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Harvinder Singh
Prashant Garg
Inderpreet Kaur *Editors*

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Preface

Conventional construction materials had already served the mankind well, and over exploitation of natural resources has created a huge ecological imbalance. Now, it is the need of the hour when sustainability and resiliency have become essential in the development of new materials and future infrastructure systems. The exploding world population and the consequent global climate changes are leading to major concerns across the globe, such as extreme geohazards, increased environmental pollution, and the rapid depletion of the natural resources. To address all these challenges, pooling of research inputs from different organization/individuals is required. Under this backdrop, the Civil Engineering Department of Guru Nanak Dev Engineering College, Ludhiana (An Autonomous Institute under UGC Act) in association with the Indian Geotechnical Society: Ludhiana Chapter and Testing & Consultancy Cell of the college have planned to organize an international conference on 'Sustainable Waste Management through Design' on November 2–3 , 2018, at Ludhiana (Punjab), India.

The conference aims to provide a unique opportunity to highlight recent advances, new directions, and opportunities for sustainable and resilient approaches to design and protect infrastructure and the environment, and accordingly, call for papers was flashed to invite original research and practice papers on all civil engineering and construction-related aspects of the resource management cycle, for minimization of waste through the eco-friendly reuse and disposal of residual wastes. About 15 speakers from academia and industry have agreed to deliver expert lectures during the conference. In addition, 125 papers have been received from various researchers/academician/industry experts on the conference themes; out of these, about 69 papers have been recommended by a panel of reviewers for the presentation and publication in the conference proceeding. The organizing committee extends a sense of deep appreciation to the Springer, who is publishing the conference proceeding.

We also express our sincere gratitude to the members of the advisory committee, organizing committee, editorial/technical committee, reviewers, and the student volunteers for their untiring efforts, besides the several individuals who made their sincere efforts for making this conference a great success. At the end, we can gratefully acknowledge one and all for their generous support and inspirational participation.

The success of any event in general and technical event in particular depends on the contributions and involvement of a maximum number of practicing engineers/academicians/researchers in their field of excellence, but also coming together of various organizations/individuals to support such activities because the aim of such activities is to take the information from the laboratory to the field.

The organizing committee has received financial support from several other organizations, agencies, and individuals, and our salutation is to them for supporting the event. We also appreciate and extend hearty thanks to the TATA TISCON, main sponsor of the conference, for their liberal financial assistance. We also hope that the participants will return to their destination fully satisfied with the deliberations of the conference, and we do hope that this conference will rejuvenate the civil engineering department to conduct many more such events in the future.

Harvinder Singh
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Contents

Use of an Innovative Technique to Detect the Leakage of Bayer Liquor Through a Liner Defect

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Abstract. Bayer liquor is a major liquid effluent of the aluminium manufacturing process. It needs to be stored and managed properly for contamination control. Hence, it is stored in containment structures which are equipped with highly engineered lining systems. These lining systems are designed such that their performance can be ascertained over their intended period of operation. However, the liners are found to fail due to various factors. Therefore, there is a need for the use of real-time monitoring method for the lining systems. The current study uses an electrical resistivity-based leak detection technique to determine leakage issues in the lining systems of containment facilities in aluminium industry. Bayer liquor procured from an aluminium manufacturing company in Perth, Australia was used for the tests. Based on the results, the leak detection technique was found to be effective in detecting leakage issues through liners in aluminium industry, irrespective of the leakage duration. Furthermore, the system can help the practicing engineers in the design and placement of sensor systems, numerical modelling, and so on.

Keywords: Bayer liquor · Electrical resistivity · Leak detection
Liner defect · Soil

1 Introduction

The Australian aluminium industry is a significant contributor to the national economy for over 50 years. This industry consists of 5 bauxite mines, 6 alumina refineries and 4 aluminium smelters. Australia is the world's second largest producer and exporter of alumina, accounting for 22% of the global production (Australian Aluminium Council 2018). As per the Australian Aluminium Council (2011), 19.1 million tonnes of metallurgical alumina and nearly 0.5 million tonnes of chemical grade alumina, were produced domestically.

Alumina is extracted from bauxite by digesting it in a severely caustic solution, at high temperature and pressure. This process is known as the Bayer process and the liquid effluent generated from this process is called the Bayer liquor. Bayer liquors are challenging leachates due to their high dissolved aluminium, sodium carbonate, sodium

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chloride, sodium sulphate, and sodium oxalate content (Bouchard *et al.* 2009; Busetti *et al.* 2014).

Due to the high concentration of contaminants in the Bayer liquor and the threat it poses to the environment, its proper handling and storage are of critical importance. In an effort to prevent soil and groundwater contamination, highly engineered lining systems are used by aluminium manufacturing companies for the containment of Bayer liquor. Although the integrity of these liners should ideally not be compromised during their operating period, however, due to various factors, the liners often develop defects and tend to fail. Figure 1 is a photograph of one such liner failure. This leads to subsequent soil and groundwater contamination issues (Pandey *et al.* 2017). Therefore, the lining systems need to be proactively monitored to ensure the early detection of liner defects so that adequate hazard mitigation measures can be taken (Pandey and Shukla 2018a).

Fig. 1. A typical liner failure (*Courtesy of Iluka Resources, WA, Australia*).

Pandey and Shukla (2018a) have developed and presented an innovative method for the detection of leakages through liners by simulating actual lining systems. This system was further tested and found to be effective in detecting leakages across liners when municipal solid waste (MSW) landfill leachate was used as the leaching liquid (Pandey *et al.* 2017). However, the efficacy of this system in detecting leakage issues when Bayer liquor is the leachate, has not been examined yet. The current study aims to fill this gap in knowledge by conducting leak detection tests in the setup developed by Pandey and Shukla (2018a), using the Bayer liquor leachate procured from an actual aluminium manufacturing company in Perth, Western Australia (WA), Australia. Based on the results from this study, the effectiveness of the use of this innovative leak detection technique in Bayer liquor containment systems in the aluminium industries can be adjudged. The understanding developed by this study will assist practicing engineers in Australia as well as internationally to detect contamination and liner leakage issues, design and placement of sensor systems, numerical modelling, and so on.

2 Materials Used

Sandy soil was used for this study. This soil is a good representation of Perth, WA, Australia, and is widely used for engineering works. The properties of this poorly graded sand are presented in Table 1.

Table 1. Physical properties of sand.

Property	Unit	Value
Specific gravity	Dimensionless	2.68
Coefficient of uniformity	Dimensionless	2.27
Coefficient of curvature	Dimensionless	1.22
Effective size	mm	0.15
Minimum dry unit weight	kN/m^3	14.02
Maximum dry unit weight	kN/m^3	15.56
Soil classification as per USCS (Unified Soil Classification System)	Dimensionless	Poorly graded sand (SP)

Bayer liquor was used as the leaching liquid for this test. It was procured from Alcoa, WA, Australia. The composition of the liquor is given in Table 2. Its pH is 13.8 and the specific gravity is 1.25.

Table 2. Composition of Bayer liquor (*Courtesy of Alcoa, WA, Australia*).

Chemical	Percentage by weight
Sodium aluminate	5–20
Sodium hydroxide	2–9
Sodium carbonate	<4
Sodium oxalate	<3.5
Sodium sulphate	<3
Sodium chloride	<2
Water	64–90

A 220 μm thick geomembrane (GMB) liner was used for the test. A piece of 550 mm length and 250 mm width was pre-cut, and a leak was intentionally introduced in the centre of the GMB piece using a gravel-size particle, to simulate an actual puncture defect as observed in practice.

3 Test Methodology

The experiments were conducted using the innovative leak detection technique developed by Pandey and Shukla (2018a). This technique is based on the electrical resistivity. The electrical resistivity of soil below liner is very high. As soon as leakage occurs, the leachate tends to contaminate this soil. Generally, leachates possess much lower resistivity than any soil. Hence, in case of even mild leachate contamination, the soil resistivity decreases significantly. This change can be easily detected to determine the leakage issue (Pandey *et al.* 2015; Pandey and Shukla 2017, 2018b). Based on this well-established fact, a new leak detection technique was developed and presented (Pandey *et al.* 2017; Pandey and Shukla 2018a).

As per this method, a resistivity box as shown in Fig. 2, was filled with the soil specimen and covered with the punctured geomembrane (GMB) liner. Initially the leak was kept covered. The Bayer liquor was then filled over this GMB layer and the leak was uncovered to allow leakage to the underlying soil. Resistance readings were then taken at various leakage durations (t) using the electrodes fitted on the resistivity box using a four-point resistance testing machine. Resistivity was obtained between each pair of electrodes. The resistivity profile was then generated to locate the leak in the GMB liner. This method has been discussed in greater detail by Pandey *et al.* (2017) and Pandey and Shukla (2018a).

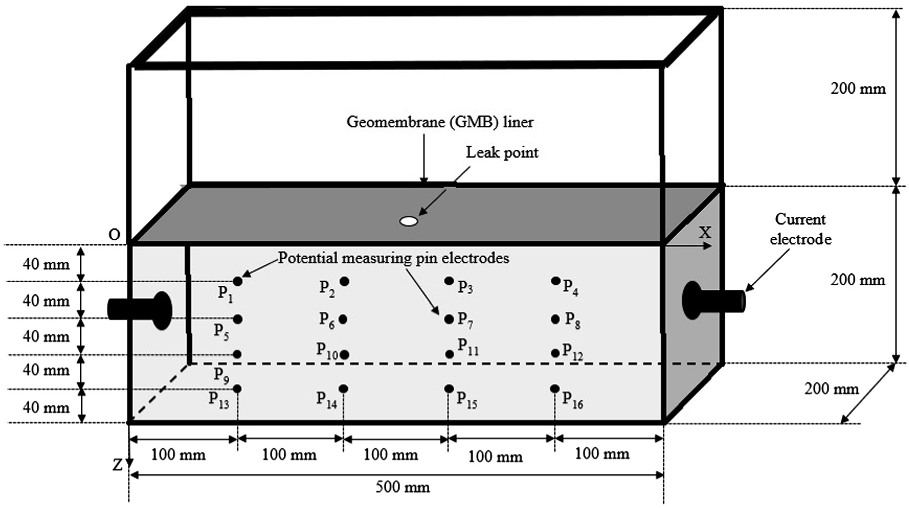

Fig. 2. Schematic diagram of the resistivity box used in the leak detection test (*Adapted from Pandey and Shukla (2018a)*).

4 Results and Discussion

Figures 3 and 4 give the resistivity profiles for the leakage durations, t = 80 min and 90 min, respectively, for the Bayer liquor as the leachate.

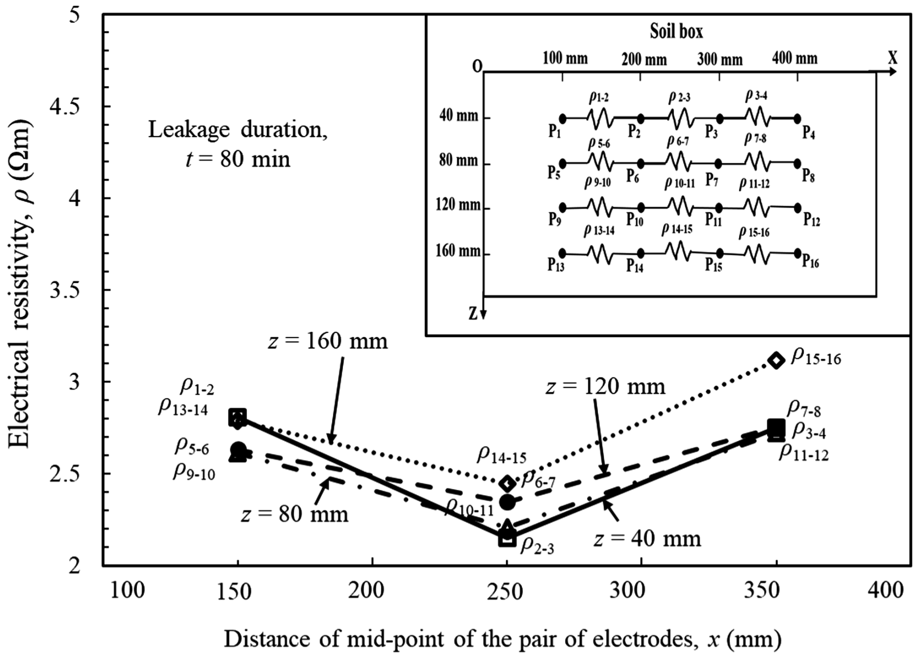

Fig. 3. Resistivity profiles at the leakage duration of 80 min.

It can be observed that at any depth (z), the resistivity first decreases and then increases with an increase in the distance (x) of the mid-point of electrode pair. The hole in the geomembrane (GMB) liner was positioned directly above the mid-point of the electrodes, P_2 and P_3, as given in Fig. 2. Hence, the amount of leachate between these electrodes would be greater than the amount of leachate between the adjacent electrode pairs. Therefore, this observation was as expected.

It can be seen from Figs. 3 and 4 that at any given x, soil resistivity decreases with a decrease in the depth z. This observation also complies with the expectation that with a decrease in z, the amount of leachate in soil would increase, and consequently resistivity would decrease.

It can be observed from Figs. 3 and 4 that with an increase in the distance/depth from the leak, the resistivity of the soil shows an increase. Therefore, the location of the liner leak can be determined based on the resistivity profile of the soil.

In addition, it is interesting to note that the resistivity profiles show a similar trend, irrespective of the leakage duration. This indicates that the leakage can be located at any leakage duration, using the resistivity profile.

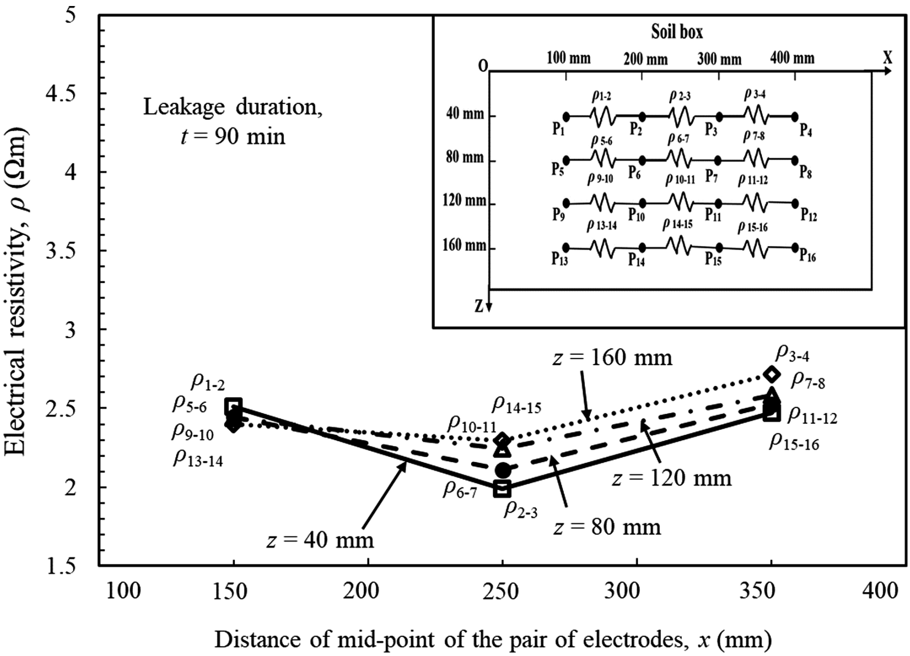

Fig. 4. Resistivity profiles at the leakage duration of 90 min.

Based on these observations, it can be concluded that the leak detection technique is reasonably effective for detecting and locating leakages through lining systems used in the Bayer liquor containment facilities of aluminium manufacturing industry.

5 Conclusions

Results have been given for the leak detection test conducted using Bayer liquor from aluminium manufacturing process, for the leakage durations of 80 min and 90 min. The resistivity of the soil increased with an increase in the depth/distance, of the mid-point of the pair of electrodes, from the liner leak, irrespective of the leakage duration. It was observed that the newly developed system can be used by containment systems in aluminium industry to effectively detect and locate leakages in liners. Additionally, the system can help the practicing engineers in the design and placement of sensors, numerical modelling, leakage detection, and so on.

Acknowledgements. The authors would like to thank Mr Michael Leahy (Alcoa, Western Australia (WA)) and Mr. Tim Morris (Edith Cowan University, Western Australia (WA)) for their help in procuring the Bayer liquor.

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Comparative Studies of Small-Scale Aerobic and Anaerobic Bioreactor Landfills Treating MBT Waste of Bangalore City

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Abstract. Experimental studies on small-scale bioreactor landfills treating mechanically and biologically treated waste under aerobic and anaerobic conditions are presented in this study. The waste was collected from one of the Municipal Solid waste processing units of Bangalore City. The performance of the bioreactors in terms of organic content, gas emissions and settlement are presented here. The monitoring was carried out for a period of 300 and 380 days for aerobic and anaerobic bioreactors respectively. The aerobic reactor produced about 21.5 L of carbondioxide within 150 days and the anaerobic bioreactor produced 20.9 L of biogas in 380 days of operation. Results indicate that the waste can be degraded in a short time period in aerobic bioreactors and achieve almost the same degree of settlement in comparison to the anaerobic bioreactors.

Keywords: Bioreactor landfills · Aerobic · Anaerobic · MBT waste

1 Introduction

Landfilling is one of the preferred methods of waste disposal throughout the world mainly due to its economic considerations (El Fadel 2014). The benefits associated with the use of bioreactor landfills for waste containment and treatment is well documented in the literature (Pohland 1995; Reinhart and Townsend 2002). Anaerobic bioreactors have the advantage of methane production which can be used for energy generation. On the other hand, aerobic bioreactors have other benefits such as, increased waste stabilization and settlement in a shorter period (Rich et al. 2008), enhanced removal of ammonia nitrogen from the leachate (Berge et al. 2005), decreased leachate strength and quantity (Yang et al. 2012) and no methane emissions. However, the choice between the two types of bioreactor landfills depends on the various constraints such as availability of space, the time required for stabilization and economics.

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In this study, the feasibility of employing a small scale aerobic bioreactor in treating MBT waste of Bangaloreis explored. The reactor performance in terms of the settlement, gas emissions and decrease in organic content are compared with that of an anaerobic bioreactor of similar size and configuration. The results of this study would be beneficial to implement the aerobic process on large scale/field scale studies.

2 Methodology

2.1 Characteristics of MBT Waste

The waste used in this study was collected from the Mavallipura waste processing unit Bangalore. The waste collected was subjected to mechanical and biological treatment like size separation and windrow composting respectively in the processing unit was >4 mm and <35 mm in size. The physical composition of collected waste was determined by hand sorting into various components like paper, plastics, inerts (rubber, leather), glass, stones and the organic fraction (Lakshmikanthan et al. 2018). The composition of waste used for aerobic and anaerobic bioreactors are shown in Table 1 and are considerably different in composition even though the origin of both the wastes were same.

Table 1. Physical composition of MBT waste used in the study

Type of waste	Percentage (%)	
	Aerobic	Anaerobic
Clothes	0.59	6.34
Plastics	4.62	28
Glass	4.93	1.28
Leather	–	0.8
Coconut	–	5.56
Stones	20.06	1.96
Rubber	–	0.88
Wood	7.59	0.16
Metal	1.08	–
unidentifiable	61.13	55.02
Organic content	38.94	54.2

The organic content of the waste was studied in the laboratory by the Total Volatile Solids (TVS) method according to the APHA (American Public Health Association 1965) standard methods. Organic content of the compost rejects <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.

Specially designed cells were fabricated (Fig. 1) to monitor the MBT waste under bioreactor conditions. The reactor cell was 0.19 m in diameter and the height of the sample was 0.1 m. The MBT reactor was monitored for a period of 300 and 380 days under aerobic and anaerobic conditions respectively. Both the reactor configurations used in the study are given in Table 2. Leachate quantity equivalent to 10% of the volume of the reactor was recirculated three times a week. The organic content of MBT waste was measured before placing the waste in the cell and after the end of experimentation.

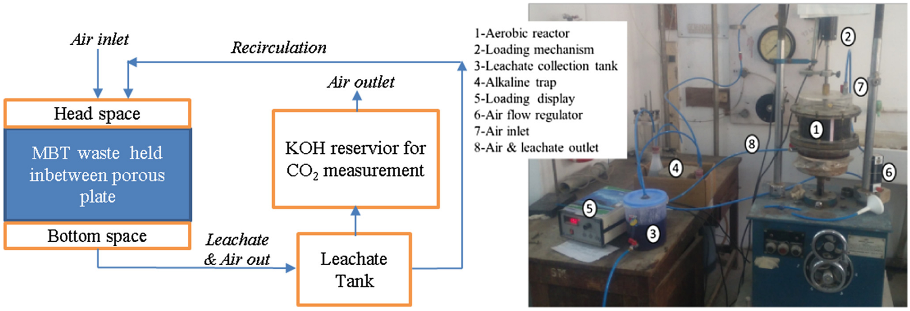

Fig. 1. Schematic view and laboratory setup of the small-scale aerobic bioreactor.

Table 2. Configuration of aerobic and anaerobic bioreactors

	Aerobic	Anaerobic
Volume of reactor; liters	2.835	2.835
Initial moisture content	0.5	0.44
Bulk density of MBT; kN/m^3	10.3	10.3
Organic content	38.94	54.2
Staticload applied; kPa	50	200

2.2 Gas Quantification and Settlement

The generated gas from the anaerobic reactor was measured by the downward displacement of water. The method as suggested by Dimitry komilis et al. (2000) was used to quantify the carbondioxide liberated from the aerobic reactor. The method involved passing the liberated gas from the aerobic reactor through a 5 N solution of KOH to capture the carbondioxide (CO_2). The cumulative mass of CO_2 captured expressed in terms of total carbon was measured by titration. The difference between the phenolphthalein and total alkalinity of KOH solution gives the carbonate species accumulated due to the dissolution of CO_2 gas. The efficiency of the CO_2 trap was checked by analyzing the gas extracted from both the inlet and outlet of the trap using a Gas chromatograph atperiodic intervals. A wide range of aeration rate (2.62×10^{-3} to 1.33 L/min per kg of waste) is reported in the literature (He et al. 2011 and Sang et al. 2008). An air flow rate of 80 to 100 ml/min corresponding to 0.03 L/min/kg of waste was used in this study. The settlement of waste was noted visually by taking the average of the drawdown at four sides of the reactor.

3 Results and Discussion

About three kg of MBT waste was treated in both the bioreactors but the organic content in the aerobic reactor was less than the anaerobic reactor (Table 1). This might be due to the relative age of MBT waste at the time the study was conducted. The waste in the anaerobic reactor was relatively fresh (4–5 weeks after composting) in comparison to the waste in aerobic setup (at least 2-year-old which was kept in an enclosed container until tested). The total carbondioxide gas liberated from the aerobic reactor was 21.49 L in a period of 150 days. About 20.89 L of biogas was liberated from the anaerobic reactor in 380 days. When gaseous emissions are expressed in terms of grams of carbon per kg of volatile solids (VS), the carbon released per kg of VS is more in aerobic bioreactor by a factor of 1.32 in comparison to the anaerobic reactor and is shown in Fig. 2.

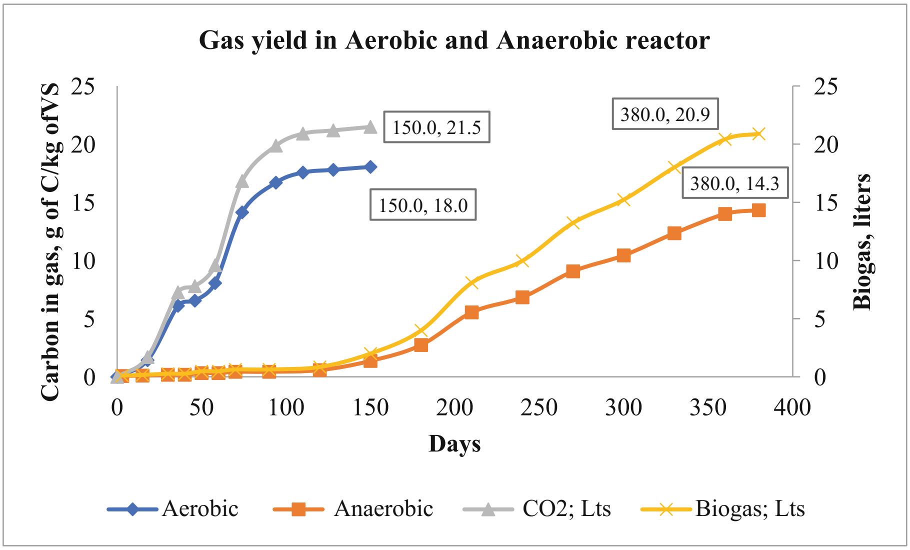

Fig. 2. Comparison of gaseous emissions in the aerobic and anaerobic bioreactor.

The maximum rate of 0.45 L/day is achieved at around 80th day of operation which reduces considerably to less than 0.015 L/day beyond 128 days. Therefore the aerobic bioreactor was stopped after 150 days when the decreased rate was confirmed consecutively for the second time. Figure 3 shows the variation of carbondioxide production rate as a function of time.

The study indicated that the aerobic bioreactor is capable of degrading the organic matter in a lesser time frame (a factor of 0.34). The waste stabilization can be achieved in a period of four months which in case of anaerobic bioreactor might have taken more than a year. In anaerobic bioreactor at the initial stages the gas generation was very low, and it might be due to the inhibitive condition prevailing in the reactor (Fig. 2).

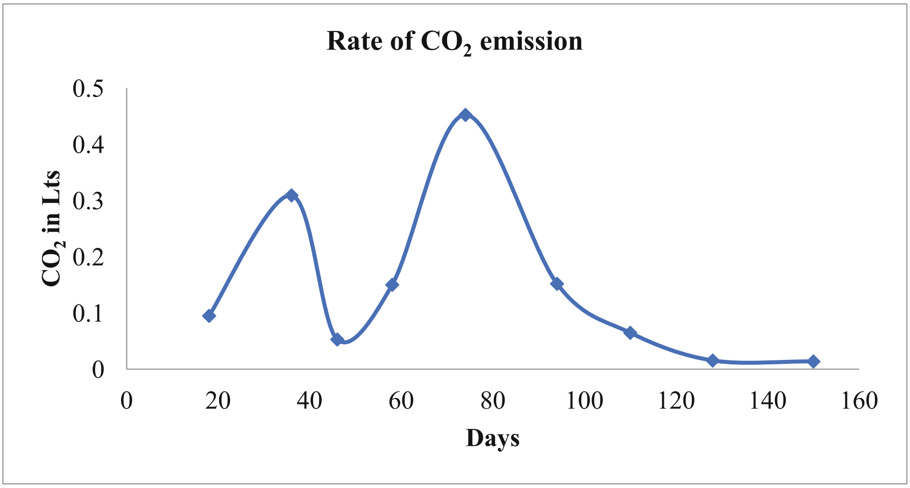

Fig. 3. The rate of carbondioxide production.

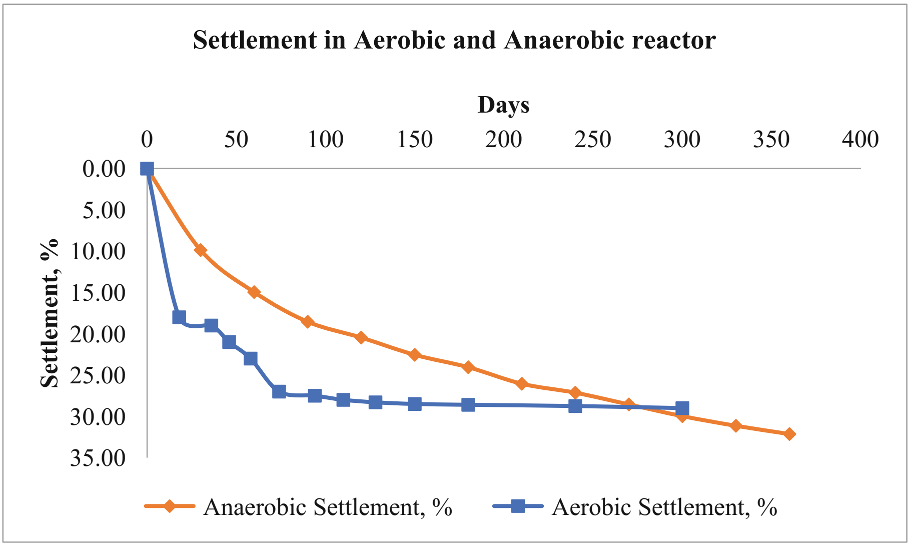

Fig. 4. Settlement observed in the aerobic and anaerobic bioreactor.

The settlement observed in the anaerobic and aerobic bioreactors were 32.14% and 29% respectively. The increased settlement in the case of anaerobic reactor might be due to the high overburden stress imposed (200 kPa) and high initial organic content. The settlement rate in the aerobic reactor had decreased considerably after 100 days and can be related to the decreased carbondioxide emissions. This indicates the complete degradation of the organic compounds at around 100–120 days of operation.

The organic content measured at the end of the study were 18.04% and 35% (Lakshmikanthan et al. 2017) in the aerobic and anaerobic bioreactors. The leachate characteristics of only the aerobic bioreactor was analyzed and are as given in Table 3.

Table 3. Leachate characteristics of aerobic bioreactor at various degradation stages.

	Parameter	Initial	15 days	45 days	80 days
1	pH	7.3	7.6	8.7	8.0
2	Electrical Conductivity in µmhos/cm	25,300	20,800	14,730	9,900
3	Total Dissolved Solids, mg/L	18,800	15,272	10,552	7,200
4	Biochemical Oxygen Demand, mg/L	650	700	500	380
5	Chemical Oxygen Demand, mg/L	2,150	2,560	1,693	1,300
6	Sulphate as SO_4, mg/L	2,936	1,646	1,466	1,034
7	Chloride as Cl, mg/L	4,431	3,864	2,978	1,361
9	Total alkalinity as $CaCO_3$, mg/L	500	250	350	240
10	Iron as Fe, mg/L	20.2	0.4	1.1	1.2
11	Copper as Cu, mg/L	–	–	–	–
12	Potassium as K, mg/L	4,063	3,416	1,106	1,422
13	Magnesium as Mg, mg/L	34	22	124	109
14	Nitrate as NO_3, mg/L	14,130	12,690	61	62
15	Ammoniacal Nitrogen as N, mg/L	4.6	4.0	–	11.2
16	Total Kjeldhal Nitrogen as N, mg/L	5.9	25.2	1.4	25.2

The pH in aerobic bioreactors is generally acidic during the early stages due to the production of organic acids and increases to around 7–9 at the later stages (Erses et al. 2008). The pH observed in this study was greater than 7, indicating that the MBT waste was matured and the organic acids which are commonly found during the initial stages of degradation are absent in the waste. Low concentration of total organic nitrogen and ammoniacal nitrogen in the leachate also confirms that the organic matter in the waste might have been completely nitrified. The concentration of nitrate in the leachate at the initial stages also indicates that the waste might have been nitrified (even the approximate age of MBT waste was around two years). By the end of 80 days, the nitrates were almost reduced by 99.5% indicating almost complete denitrification of leachate.

The BOD and COD removal efficiencies were around 39.5% and 41.5% respectively. The BOD/COD ratio was almost constant throughout the study (around 0.3) indicating that the biodegradable content in the leachate was still prominent at the end of the experiment. The decrease in EC and TDS was around 61%. The chlorides, sulphates, Iron and potassium concentration decreased with the age of the leachate. The concentration of Magnesium increased in the leachate indicating the release of the ions during biodegradation.

The Organic Content of the Waste in the Aerobic and Anaerobic Bioreactor Were Reduced by 53.67% and 35.42% Respectively.

4 Conclusions

The study presents the comparison of the performance of small-scale anaerobic and aerobic bioreactors. The results showed that the gas and settlement in both the reactors were almost same. The time required for stabilization of waste in the aerobic reactor is considerably less when compared to anaerobic reactor. The MBT waste used in the aerobic reactor was partially stabilized and had less VS compared to the anaerobic reactor. Despite the lower VS, the aerobic reactor was capable of reducing the organic content by almost 53%. The aeration and the leachate recirculation rates employed in this study yielded satisfactory results and the same can further be used for large-scale studies. The study explores the potential of aerating the anaerobic reactors to increase the waste stabilization process further once the methane yield decreases substantially.

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Spirodela polyrhiza: A Potential Accumulator of Pb from Contaminated Water

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Abstract. Today environmental pollution is a matter of great concern. Amongst the different causes, pollution caused by heavy metals is a major issue. Due to increased industrialization and urbanization, use of different heavy metals like Pb, Cu, Zn, Cd has increased manifold. These are toxic metals that have hazardous effects on all living forms. Lead (Pb) is one such pollutant that may disrupt the food chain and has major health effects. With the objective to find an eco-friendly cost-effective treatment process for Pb, phytoremediation of Pb contaminated water has been studied in the present investigation. Phytoremediation is a green technology that utilises a plant's ability to remove and accumulate different toxic pollutants in their biomass. Duckweed *Spirodela polyrhiza* were exposed to different Pb concentrations of 0.91, 1.97, and 2.88 mg/L for a period of 22 days. *Spirodela polyrhiza* was found to remove 93.19% at 0.91 mg/L that decreased to 82.23% at 1.97 mg/L Pb contaminated solution. Thus removal percentage and rate of removal was found to decrease with increase in initial Pb contamination. Relative growth factor in *Spirodela polyrhiza* exposed to different initial Pb concentrations reduced significantly with increase in concentrations. Pb accumulation capacity of *Spirodela polyrhiza* was found to increase with increase in initial Pb concentration. An accumulation of 7051 $\pm$ 631.54 mg/kg was obtained by *Spirodela polyrhiza* at initial Pb concentration of 2.88 mg/L. The study thus concludes that *Spirodela polyrhiza* is a suitable candidate for the phytoremediation of low concentration of Pb from contaminated water.

Keywords: Lead · Spirodela polyrhiza · Removal · Relative growth factor Accumulation

1 Introduction

Today, one of the most critical environmental crisis is caused by toxic heavy metals that not only affects environment but also all the life forms prevailing there. Environmental degradation, contamination of groundwater, metal contamination in

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foodchain are some of the examples of environmental pollution (Yuanqing *et al*. 2013). There are different conventional physical and chemical remediation technologies that may remove or treat the pollutants. Owing to the cost and disposal of huge amount of sludge, search for a cost-effective and environment-friendly treatment process has evolved. Phytoremediation is a green technology that utilises a plant's inherent ability to arrest and accumulate heavy metals in their biomass (Tremp and Kohler 1995; Weiss *et al*. 2006). There are different aquatic plants like water hyacinth, duckweeds, water lettuce (Yuanqing *et al*. 2013) etc. that can significantly accumulate heavy metals in them (Reed *et al.* 1995; Vermaat and Hanif 1998). Significant level of Pb accumulation has also been obtained by aquatic plants like *Nerium oleander* (Aksoy and Ozturk 1997), *Lemna minor* (Mishra and Tripathi 2008; Mohan and Hosetti 1997), *Ipomoea aquatic* (Gothberg et al. 2004), *Pistia stratiotes* (Odjegba and Fasidi 2004), *Ceratophyllum demersum* (Mishra et al. 2006). The objective of the present investigation includes the study of Pb removal efficiency as well as accumulation capacity of *Spirodela polyrhiza* under hydroponic conditions.

2 Materials and Methods

Plants *Spirodela polyrhiza* were obtained from a local pond near Jadavpur University, Salt Lake Campus, Salt Lake. The collected plants were washed with tap water, followed by deionised water to remove debris. Later on they were acclimatized for a period of seven days with the pond water under laboratory conditions. 25 L capacity plastic tubs were procured for incubation. In these tubs, 40 gm of fresh *Spirodela polyrhiza* were incubated in 20 L of Pb contaminated solutions at different initial Pb concentrations of 0.91, 1.97 and 2.88 mg/L respectively. Experiments were replicated in triplicates. All chemicals used were of analytical grades.

Over completion of the experimental period of 22 days, the plants were harvested, washed with deionised water, blotted dry and their fresh weight was recorded. Later on, the dry weight of the plant was obtained after oven-drying them for 48 h at 60 °C. Further the plants were ground to powder and digested to quantify the metal accumulated in the plant biomass. Treated water samples were also collected and analysed using Atomic Absorption Spectrophotometer (Perkin Elmer model). The procedures for Pb analysis in water and plant samples were as per Standard Methods.

3 Results and Discussion

3.1 Morphological Symptoms

Duckweed *Spirodela polyrhiza* on being treated with different initial concentrations of lead showed minor visible changes, and the fronds found were green. At higher initial concentration of lead examined, i.e. 2.88 mg/L, effects like partial wilting and gradual yellowing of the fronds were found to a certain extent with the increase in number of days of treatment. Similar observations have been reported by Mishra *et al*. (2006) where they found a decline of photosynthetic pigment chlorophyll in *Ceratophyllum*