Chapter 14
Evaluation of Bioreactor Landfill as Sustainable Land Disposal Method

P. Lakshmikanthan, L.G. Santhosh, and G.L. Sivakumar Babu

Abstract Sustainable municipal solid waste management has become a challenge to the engineers in the present world. Good pretreatment methods coupled with landfilling are looked as sustainable means of disposal of municipal solid waste. Bioreactor landfill is one such sustainable option. In the present study two landfill simulators (dry and leachate recirculation) were used to investigate the effect of leachate recirculation on the stabilisation process of mechanically biologically treated (MBT) municipal solid waste (MSW). The simulator with a leachate recirculation had a higher degree of waste stabilisation towards the end of the experiment due to higher moisture content and micro-organisms. The results observed at the end of 380 days prevail that the process combination of above operational parameters adopted in bioreactor was a more efficient approach for stabilisation of MSW. After 1 year of operation, the residues of the simulators were analysed, and it was found that the settlement and gas production were greater in leachate recirculation simulator than the dry simulator. The carbon content reduced in the bioreactor simulator by more than 60 % compared to the dry simulator. It was also observed that the biodegradation time for MBT-MSW was reduced in bioreactor simulator compared to maximum values presented in the literature.

Keywords Municipal solid waste • Bioreactor landfill • Sustainability • Stabilisation • Landfill gas

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14.1 Introduction

Use of bioreactor landfills for landfilling is relatively new to Asian countries. Modern technology and research in the area of landfill engineering have paved way to engineered landfills and bioreactor landfills. In the engineered landfills which are often termed as conventional landfills and have inerts as main constituents, the stabilisation times are longer and bioreactors have emerged as alternatives. Bioreactor landfill is defined as a sanitary landfill operated for the purpose of transforming and stabilising the readily and moderately decomposable organic waste constituents within 5–10 years following closure and needs to have control and understanding of microbiological processes (Pacey et al. 1999). This process is in contrast to a traditional landfill that stores layers of compacted garbage in a dry condition to minimise the leachate which then biodegrades within its boundaries. There are three types of bioreactor operational processes which can be used: aerobic, anaerobic and hybrid or facultative. In an aerobic bioreactor, air (oxygen) is added to increase aerobic activity and accelerate waste stabilisation of the landfill. In an anaerobic bioreactor landfill, moisture is added in the form of leachate to obtain optimum moisture levels of at least 40 %t by weight to accelerate biodegradation of the waste. Biodegradation occurs in the absence of oxygen (anaerobically) and produces gas. The application of leachate storage and recirculation technique in landfill has proven its beneficial effect on waste biodegradation in landfill (Chiemchaisri et al. 2002). A hybrid or facultative landfill accelerates waste degradation by employing a sequential aerobic-anaerobic treatment to decompose organics in the upper sections and collect gas from lower sections. There are four reasons indicated as justification for use of bioreactor technology: (a) to enhance potential for waste to energy conversion, (b) to store and/or treat leachate, (c) to recover air space as well as overall landfill space and (d) to ensure sustainability in terms of reduced greenhouse gas emissions. The fourth justification, i.e. to ensure sustainability, has considerable significance and results in reduced costs associated with avoided long-term monitoring and maintenance and delayed the location of a new landfill (Reinhart et al. 2002). In sustainable landfills, processes, control and use of products and residues are best handled with full knowledge of what is likely to happen within landfill, and there are minimal negative effects on the environment. This can be achieved after the stabilisation of waste within a landfill and the stabilised waste can be mined to release the space for refilling. Landfill mining in a landfill should be undertaken when the landfilled wastes are sufficiently stabilised. Stages of stabilisation depend to a large extent on parameters that control the chemical and biological processes (e.g. chemical and biological compositions, stress, moisture content, temperature and micro-organisms) occurring in the landfill waste.

In the present study, two landfill simulators (dry and bioreactor) were used to analyse conventional landfill and bioreactor landfill in terms of stabilisation and sustainability. The evaluation is carried out by analysing the geotechnical properties and the chemical properties of waste initially and after 1-year monitoring. Laboratory experiments were conducted on mechanically biologically treated (MBT) municipal solid waste (MSW) retrieved from Mavallipura landfill situated in the outskirts of Bangalore. The MBT waste is referred to as MSW in this paper.

14.2 Test Methods

Although there are several tests conducted on MSW landfills, the bioreactor landfill area needs further research and understanding of the physical, chemical and biological processes over a period of time. Specially designed cells were fabricated (Fig. 14.1) in order to monitor the MSW for dry and bioreactor condition. The MSW setups were monitored for 1 year. In the dry condition leachate was not recirculated. In the bioreactor setup, the leachate was recirculated at regular intervals. MSW was placed in both the setups that had a water content of 44 % and bulk density of 10.3 kN/m^3. The geotechnical and chemical characterisation of MSW were measured before placing the MSW in the cell and after 1 year of monitoring. Specific gravity, hydraulic conductivity, compressibility, shear strength and carbon content analysis tests were conducted.

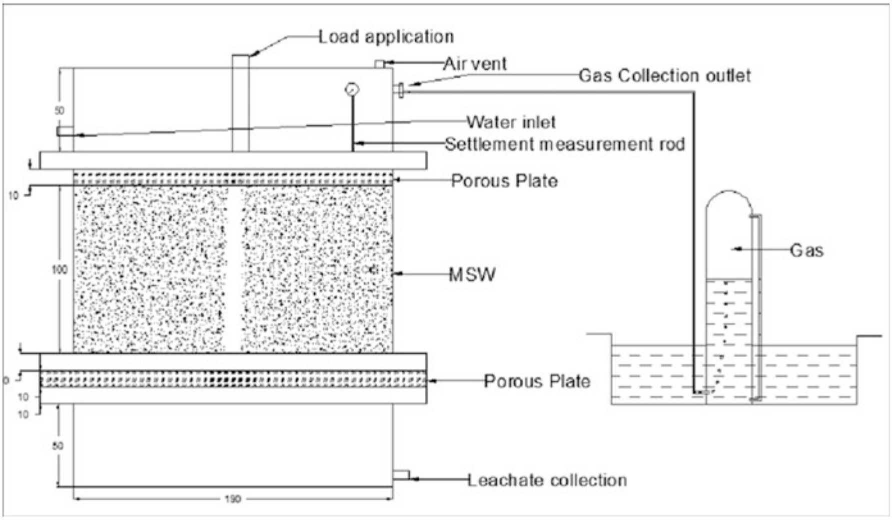

Fig. 14.1 Experimental setup for MSW gas collection

14.2.1 *Physical Composition, Total Volatile Solids and Particle Size Distribution of MSW*

The physical characterisation of MSW is done in order to study the effect of the physical composition on the stability characteristics of the MSW. The characterisation of MSW size <35 mm was used in this study. The waste is segregated by hand sorting into paper, plastics, inerts (rubber, leather), glass, stones and the organic fraction of the waste. Table 14.1 shows the MSW composition prior testing.

The organic content of the MSW was studied in the laboratory by the TVS method according to the APHA (1965) (American Public Health Association) standard methods. Organic content of the compost reject <35 mm particle size was calculated as the ratio of the weight loss to the initial specimen weight after heating to a temperature of 550 °C in a muffle furnace. Organic content of the waste was calculated as the ratio of the weight loss to the initial specimen weight after heating from a temperature of 105 °C to a temperature of 550 °C in a muffle furnace. The initial decomposable organic content of the waste was found to be 55 % and the inerts constituted to 45 %. The TVS of MSW decreased from 54 % to 38 and 29 in dry simulator and bioreactor simulator, respectively.

Sieve analysis of the MSW is conducted in the laboratory in accordance with the ASTM D422 standards. Sieve analysis was performed with opening sizes from 0.075 to 35 mm using the waste components after drying. Figure 14.2 presents the size distribution of MSW samples for the dry and bioreactor conditions. As can be seen, particle size of the MSW samples increases with age. In fresh waste samples, 50 % of the elements are smaller than 30 mm. The percentage passing increases from 90 to 98 for the bioreactor condition. This indicated the reduction in the MSW particle size in the bioreactor case. This is probably due to the effect of the biodegradation progress, which acts by disintegrating the MSW particles and making the MSW a finer material over time.

Table 14.1 Composition of MSW

Type of waste	Percentage (%)
Clothes	6.34
Plastics	28
Glass	1.28
Leather	0.8
Coconut	5.56
Metal	–
Stones	1.96
Rubber	0.88
Wood	0.16
Organic content	54.2

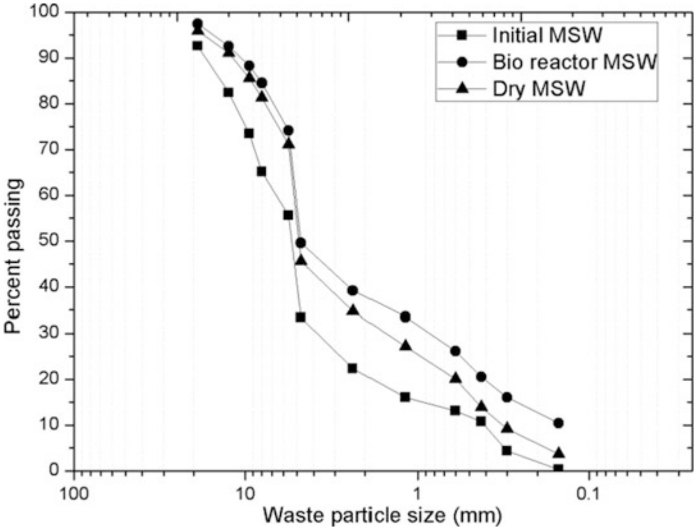

Fig. 14.2 Particle size distribution of MSW

14.2.2 Gas Quantification and Settlement

The gas production and settlement were monitored for two cases. A static load of 100kPa was applied on both the cases. The field capacity of the MSW was calculated as 45 %. The leachate that was recirculated was brought from the landfill site. Around 1.6 L of leachate was added initially in the bioreactor case, whereas no leachate was added in the dry case. The quantity of gas was measured by the downward displacement of water as shown in Fig. 14.1. The quality of gas was measured using a gas chromatograph. Elemental analysis was conducted in a CHN analyser in order to find out the elemental carbon, nitrogen and hydrogen contents in the MSW initially and after 1 year in both the considered cases.

14.2.3 Geotechnical Characterisation

14.2.3.1 Specific Gravity

The specific gravity tests were conducted in accordance with ASTM test method ASTM D 854–02 and ASTM D 5057–90. Pycnometer and density bottle methods were employed on particles passing through the 35 mm sieve in laboratory for finding the specific gravity of MSW. Five tests were conducted on representative MSW samples for the initial, dry and bioreactor cases.

14.2.3.2 Hydraulic Conductivity

Laboratory tests were conducted to determine hydraulic conductivity by constant head and falling head methods. The tests were performed according to ASTM D2434. The water content and the bulk density of MSW were 44 % and 10.3 kN/m^3. The waste was compacted into the mould of 50 mm internal height and 80 mm internal diameter. The permeability was calculated based on Darcy's law.

14.2.3.3 Compressibility

Compressibility testing was carried out in an oedometer in order to determine the compressibility characteristics of fresh MSW and one-year-old MSW. The size of the sample was 100 mm diameter and 25 mm height. The water content and the bulk density of MSW were 44 % and 10.3 kN/m^3. The maximum load applied was 920 kPa. The waste was compacted into the mould using a circular tamping plate and placed in between the porous stones.

14.2.3.4 Consolidated Undrained Shear Strength

The consolidated undrained triaxial tests were performed according to ASTM D4767. The MSW was compacted statically and then placed in the triaxial cell. The sample size was 50 mm diameter and 100 mm height. The water content and the bulk density of MSW were 44 % and 10.3 kN/m^3. The samples were initially subjected to saturation, consolidation and finally compression. The confining pressures applied were similar to the drained tests (50, 100, 150 kPa). The deviator stress-axial strain graphs were plotted.

14.2.3.5 Consolidated Drained Shear Strength

The consolidated drained tests were performed in accordance with the ASTM D3080. Laboratory triaxial testing was conducted on waste samples of water content and the bulk density of MSW were 44 % and 10.3 kN/m^3, with unit weight of 10 kN/m3. The sample size was 50 mm diameter and 100 mm height. Shearing was done at a strain rate of 0.5 mm/min. The confining pressures applied were 50, 100 and 150 kPa.

14.3 Results and Discussions

14.3.1 Gas Quantification and Settlement

The gas production in the bioreactor case was around 20 L compared to 5 L in the dry case (Fig. 14.3a). The gas production was less in the dry case due to the limited availability of the moisture and nutrients which was supplied through leachate circulation in the bioreactor case. The results of gas composition analysis found 37–39 % of methane in the bioreactor case and 30–32 % in the dry case. The gas production had decreased after 350 days in the bioreactor case. In bioreactor case, there was 30 % settlement compared to around 16 % settlement in dry case (Fig. 14.3b). This indicated a higher settlement in bioreactor case. CHN elemental analysis showed a 61 % reduction in carbon content in the bioreactor case compared to 14 % in the dry case as shown in Table 14.2. This may be attributed to the inadequacy of moisture and nutrients to the micro-organisms in the dry case. However, there was no significant decrease in the nitrogen and hydrogen content in both the cases.

14.3.2 Geotechnical Characterisation

14.3.2.1 Specific Gravity

Specific gravity of the initial MSW sample in the present study was found to be 1.33. The specific gravity for the dry case and bioreactor case was found to be 1.26

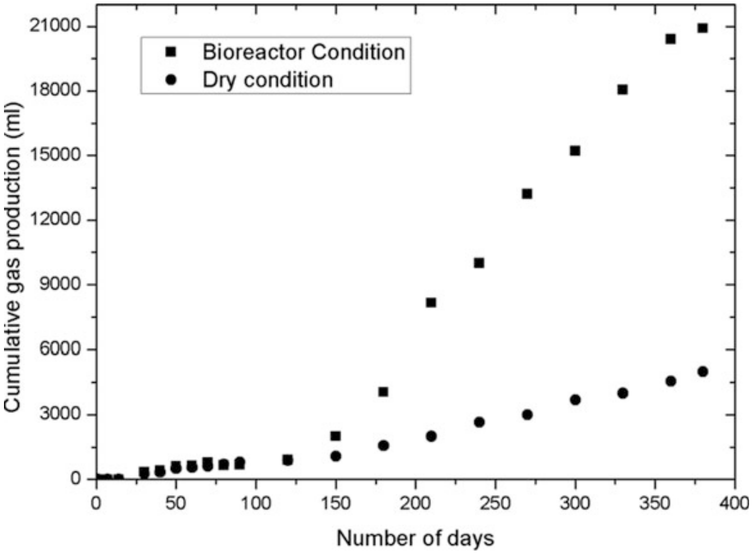

Fig. 14.3a Variation of landfill gas production with time for the considered cases

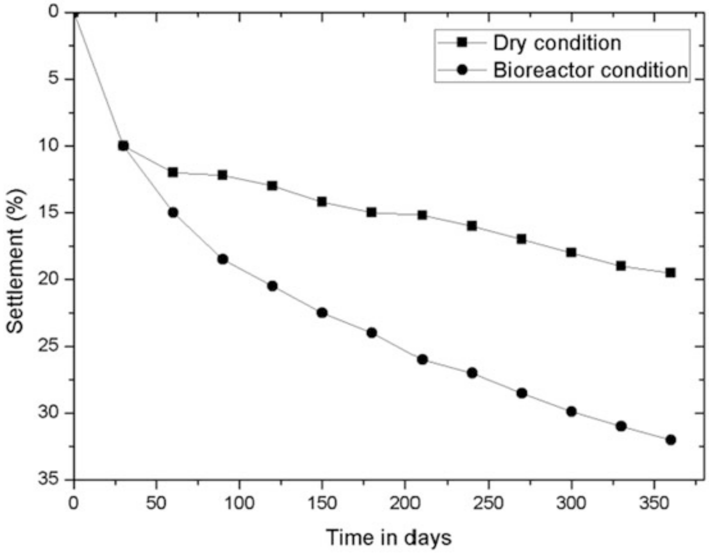

Fig. 14.3b Variation of MSW settlement with time for the considered cases

Table 14.2 Elemental analysis of MSW

Parameter	N %	C %	H %
Initial MSW	1.6389	19.279	2.5872
After 1 year			
Dry condition	1.4822	16.697	2.4686
Bioreactor condition	0.12771	7.4557	1.2817

and 1.20, respectively. Hettiarachchi (2005) reported values of 1.59 and 1.67 for mixed simulated waste. Gabr and Valero (1995) reported the specific gravity of the MSW from the tests done on the entire particle size distribution as 2.0 and for the finer fraction (<No. 200 sieve) as 2.4. The lower values of specific gravity can be attributed to the presence of decomposed organic matter.

14.3.2.2 Hydraulic Conductivity Tests

The hydraulic conductivity obtained from the tests was 6.4×10^{-4} cm/s and 4.35×10^{-3} cm/s for falling head and constant head method, respectively. The hydraulic conductivity decreased to 5×10^{-6}cm/s and 3.2×10^{-5}cm/s in the dry case and bioreactor case, respectively. Therefore, there is a decrease in the permeability of MSW with age. This is in agreement with Reddy et al. (2009b) who stated that the decrease in permeability in aged MSW is attributed to the increase in the smaller particles resulting from degradation.

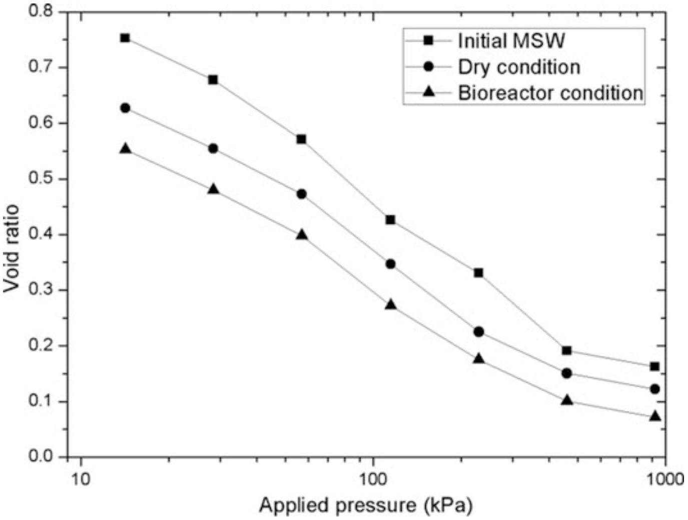

Fig. 14.4 *e-log (p)* of MSW samples for the considered cases

14.3.2.3 Compressibility Tests

The compression index values decreased with the age of waste (Fig. 14.4). The compression index values obtained were 0.347 for the initial MSW, 0.27 for the dry case and 0.264 in the bioreactor case. Hossain (2002) reported 0.16–0.25 as compression ratios for fresh MSW. The compression index values published by Reddy et al. (2009a) were in the range of 0.24–0.33. The void ratio also decreased from 0.79 to 0.70 and 0.63 in dry case and bioreactor case. The compression index values and void ratios decreased with the age of waste. This is in agreement with Hossain et al. (2006) concluded that with degradation the MSW structure will change and the MSW particles break down leading to a decrease in the MSW void ratio and thus a decrease in the MSW. However, there was no significant difference in the compression index values of dry and bioreactor cases.

14.3.2.4 Consolidated Drained Shear Strength

Deviator stress increased with axial strain without showing any peak in the stress-strain curve (Fig. 14.5a, b). MSW shear strength in triaxial compression has been defined in the literature as the mobilised shear stress at 5–25 % axial strain. Though the tests were conducted for strains up to 35 %, shear strength at 20 % strain was used for generating the Mohr-Coulomb shear strength envelopes. The friction angle (Φ) values were found to be 33° for the initial MSW samples. The Φ values decreased to 27° and 22° in dry and bioreactor case. The cohesion values did not

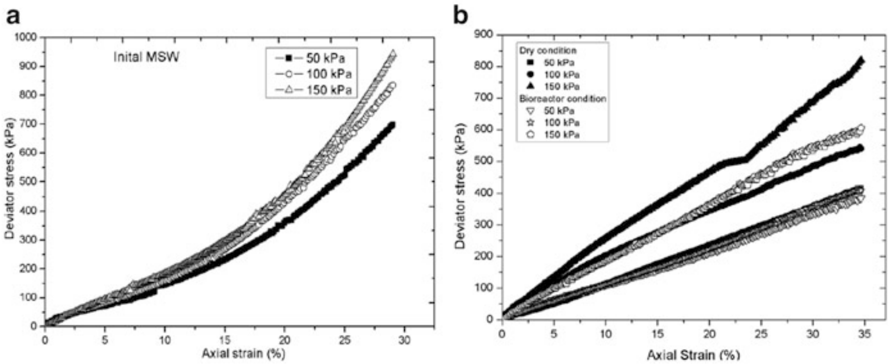

Fig. 14.5 (**a**). Deviator stress-strain curves of consolidated drained tests of initial MSW samples. (**b**). Deviator stress-strain curves of consolidated drained tests for dry and bioreactor case

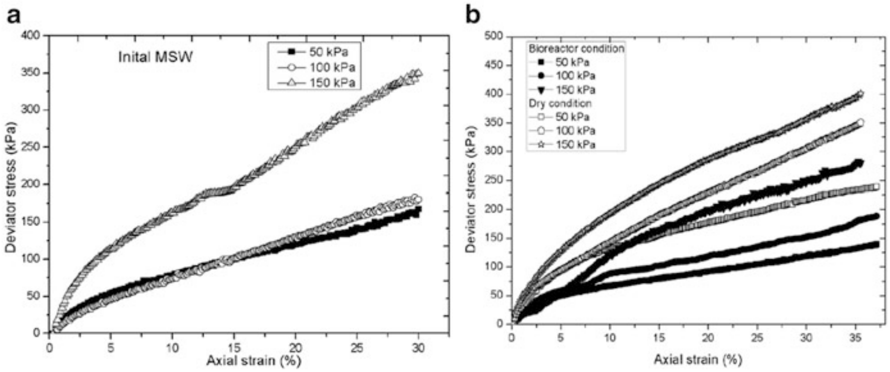

Fig. 14.6 (**a**). Deviator stress-strain curves of consolidated undrained tests of initial MSW samples. (**b**). Deviator stress-strain curves of consolidated undrained tests for dry and bioreactor case

vary considerably. There is a reduction in the Φ values with the increase in the age of waste.

14.3.2.5 Consolidated Undrained Shear Strength

The deviator stress increased with axial strain without showing any peak (Fig. 14.6a, b). The friction angle (Φ) values were found to be 32° for the initial MSW samples. The Φ values decreased to 25° and 28° in dry and bioreactor case. Though there is a reduction in the Φ values with the increase in the age of waste, the Φ value in bioreactor case was greater than in the dry case. The cohesion values did not vary considerably

14.4 Summary and Conclusions

This study summarises the evaluation of the dry type landfill and bioreactor landfill. The geotechnical and the chemical properties of initial MSW samples and the MSW residue after of 380 days of monitoring were studied and analysed. The following conclusions can be drawn from this study:

1. The landfill gas production was greater in the bioreactor case (21 L) than in the dry case (5 L). The methane content also was higher in the bioreactor case (37–39 %) than in the dry case (30–32 %).
2. The bioreactor was able to effectively reduce the carbon, nitrogen and hydrogen content in the MSW. There was a reduction of 60 % in carbon content, 90 % in nitrogen and 50 % in hydrogen compared to 13 % in carbon content, 10 % in nitrogen and 4.5 % in hydrogen. Stabilisation of waste is faster in the bioreactor case.
3. The MSW particle sizes decreased with increase in age. The aged MSW exhibited a reduced compression index, specific gravity and hydraulic conductivity values.
4. The friction angle values also decreased from 33° to 22°, whereas no significant change in the cohesion values was observed.

It can be concluded that the bioreactor case is a better sustainable option compared to the dry case. Since this study is restricted to laboratory experiments, large-scale experiments and field-scale studies are required to prove the bioreactor landfill as an effective sustainable technology.

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