landfill. However, to understand the climatic influence on settlement characteristics, long-term monitoring is essential.*

### **INTRODUCTION**

Management of waste, both liquid and solid has become a critical environmental concern particularly in the more urbanized areas of Sri Lanka. With growing quantities of waste materials and changing consumption patterns, the volume of solid waste has exceeded the present capacity for adequate and effective waste management. The best estimate shows that the total waste generation in Sri Lanka is around 6400 tons per day (MOFE, 1999).

Open Dump (OD) approach is an adapted method, which is being practiced by the Local Authorities for disposing of Municipal Solid Waste (MSW), creating considerable nuisance and environmental problems. Under the Open dumping practice, solid wastes are disposed haphazardly. This practice does not protect the environment as

MSW is susceptible to open burning, and is exposed to the elements of disease vectors and scavengers. The problem is further aggravated due to the dumping on marshes and lowlands resulting in contamination of surface and ground water. It was found that the 41 existing disposal sites in the Greater Colombo Area are all open dumps with the exception of one site where market waste is buried in trenches. None of the open dumpsites are engineered to minimize or control pollutants released from waste due to high cost involved. Therefore, there are many impacts on water resources, land, health and bio-diversity. Under these conditions there should be careful attention on sanitary waste disposal methods.

Lack of base data for designing of appropriate guidelines for MSW land filling and their monitoring are the biggest problems, which are being faced by most of the Local Authorities in Sri Lanka. Therefore this lysimeter study is an attempt to generate and understand the design criteria through interpretation and analysis of different interactive parameters. This will lead to a greater understanding of the landfill dynamics as a preliminary tool for developing appropriate MSW landfill design guidelines.

## **MATERIALS AND METHODS**

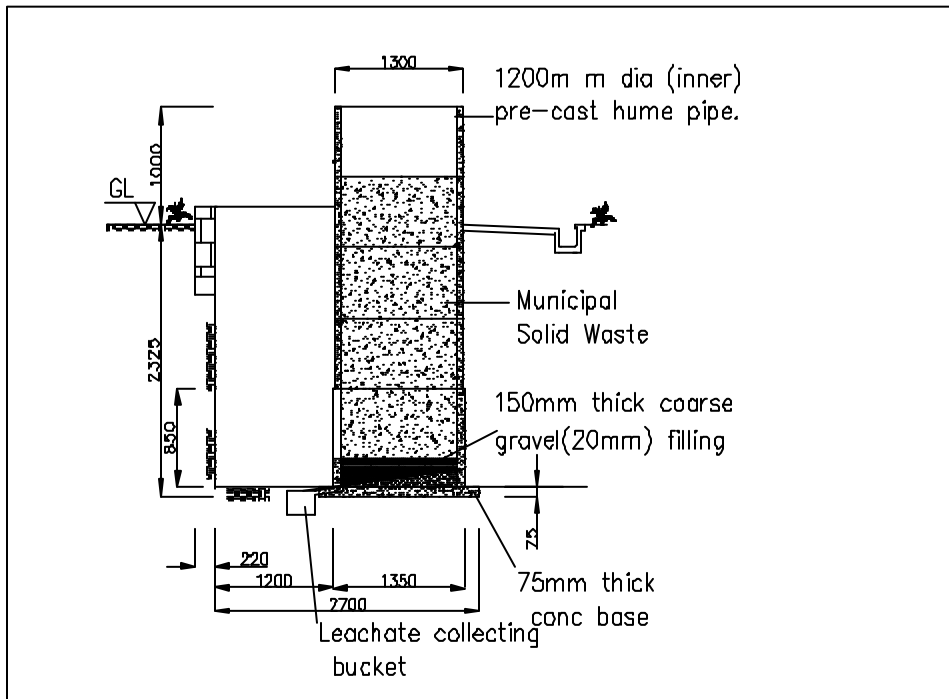
Municipal Solid Waste landfill lysimeter simulation studies were conducted at Meewathura research unit, Peradeniya University, Sri Lanka. Three constructed lysimeters have been used for the study. Plate 1 shows the technical details of the constructed lysimeters. The lysimeters were built of concrete rings with the diameter of 1.3 m, depth of 2.32 m below the ground level and 1m above the ground level. The joints in same level of each lysimeter were connected together by a horizontal concrete layer to prevent future displacement due to compaction of waste. Gravel pack was laid at the bottom of the lysimeter to facilitate filtration of leachate and their movement. The bottom of the lysimeters was constructed with a slope towards front side. At the end of the slope leachate-collecting pipe with a valve was embedded. In the front side of the bases, doors (60cm x 75cm) were built and sealed well using a rubber beading to prevent outward movement of gas and leachate.

### **Filling the Lysimeters**

Lysimeters were filled with MSW focusing on different simulation studies of tropical climatic influence on MSW landfills. The collected MSW was sorted manually to remove large sized polythene, plastics and other non-biodegradable materials. The columns of first and third lysimeter were filled with known weight of the sorted MSW. Second lysimeter was filled with pretreated (composted) MSW. Table 1 shows in detail the conditions applied for all lysimeters.

**Table 1. Different simulation studies of MSW landfill.**

Description	Lysimeter1	Lysimeter2	Lysimeter3
Treatment	Open Dumping	Pretreated Sanitary landfill	Landfill
Type of the waste	Fresh MSW	Composted MSW	Fresh MSW
Composition	Organic 89%, Plastic & polythene 6.34%, glass 0.52%, tin 0.56% Clay 3.32%		Organic 81%, Plastic & polythene 12.8%, glass 3.0%, tin 0.2% , Clay 3.0%
Moisture content	50-60%	25-30%	55-65%
Density	940kg/m <sup>3</sup>	1007kg/m <sup>3</sup>	756kg/m <sup>3</sup>
Top cover design	No	Compacted topsoil - 10 cm	Compacted topsoil - 10 cm



**Plate 1: Municipal Solid Waste Landfill Lysimeter construction details.**

## RESULTS AND DISCUSSION

### Ambient boundaries

Fig.1, demonstrates temporal variation of temperature and rainfall at the experimental premises from April, 2003 to December, 2003. There is a significant temporal and spatial variation in the island climate. Kandy is served by two seasonal monsoons, namely North East (October to January) and South west (March to August), and also by inter-monsoons. The dry periods of the year starts from second half of January to first half of March. Wet period starts from April to July (r1) and August is also a dry period (d2). The wettest period of the year is October to November (r3). However during the study period an unexpected drought was experienced in June (d1). The average annual rainfall was more than 2500mm. Annual average temperature was about 28°C.

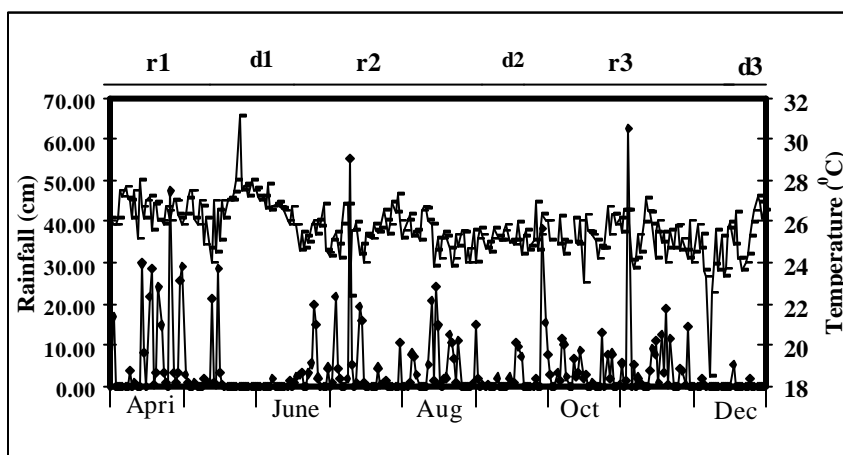


Fig. 1. Temperature and rainfall variation at the experimental site.

### Leachate generation

Leachate in MSW landfill is contaminated liquids that contain a number of dissolved or suspended materials. Generally the leachate generated in MSW landfill is based on the available moisture above field capacity. The squeezed leachate after land filling is called 'Primary Leachate' which is generated as a result of the expulsion of liquid form the waste due to its own weight or compaction loading. Later, secondary leachate is generated due to the balance of initial moisture content of MSW, water generated due to biological and chemical reactions and percolation of rain water through the landfill (Qian *et al.*, 2001). Cumulative leachate flow through each of the lysimeters and their relationship with rainfall are shown in fig. 2.

Just after few days of filling OD lysimeter, it was observed that a higher amount of leachate was generated (primary leachate) compared to the other two lysimeters. During this period there were very few rainfall incidents. Afterwards heavy rainfall incidents (r1) influenced the system and a notable amount of leachate was collected from OD lysimeter.

During the unexpected dry period in June (d1) the rate of leachate generation was very low. Generally the pattern of leachate generation from the OD lysimeter was highly correlated with the pattern of rainfall. Throughout the monitoring period of OD lysimeter, the cumulative generation of leachate was well above the cumulative amount of rainfall water.

Generation of the primary leachate from both LF and PT lysimeters were comparatively less than that from the OD lysimeter. However the effect of rainfall incident on leachate generation was visible but the effects on both PT and LF lysimeter were comparatively less than that on OD lysimeter. Considering the long-term behaviour for generation of secondary leachate, PT lysimeter did not show a direct relationship with rainfall incidents of the experimental site.

According to the Koerner and Daniel (1997), and Reinhart and Townsend (1998), the quantity of leachate production is affected by many factors such as precipitation, type of site, ground water intrusion, surface water infiltration, waste composition, moisture content, density of waste, climate, evaporation and evapotranspiration, gas production, final cover design and surface flow pattern. The precipitation represents the largest single contribution to the production of leachate. However, effect of rainfall on leachate generation depends on rainfall pattern and surface characteristics of cover design. Applied surface cover on both PT and LF must have resulted in the reduction of percolation significantly by evaporation. The low permeability barrier of the interface between soil and wastes reduces percolation. Further higher rate of leachate generation in OD could be attributed to the condition of the waste such as moisture content and higher placement density. Therefore it releases a large amount of pore water when squeezed at the initial stage. LF lysimeter had similar moisture contents as OD but leachate generations were comparatively less due to less placement density. The moisture state of the wastes in PT lysimeter was lower than its field capacity and the amount of leachate released was therefore less.

Fig. 3 illustrates the water balance of the OD lysimeter. Initial moisture content and the total rainfall account for 2456 litres of the OD lysimeter until December, 2003 (Table 2). At the end of 175 days, 44.9% of water has been discharged as leachate and as vapour through evaporation and 55.01% of water retained within the waste due to sorption properties of the waste. With the stability and reduction of pore spaces of the OD lysimeter, moisture sorption property of MSW changed and as a result moisture absorption percentage of the wastes reduced to 46.76% at the end of December, 2003. However, the PT lysimeter, which has a top cover, lost water as leachate and vapour that was less than that of OD and could account for 36.09 % of the total rainfall. Furthermore, waste moisture absorption percentage was very high, (63.9%). This could be attributed to higher sorption property of composted MSW. However LF lysimeter discharged a greater amount of leachate due to less placement density of MSW that facilitated percolation of rainwater through the column. This observation could be an important point to be noted in the leachate management point of view in tropical Asia where 70 to 90 % landfills account for open dumps (Kuruparn *et al.*, 2003).

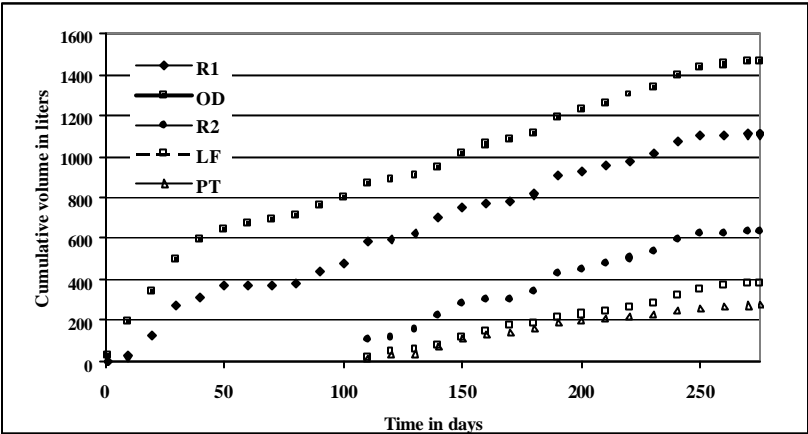


Fig. 2. The relationship between the cumulative lechate flow and rainfall

Table 2. Calculated water balance of OD, LF and PT lysimeters.

Lysimeter	Duration	W+R(l)*	E+L(l)*	S+W <sub>b</sub> (l)*
OD	175days	2456.3	1105.14(44.99%)	1351.6(55.0%)
	275days	2750.5	1464.4(53.2%)	1286.1(46.76%)
PT	175days	2940.11	1061.36(36.09%)	1878.7(63.9%)
LF	175days	2257.8	1166.9(51.68%)	1090.9(48.31%)

W=Initial moisture content, R=Rainfall, E= Evapo-transpiration, L=Leachate  
S= Sorption ,Wb= Bound water

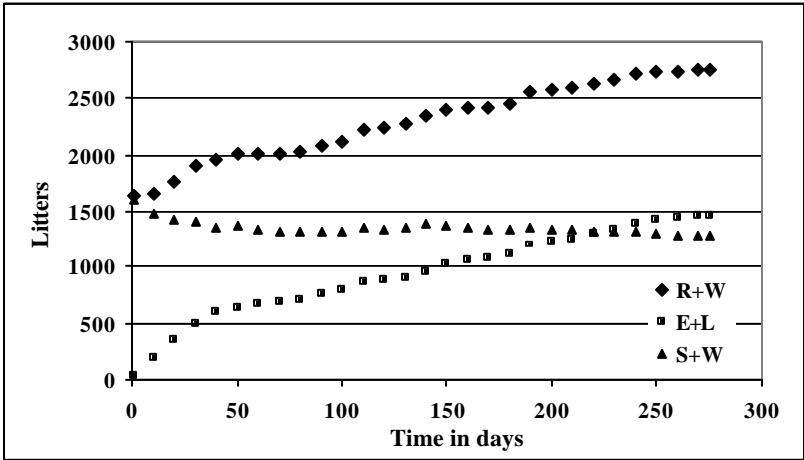
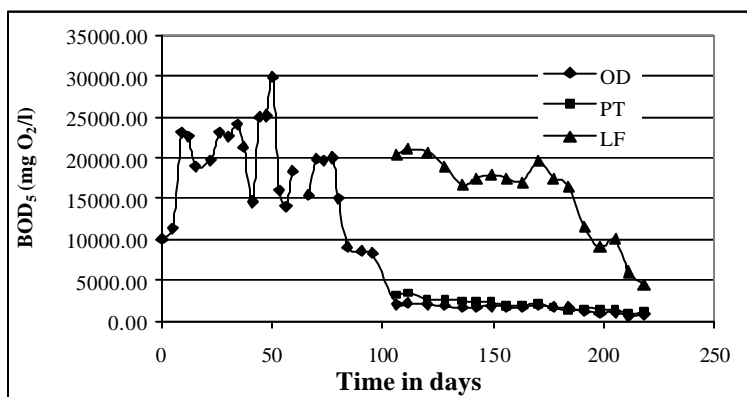


Fig. 3. Water balance of OD lysimeter plotted as cumulative values of initial moisture and rainfall (R+W) cumulative values of Evapo-transpiration and leachate (E+L) and moisture retention as sorption and bound water (S+Wb).

### Organic pollution load in leachate

Biochemical Oxygen Demand (BOD) is a measure of biodegradable organic mass of leachate and that indicates the maturity of the landfill which typically decreases with time (Qasim *et al.*, 1994), Chain and De Walle (1976) and Ehrig (1989). They have reported that BOD<sub>5</sub> value of MSW landfill leachate ranges from 3.9 to 57,000 mg/l. Fig. 4, illustrates BOD<sub>5</sub> concentrations during the monitoring of lysimeter. It shows the typical pattern of BOD<sub>5</sub> variation in Landfill leachate. OD and LF lysimeters show the highest concentrations of organic pollutants of the leachate during the first three months of monitoring and PT lysimeter shows the lowest value. This difference is mainly due to the stabilization of substrate during pre-treatment operation before land filling. It could be noted that the concentration of organic pollutants of leachate discharged from OD and LF had fallen down drastically and remained stable after three and half months of monitoring as shown in Fig. 4 and the BOD concentrations remained below 2500 mg/L and 5000 mg/L for OD and LF lysimeters, respectively. However stabilizing periods of both OD and LF lysimeters are very short when compared with same type of studies, which have been reported in the literature in other regions of the world (Reinhart, 1996, Kuruparan *et al.*, 2003). This was mainly due to climatic influence on MSW landfill. Higher ambient temperatures and higher average annual rainfall in tropical regions enhance both aerobic and anaerobic microbes and leads to rapid stabilization of MSW landfill.

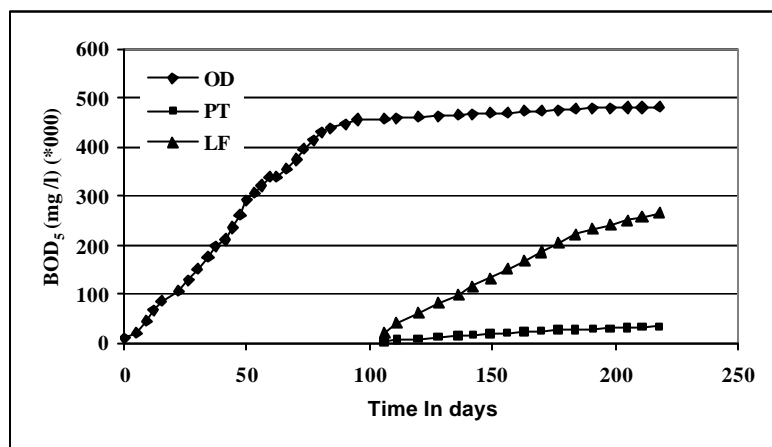


**Fig. 4. Change in BOD<sub>5</sub> concentrations with increasing age of the OD and landfill.**

Fig. 5 illustrates the cumulative variation of BOD<sub>5</sub> of the three lysimeters. Higher cumulative BOD<sub>5</sub> of OD could be attributed to higher compaction of MSW at the filling stage and lack of top cover permits the penetration of rainwater through the cell column as compared to LF lysimeter. It should be noted that higher compactions lead to anaerobic conditions that promote leachate formation. However cumulative BOD<sub>5</sub> concentration of PT lysimeter is seven times less than LF due to the effect of pre-treatment. This indicates the importance of pre-treatment of MSW prior to landfill.

## Settlements

The settlement of landfill affects the design of protection systems such as covers, barriers, and drains. The mechanisms of refuse settlement are complex because of the extreme heterogeneity of waste fill and the presence of larger voids (Qian *et al.*, 2001). The main mechanisms involved in waste settlement are mechanical compression, raveling, physical-chemical changes and biochemical decomposition (Sowers, 1973; Murphy and Gilbert, 1985; Edil *et al.*, 1990).



**Fig. 5. Cumulative variation of BOD<sub>5</sub> of three lysimeters.**

Fig. 6 illustrates cumulative settlement patterns of the three lysimeters during the monitoring period. Typical pattern of the settlements could be observed in all three lysimeters. The highest cumulative settlement during 175 day, was shown in LF lysimeter (22.18%), Whereas, PT lysimeter showed the least cumulative settlement during same time period (11.85%). The settlement % of OD lysimeter was medium (15.36%). Lower compaction density and higher void ratio of MSW in LF lysimeter contributed greater mechanical compression (distraction, bending and crushing of solid waste) and raveling (movement of finer particles in to larger voids or cavities) which results in greater primary settlement. Later reduction of waste mass by fermentation and decay, both aerobic and anaerobic processes, caused comparatively higher secondary settlement.

Pretreatment process (composting) of MSW increases the density of waste by reducing void spaces. Therefore pre-treated waste has minimum chances for mechanical compression after land filling. The secondary settlement is also very low in PT lysimeter due to limited bio-chemical decomposition. This indicates the importance of operational mode (pre-treatment prior to landfill) of MSW landfill. However to understand the influence of tropical climate (rainfall and temperature) on settlement and stabilization, mathematical expressions are required to interpret the results so that predictions could be made. Therefore further monitoring of those lysimeters are very important to understand long-term climatic influence on MSW landfill settlement and stabilization.

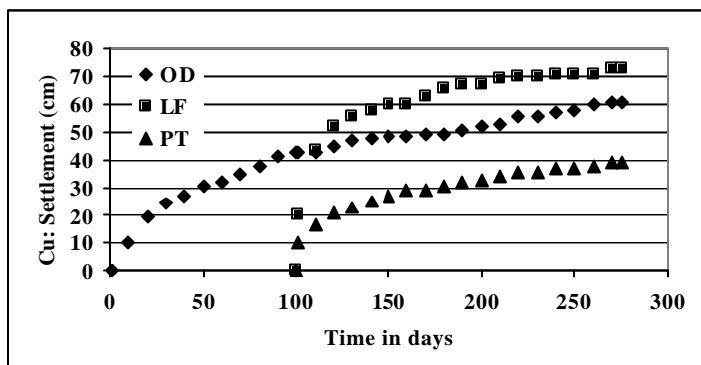


Fig. 6. Settlement Patten of different lysimeters.

## CONCLUSIONS

The data generated through the lysimeter studies are very useful to understand climatic influence and MSW landfill dynamics under tropical climatic condition which can be used as a preliminary tool for developing sanitary landfills with appropriate MSW landfill guidelines.

Leachate generation is highly influenced by the tropical climate. The generation of the primary leachate from both LF and PT lysimeters were comparatively less than the OD lysimeter. However the effect of the incident rainfall on leachate generation is visible in all lysimeters while the effect on both PT and LF lysimeters were comparatively less than that on OD lysimeter. The highest percentage of moisture lost through evaporation from LF lysimeter may be due to less compaction at the time of filling the lysimeter, whereas the highest percentage of moisture is held by the PT lysimeter. Therefore compaction density, moisture status and pre-treatments are some of the critical parameters that influence the water balance of the MSW landfill.

Based on the literature and this study, the stabilization of MSW landfill under tropical climatic conditions (high annual average rainfall) is comparatively higher than other regions. After three and half months of monitoring OD lysimeter, BOD<sub>5</sub> concentrations have fallen down to 2500mg/l from 30,000mg/l. Pre-treatment of MSW before land filling has reduced organic pollutant load on landfill leachate, which was seven times less than that of the LF lysimeter and more than seven times when compared with OD conditions.

Placement density, moisture content and nature of the MSW are the controlling factors influencing physical settlement of MSW landfill. Loosely compacted LF lysimeter gives a greater settlement of 22.18% of initial height after 175 days of operation. Pre-treatment and high compaction can reduce post-closure settlement of MSW landfill. However to understand climatic influence on settlement pattern long-term monitoring is essential. Gritical evaluation of the acquired data is needed to understand the effect of top cover on MSW landfill dynamics.

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