

Evaluation of Reactivity and Inhibitions in Developing Municipal Solid Waste Landfill Bioreactors for Tropical Climatic Conditions

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ABSTRACT. Landfill bioreactor concept is one of the novel technologies to satisfy the emergent power requirement of the world while minimizing the burden on the environment from municipal solid waste (MSW). However, performance evaluations of landfill bioreactors (LBR) studies in terms of defining failure in tropics were few. Three stages of researches in series were carried out for overcoming the shortcomings.

In stage-1, a concrete lysimeter simulating a control landfill with diameter 1.3 m and height 3.32m was constructed and filled with 2727.9 kg of MSW. Stage-2 LBR-1 was constructed with a lower height 1.8 m and loaded with 1149.6 kg of MSW to identify the leachate recirculation effects to accelerate biological activity. Stage-2 LBR-2 was constructed with similar dimensions in stage-1 control landfill and 2052.7 kg of MSW was applied to enhance gas production and identify onset of inhibitions and toxicity. Finally, stage-3 LBR "test cell" was constructed with an extent of 8.3×5.3 m² and 51,940 kg of MSW filed at a placement density of 756.3 kg/m³. Bottom liner plus capping was constructed using clay -polyethylene-clay composite layer to minimize the toxicity and outfit the conditions.

Stage-1 control landfill study explains the effect of rainfall on leachate generation and biological degradation. Stage-2 LBR-1 explains effect of leachate re-circulation and inoculation of cow dung on biological processes. Nevertheless, in LBR-2 created inhibitions and toxicity which exceeded 50,000 mg L⁻¹ Biochemical Oxygen Demand (BOD₅) and 80,000 mg L⁻¹ Chemical Oxygen Demand (COD). Finally, the LBR 'test cell' liner removed nitrate nitrogen 30.1±1.9 mg L⁻¹, ionic compounds in the system and achieved standard permeability while generating helpful renewable landfill gas.

INTRODUCTION

The rapid growth of the population and improvement of living standards have created notable pressure on the natural environment of the country. Disposal of Municipal Solid Waste (MSW) is a critical issue due to limitation of available lands in the most of the urban centers. Therefore, rehabilitation of existing open dumpsites and application of advanced

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engineering techniques in future waste disposal facilities are the most realistic approaches to resolve this problem (Nagendran *et al.*, 2006).

Selection of sites, construction, operation and monitoring of the modern landfills facilities are complex due to negative environmental impacts associated with MSW. Production of leachate and transport away from the landfill sites has lead to pollution of ground and surface water bodies (Loizidou and Kapetanios, 1993). At the same time landfill gas emissions can lead to adverse health effects and global warming. Furthermore, spread of animal and insect vectors diseases associated with MSW make open dumps unsustainable (Das *et al.*, 2002). Therefore, in order to overcome the above environmental consequences and emergent power requirements all over the world, the trend is to convert open dumps to more energy recovering landfill bioreactors.

A landfill bioreactor is a sanitary engineered landfill that uses enhanced microbiological processes to transform and stabilize the readily and moderately decomposable organic waste constituents within 5 to 10 years. Most of the research conducted all over the world are to create wet conditions in landfills by leachate recirculation (Reinhart and Townsend, 1998) and external water or treated leachate addition (Sanphotia *et al.*, 2006). Although, a higher rate of liquid application can enhance the biological degradation and gas production for energy recovery (Sponza and Agdag, 2003), during the past decades, research studies were few, lacking of performance evaluations in terms of defining failure, particularly in the tropics.

Therefore, the lack of technology of suitable bio film liners to minimize inhibitions and toxicity inside the reactors were the reasons for undertaking the task of developing landfill bioreactor (LBR) technology for tropical climatic conditions. This paper describes the research studies carried out as a series in reporting the shortcomings that took place in developing landfill bioreactors to minimize inhibitions and toxicity inside the reactor while maintaining continuous landfill gas production.

MATERIALS AND METHODS

A series of research studies were conducted in three stages. Stage-1 was lysimeter establishment as control landfill to identify landfill conditions. The stage-2 LBR-1 was constructed to identify the leachate recirculation impacts and to accelerate biological activity. Also, during stage-2, LBR-2 research was carried out to enhance gas production and identify onset of inhibitions and toxicity. Finally, in the stage-3, LBR “test cell” was established with low cost clay-polyethylene-clay liner to minimize the toxicity inside the reactor and outfit the conditions. During the third study, moisture was added continuously through leachate recirculation, precipitation to enhance, and continuous methane gas generation while facilitating rapid waste decomposition.

Simulation of controlled landfill condition at stage-1

During the stage-1, a concrete lysimeter simulating a control landfill was constructed with a diameter of 1.3 m and the height of 3.32 m. It was 2.32 m below the ground level and the rest (1.0 m) was above the ground level. To facilitate the filtration of leachate and their movement, gravel was placed at the bottom of the control landfill while maintaining a slope towards the front side. Leachate collecting pipe was installed at the end of the slope. The technical details of the constructed control landfill are given in Fig. 1.

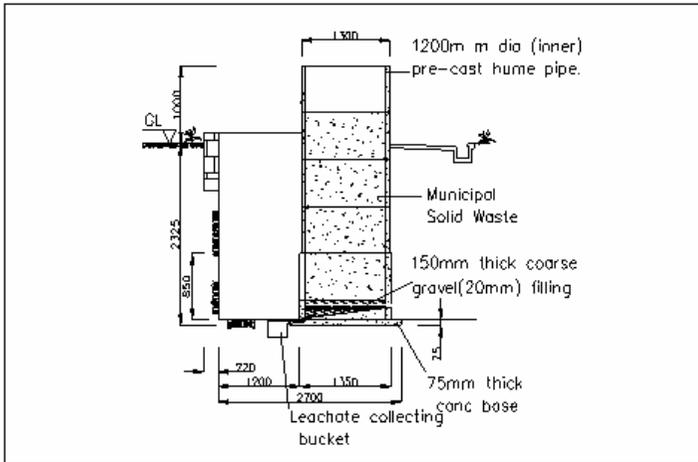


Fig. 1. Schematic view of controlled landfill established during stage-1

Simulation bioreactor landfill condition at stage-2

In stage-2, a LBR-1 was built using concrete rings with the diameter of 1.3 m and height of 1.8 m above ground. The LBR-1 was converted to landfill bioreactor by embedding perforated gas extraction pipe (0.025 m diameter with a 0.30 m thick gravel pack) and leachate collection method similar to the previous control landfill at stage-1, but a leachate recirculated system was installed. Top of the LBR-1 was covered using HDPE cover to prevent rainfall incorporation into the system. Technical details of LBR are shown in Fig. 2.

Construction of LBR-2 at stage-2

During stage-2, another LBR-2 was constructed following the LBR-1 study by modifying the capping system. The top of the bioreactor was sealed by using a steel jacket and a water barrier. The gas collection pipe was connected to the steel jacket and a condenser made out of copper spiral tube was used to facilitate the condensation of moisture in landfill gas. Leachate collection and recirculate system were installed similar to the LBR-1 study. The Fig. 3 illustrates the schematic diagram of the anaerobic LBR-2.

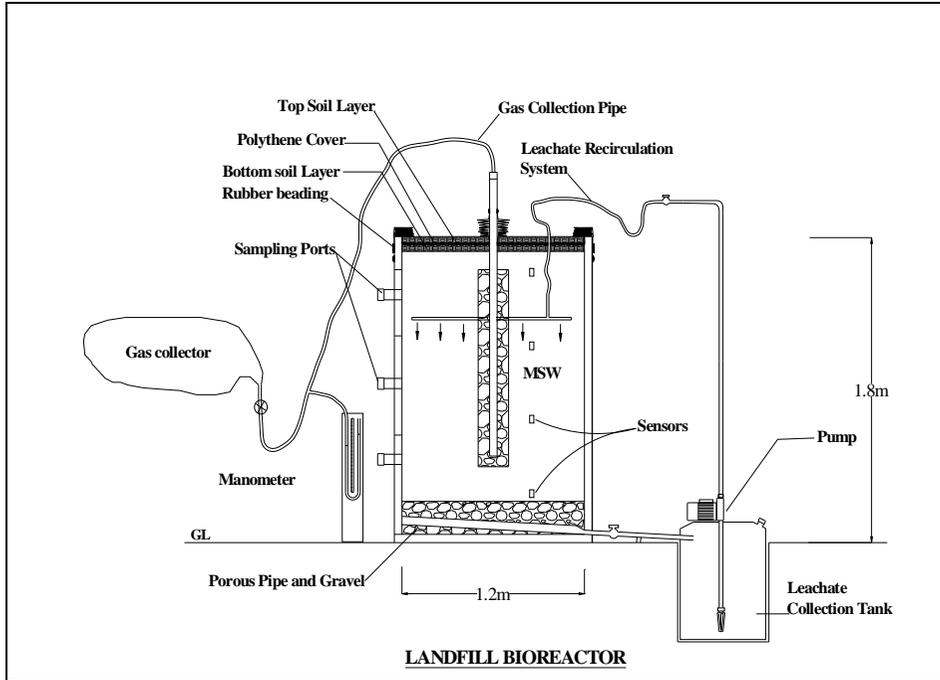


Fig. 2. Schematic view of bioreactor landfill established during stage-2

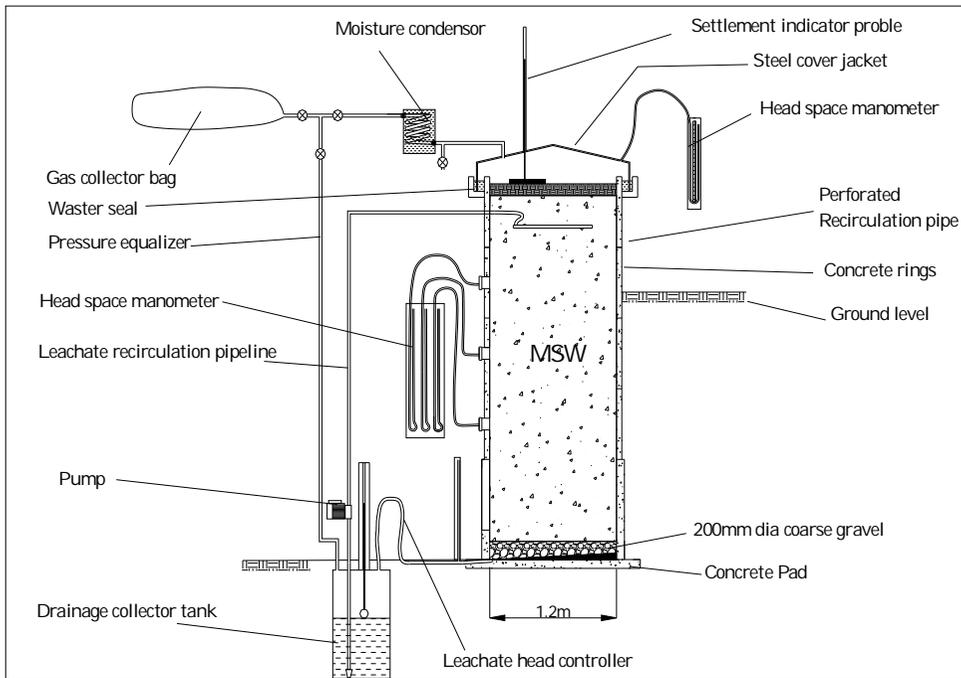


Fig. 3. Schematic diagram of the anaerobic landfill bioreactor (LBR-2)

Construction of LBR ‘test cell’ at stage-3

After getting the relevant information from the above two stages, the stage-3 LBR ‘test cell’ was constructed over a period of three months in an extent of $8.3 \times 5.3 \text{ m}^2$ with a total volume of 68.68 m^3 . Bottom liner and capping was constructed using clay-polyethylene-clay composite liners which consist of 0.05 m layers each (Gunaratna *et al.*, 2007). The low density polythene of 1000 gauge was used to prevent deep percolation, enabling collection of it to determine the quality parameters of permeate.

The weights of each waste load were obtained and the composition was noted. A total 51.94 tonnes of MSW (37.48 tonnes dry basis) were filled with an average placement density of 756.3 kg m^{-3} . Two gas extraction wells were constructed using 0.05 m perforated pipe inside the 0.3 m diameter gravel pack and leachate recirculation system was installed. After application of final clay-polyethylene-clay capping, turfing was done.

The leachate recirculation system was first operated manually and number of parameters such as leachate seeping rate, quantity of leachate recycled, rate of permeate through the composite liner and the leachate head in the reactor were measured. Then leachate recirculation system was improved and the system was automated to prevent excessive accumulation of leachate in the collection tanks. Gas was continuously extracted using diaphragm ventilator at a fixed rate of 4.2 L per min. A small torch was fabricated to combust the landfill Gas (LFG) completely. The conceptual design of landfill bioreactor test cell is shown in Fig. 4.

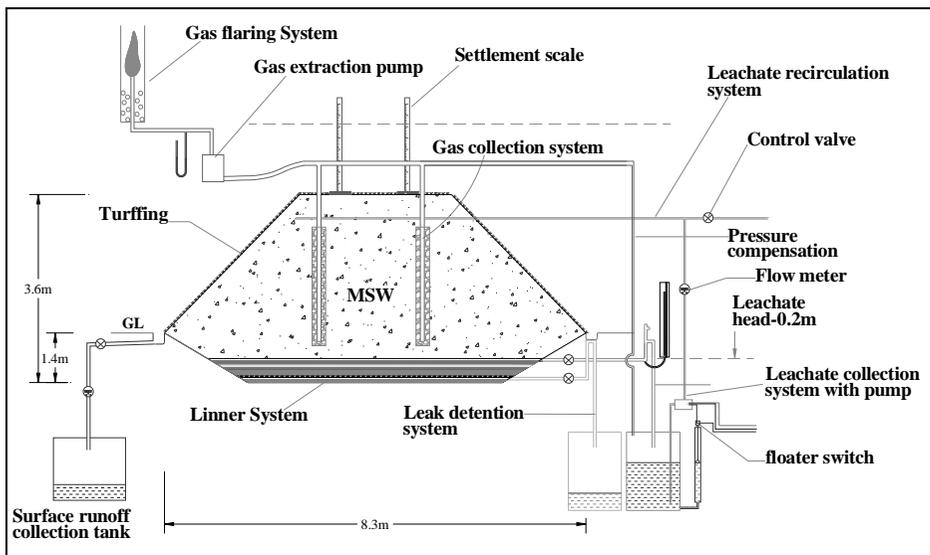


Fig. 4. Schematic view of bioreactor ‘test cell’ established during stage-3

Amount of waste used for landfill and LBR’s

Table 1 shows the summary of MSW used for the above 4 researches respectively. In each and every research, MSW composition study was carried out before loading the waste. Table 2 gives the different parameters analyzed in the above four separate researches and Table 3 gives different conditions and status of the each reactor.

Table 1. Different conditions applied for above studies.

Research	Placement density (kg m ⁻³)	Total quantity (kg)	Dry matter (%)
Stage-1 control landfill	756.0	2727.9	35.0
Stage-2 LBR-1	527.5	1149.6	34.5
Stage-2 LBR-2	580.0	2052.7	31.9
Stage-3 LBR 'test cell'	756.3	51,940.0	72.2

Table 2. Different parameters analyzed

Research	Leachate parameters	Other parameters
Stage-1 lysimeter	TS, VS	Leachate seeping rate, rainfall waste composition
Stage-2 LBR-1	BOD, COD, pH	Re-circulate amount, waste composition
Stage-2 LBR-2	BOD, COD,	Re-circulate amount, gas volume , waste composition
Stage-3 LBR 'test cell'	BOD, COD, nitrate,	settlement, gas extraction rate, permeability, waste composition

Note: TS – Total Solids; VS – Volatile Solids; BOD – Biochemical Oxygen Demand; COD – Chemical Oxygen Demand;

Table 3. Reactor status and applied different conditions

Reactor and stage	Status	Numbers of days operate	Frequency of sampling	Remarks
Stage-1 Control landfill	completed	16,07,2003 to 15,05,2008 (1772 days)	Once a week	
Stage-2 LBR-1	completed	21,07,2006 to 14,11,2006 (117 days)	daily	Cow dung added on 66th day, Lime was added on 67th day
Stage-2 LBR-2	completed	31,06.2006 to 21,06,2007 (172 days)	daily	Water added after 11 day, and 21 day
Stage-3 LBR 'test cell'	continued	From 26,03,2007	First 6 month daily then up to 365 day weekly ,then monthly	Settlement reference change after 268 days due to animal attack

RESULTS AND DISCUSSION

After conducting the above four studies sequentially, the following results were obtained. The composition of MSW in each and every study is given in Table 4.

Table 4. Composition of MSW in each Study

Composition (%)	Stage 1 <i>lysimeter</i>	Stage 2 LBR-1	Stage 2 LBR-2	Stage 3 LBR test cell
Biodegradable short term	81	44	59.8	60.2
Garden waste		-	2.2	
Paper / Cardboard		15	19.6	8.7
Fiber		13	1.7	-
Wood		1	0.5	0.5
Coconut husk, comb, shell		9	2.5	16.2
Plastic	12.8	2	1	1.4
Polyethylene		11	5.1	5.8
Metal	0.2	1	-	0.7
Glass	3	1	1	1.3
Textile	-	-	2.1	2.7
Other	3	3	4.5	2.5

The analyzed data from the composition study for the four studies show that the percentage of organic waste is more than 60% which is the general trend in the organic fraction of MSW in Sri Lanka (MENR, 2005). The waste compositions are almost similar except coconut husk, comb, and shell percentages. Therefore, input biodegradable raw materials for studies were almost same. It should be noted that, in the test cell the moisture content was very less at the time of laboratory experimentation.

Stage-1 Simulation of controlled landfill conditions

The stage-1 simulation of controlled landfill research study was conducted over four years. The quantity of leachate generation was affected by many factors such as, precipitation, moisture content and density of waste, evaporation, gas production, and final cover design. However, the precipitation represents the single largest contribution for the generation of leachate (Koerner and Daniel, 1997; Reinhart and Townsend, 1998). Leachate production due to rainfall are shown in Fig. 5. The cumulative values show the sorption properties of the wastes. Cumulative total solids (TS) and volatile solids (VS) shown in Fig. 6 have gradual increments, which show the outcome of the microbial activity in the landfill body and substrate availability in the controlled landfill.

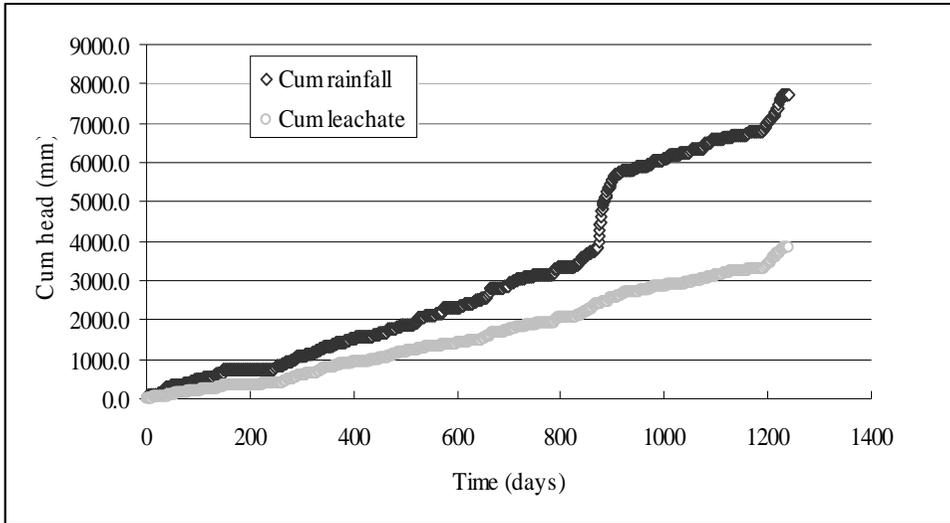


Fig. 5. Cumulative leachate and rainfall variation with time

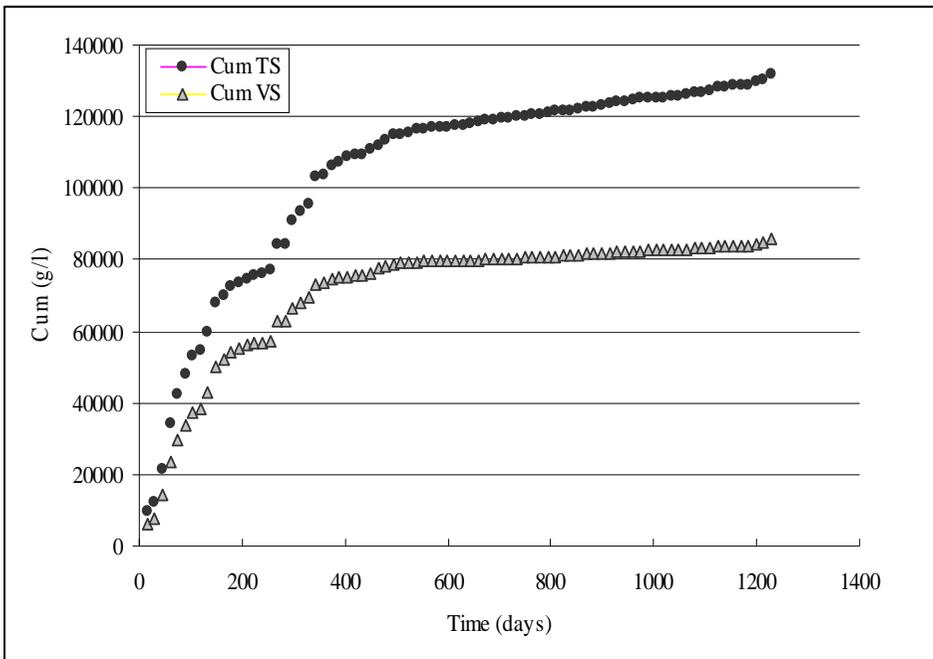


Fig. 6. Cumulative TS and VS production

Stage-2 Simulation of bioreactor landfill conditions in LBR-1

The Biochemical Oxygen Demand (BOD₅) remained more or less constant in the stage-2 LBR-1, while significant increment of Chemical Oxygen Demand (COD) occurred as shown

in Fig. 7, since dung has a high level of inorganic matter. The pH after 80 days remained in the acidic range as shown in Fig. 8, which indicates the delayed methanogenesis phase.

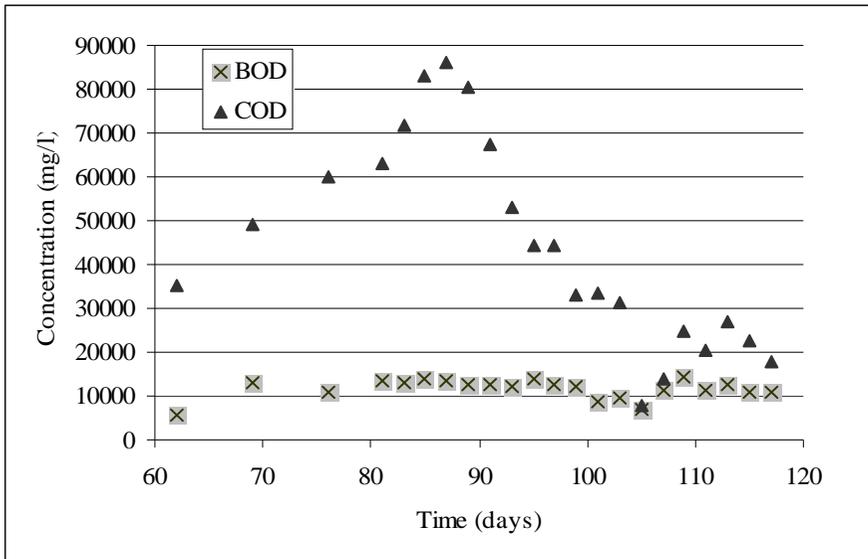


Fig. 7. BOD₅ and COD Variations in leachate from LBR-1 at stage2

Because of lime (CaCO₃) addition for pH buffer at 68 and 69 days, the pH reached to around 8 (Fig. 8). The very high COD concentrations of leachate (peaked at 86,000 mg L⁻¹) indicate its high organic and inorganic strengths. After 66 days, there were high biological activities because of cowdung inoculation and it steadily declined to 8,000 mg L⁻¹ after 100 days due to increased leachate recirculation frequency from 3 times per day to 6.

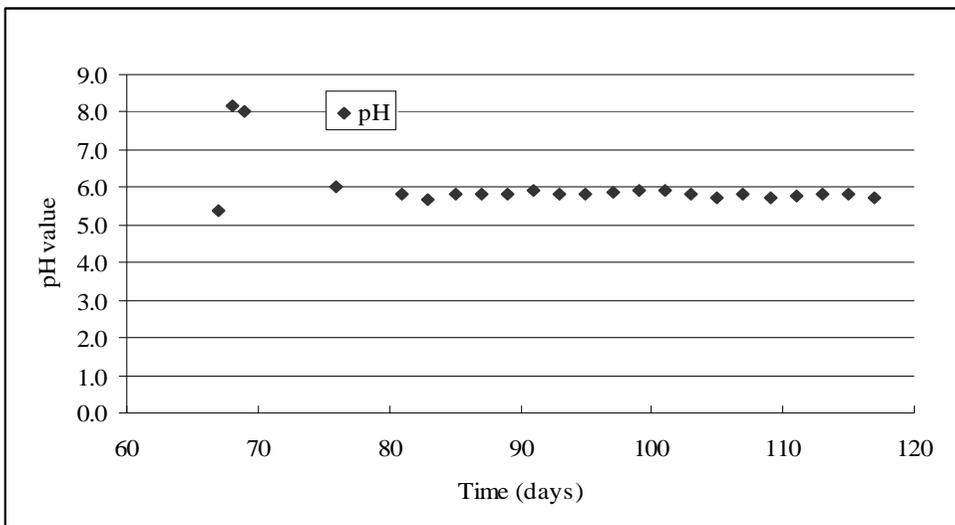


Fig. 8. pH variation in leachate from LBR-1 at stage-2

After completion of the above stage-2 LBR-1, the LBR-2 was constructed to further evaluate the performance of LBR-1 while isolating the reactor from surrounding environmental conditions such as evaporation and rainfall. Initially gas production increased with the water additions and recirculation, but after 120 days it drastically reduced (Fig. 9). At the same time, COD and BOD₅ levels increased as shown in Fig.e 10. It was convincing to observe that LBR-2 did not follow normal degradation patterns and perhaps created inhibitions. There are many supportive evidences of inhibitions and toxic reported by many authors (Dave and Nilsson, 2005; Poh and Chong, 2008).

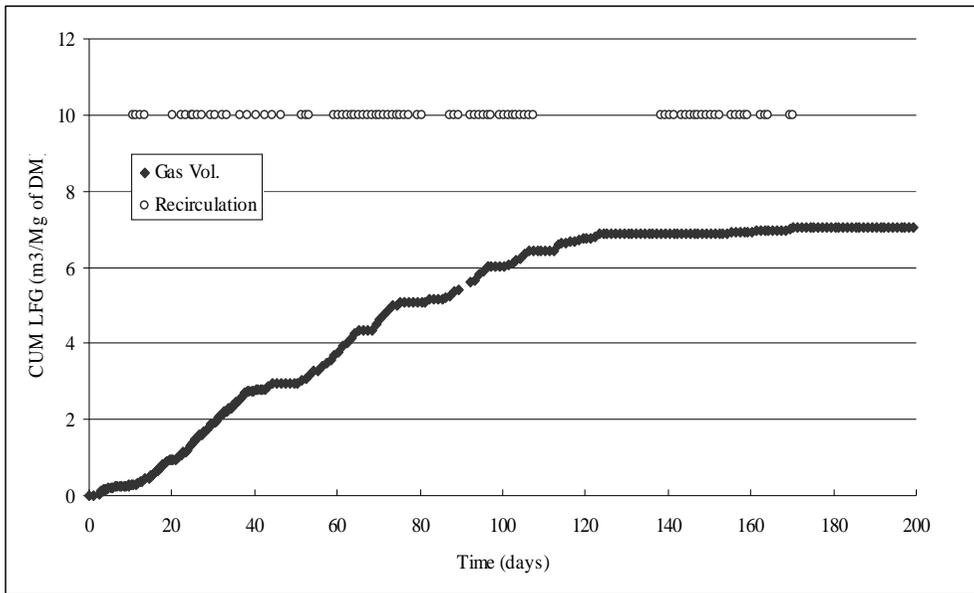


Fig. 9. Gas production and re-circulation variation with time in LBR-2

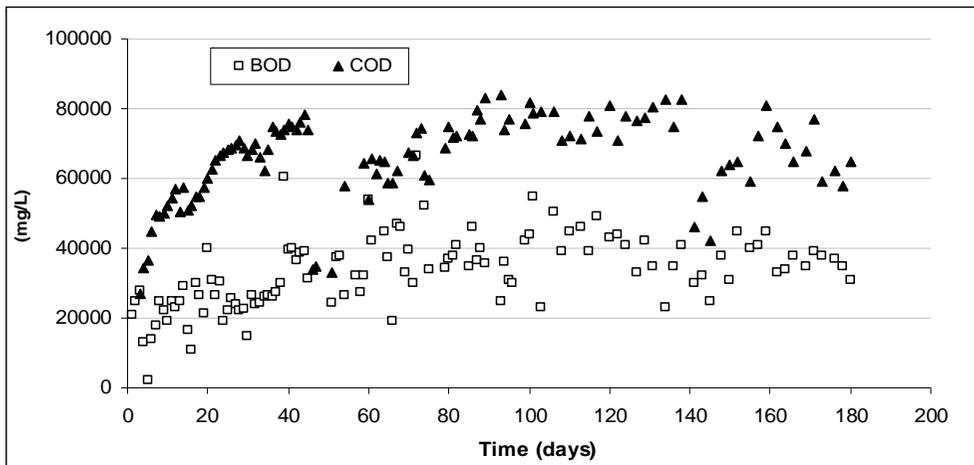


Fig.10. COD and BOD variations with time in LBR - 2

Stage 3 – Simulation of bioreactor landfill ‘test cell’

The stage-3 LBR ‘test cell’ was invented to overcome the limitations in the above stage-2 studies while maintaining continuous gas production. The forced extraction rate was 4.2 L per min. of landfill gas and it was torched to minimize the environmental pollution. The new clay-polyethylene-clay liner too eliminated pollution having permeability of 1.0×10^{-7} to 1.4×10^{-7} cm sec⁻¹ in 35.0 to 97.7 cm hydraulic range (Gunarathna *et al.*, 2007). Therefore, this liner reached the accepted standard value of 1.0×10^{-7} cm s⁻¹ (Qian *et al.*, 2002).

Fig. 11 shows BOD₅ and COD values above the liner, which recorded high values of 30,500 and 73,700 mg L⁻¹, respectively. The COD and BOD₅ drastically reduced from 73,700 to 7,000 mg L⁻¹ respectively within 90 days compared to previous studies (Fig. 11) and settlement for the same is shown in Fig. 12, where there was rapid stabilization of landfill bioreactor ‘test cell’ under tropical climatic conditions. However, the permeate which is the liquid collected after passing through the liner, even at present, maintains very low average COD values between 4-5 mg L⁻¹, indicating purification processes (Basnayake *et al.*, 2008).

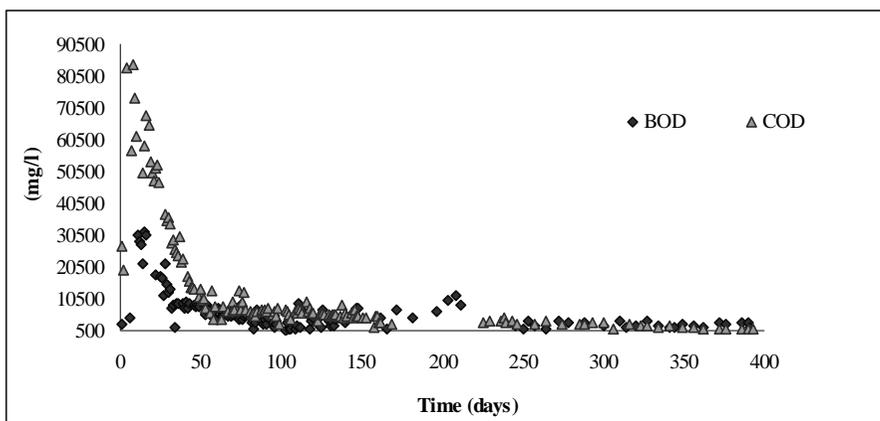


Fig. 11. Variations of BOD and COD with time

Most of the anaerobic digesters in the world have recorded high BOD₅ and COD levels due to ammonia toxicity with time of operation (Dave and Nilsson, 2005). In this LBR ‘test cell’ composite liner must have provided annamox bacterium processes to take place in the bottom of the landfill to convert ammonia to nitrate (Clabaugh 2001). The liner allowed nitrate nitrogen removal at the rate of 30.1 ± 1.9 mg L⁻¹. In fact there was an absence of ammonia throughout the experimentation showing only low levels of nitrate. Therefore, it is conclusive that the composite liner promotes annamox process that reduces ammonia toxicity in landfills under anaerobic conditions.

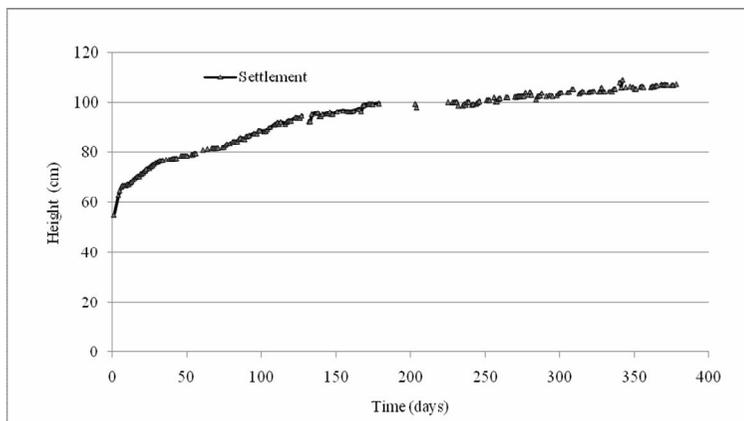


Fig. 12. Variations of settlement of wastes in LBR 'test cell'

The top cover too, certainly has had an effect on gas production. Although, it allowed water to enter the cell, it also prevented gas from escaping since moisture saturation conditions exists in cover in most instances due to frequent addition of moisture from rainfall and irrigation. The gas extraction rate was 4.2 L per min. for the initial disposal of 52 tonnes of wastes since 2007. The gas productions began very much earlier (3 months after waste filling) than reported (Pohland and Harper, 1986). Perhaps, it is the fastest rate so far for landfill bioreactors/biocells.

CONCLUSIONS

The development of MSW landfill bioreactors for tropics required simulations with a series of reactors. Stage-1 lysimeter study provided information on landfill leachate generations and biological degradation conditions under tropical precipitation conditions. It necessitated acceleration of biological processes by leachate recirculation and inoculation of cowdung in LBR-1 of the stage-2. Nevertheless under isolated conditions, LBR-2 created inhibitions and toxicity and reduced the gas production performance. Finally, the clay-polyethylene-clay liner of the LBR 'test cell' did overcome drawbacks through removing excess nitrogen and ionic compounds usually prevailing in most systems and achieving standard permeability in MSW landfill liners. This evaluation of the 'test cell' is very useful for designing landfill bioreactors to safeguard the environment for future generation and generating helpful renewable energy for emergent power requirements.

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