Journal of Environmental Science and Technology

ISSN 1994-7887

Journal of Environmental Science and Technology 9 (1): 100-110, 2016
ISSN 1994-7887 / DOI: 10.3923/jest.2016.100.110

Performance of Sand Channel as Pre-Treatment for Anaerobic Landfill Bioreactor Leachate and Biogas Generation

[1]Emmanuel Olisa, [1]Nasiman Sapari, [1]Amirhossein Malakahmad, [1]Ezerie Henry Ezechi, [1]Ali Riahi, [1]Kalu Uka Orji, [2]Oseihioria Alex-Ohunyon and [1]Salihi Umar Ibrahim

[1]Department of Civil and Environmental Engineering, Universiti Teknologi PETRONAS, 32610, Bandar Seri Iskandar, Perak Darul Ridzuan, Malaysia

[2]School of Public Health and Community Medicine, University of New South Wales, Sydney, 2052, Australia

Corresponding Author: Emmanuel Olisa, Department of Civil and Environmental Engineering, Universiti Teknologi PETRONAS, 32610, Bandar Seri Iskandar, Perak Darul Ridzuan, Malaysia

ABSTRACT

The performance of a laboratory scale landfill bioreactor with two compartments (simulated landfill reactor and a sand channel) was investigated in this study. Solid waste components similar to the typical Malaysian waste were collected from the cafeterias in University Teknologi PETRONAS (UTP), Perak, Malaysia and used to generate leachate in the simulated landfill bioreactor. Leachate produced were slowly and systematically introduced into the bottom sand channel where methanogenesis rapidly occurred thereby resulting in a better stabilized system than the simulated landfill reactor. After 20 months of anaerobic incubation of both reactors, it was observed that the Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD_5) concentrations were lower in the sand channel while the pH values were higher than the simulated landfill reactor. Reduction in COD and BOD_5 in the sand channel were 88 and 90%, respectively. The pH of the simulated landfill reactor remained acidic at 6.2 while the pH of the sand channel was 7.9. Ammonia-nitrogen (NH_3-N) concentration was also observed to be lower in the sand channel at 1435 mg L^{-1} as against 1509 mg L^{-1} in the simulated landfill bioreactor. The constituent methane gas percentage in the simulated landfill reactor and sand channel were 25 and 58%, respectively. The obtained result clearly indicates that the attachment of a sand channel to landfills can be applied for the degradation and reduction of organic pollutants in leachate while methane gas recovered is enhanced.

Key words: Landfill bioreactor, anaerobic landfill, leachate, sand channel, biogas

INTRODUCTION

The constant increase in population has led to a concurrent increase in demand for water, hence the current attention given to possible measures of wastewater reuse for both irrigation, industrial and municipal water supply. When suitable treatment methods are employed, wastewater can be recycled and reused as sources of water supply and in so doing, this lessens the environmental impact (Marchioretto and Reali, 2001). Choosing the most suitable treatment technique in order to attain optimal reuse of wastewater and nutrients at no or much reduced energy consumption and cost is a major quandary in this context. Anaerobic treatment method is favorable in that, oxygen is not required in its operation and in turn the system generates methane (CH_4) gas which is a source of green energy. Anaerobic treatment plants can be situated within or just outside the city, especially as very limited space is required for their installations (Tawfik *et al*., 2003). Furthermore, as a result of the less amount of sludge produced as well as a better sludge stability achieved under anaerobic treatment of wastes, a reasonably reduced amount in terms of cost is required to further treat the sludge generated (Ghangrekar and Kahalekar, 2003). Although the concentration of the remaining organic and microbiological pollutants represented by the Chemical Oxygen Demand and Biological Oxygen Demand (COD and BOD) and fecal coliforms, respectively are usually very high and exceed the minimum allowable effluent discharge limit of most countries, developing and developed alike, including Malaysia (Prakash *et al*., 2007; Machdar *et al*., 2000; Sato *et al*., 2006). Hence, post treatment of anaerobic discharge effluents is of necessity in order to achieve the required discharge limits.

Landfill leachate is the product of liquid that has accumulated at the bottom of a landfill, generally resulting from the seepage, infiltration and percolation of precipitations or uncontrolled run off. The liquid carries along extracted, dissolved or suspended materials in the process (Christensen *et al*., 2001). Landfill leachate is comprised of several chemical compounds obtained from the dissolution of the substances disposed of in the landfill, which constitute a wide array of organic pollutants usually measured in form of Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD_5), ammonia, halogenated hydrocarbons, suspended solids, significant concentration of heavy metals and inorganic salts (Foul *et al*., 2009; Aziz *et al*., 2009; Renou *et al*., 2008). Old (Stabilized) leachate is generally characterized as having very low biodegradability which makes it difficult to treat using biological methods. Different types of leachates have been categorized based on age of landfill and leachate degradation, which has been attributed to be the cause of variance in biodegradability (BOD_5/COD) in leachate (Schiopu and Gavrilescu, 2010; Naumczyk *et al*., 2012). They also recorded the BOD_5/COD in landfills less than 5 years (young landfills) to be >0.3, while that for landfills between 5-10 years (intermediate) and above 10 years (stabilized landfills) were recorded as 0.1-0.3 and <0.1, respectively.

Leachate treatment in conventional wastewater treatment plants is not commonly used because of the nature and high amount of organic pollutants found in leachate (i.e., high COD and ammonia and low BOD_5/COD, hence the continuous global search for a lasting solution to leachate problems (Aziz and Abu Amr, 2015). Currently, conglomerate of treatment techniques are either run concurrently or in phases in order to remove or reduce pollutants from leachate before they are discharged as there is no record of a single technique that has been effective in the removal of pollutants from leachate (Aziz and Abu Amr, 2015). Numerous treatment technologies (physico-chemical and biological) for leachate treatment have been recorded by other researchers, they include; electrocoagulation, fenton, photo-Fenton, electro-Fenton, flocculation-coagulation, ozonation, adsorption, ion exchange, persulfate and biological processes (Aziz *et al*., 2011; Bashir *et al*., 2011; Mohajeri *et al*., 2010a, b; Primo *et al*., 2008; Moravia *et al*., 2013; Ilhan *et al*., 2008; Tizaoui *et al*., 2007; Shabiimam and Dikshit, 2012; Deng and Ezyske, 2011).

The use of silica sand as a means or method for treating wastewater generally and leachate from sanitary landfill has received much attention recently due to its effectiveness in the removal of the organic components in wastewater (leachate), turbidity and Suspended Solids (SS) removal (D'Alessio *et al*., 2015; Tyagi *et al*., 2009). Sapari *et al*. (2013) also reported on the use of sand as a filter medium for treating landfill leachate as well as generating biogas in the process. This method allows contaminated water to pass through a layer of sand bed, so that as the wastewater passes through the sand bed, a hypogeal biological layer called schmutzdecke is formed at the surface of the sand layer. The schmutzdecke consists basically of agelatinous biofilm matrix of bacteria, algae, humus, fungi, rotifera and protozoa. These account for the removal of majority of the bacteria in this method. To remove particles ranging between 0.75 and 10 μm, physico-chemical mechanisms come into play (Weber-Shirk and Dick, 1997a), while for the removal of particles less than 2 μm, biological mechanisms, primarily by the ingestion of organic pollutants, come into play (Weber-Shirk and Dick, 1997b). Apart from silica sand being employed in the removal of turbidity and bacteria, reports from previous researches have also shown that there has been significant reduction in total phosphorous, Chemical Oxygen Demand (COD) and total nitrogen from contaminated waters (Lwesya and Li, 2010). The removal of iron and magnesium have also been reported by Gottinger *et al*. (2011) and Pacini *et al*. (2005).

In this present study, the treatability of the organic components (COD, BOD, NH_3-N) of leachate generated from anaerobic bioreactor through low-cost abundantly naturally occurring silica sand is investigated and documented appropriately. Since the treatment was carried out anaerobically, a fraction of the organic component of the leachate was converted into biogas. The composition of the gas generated in the process, which are chiefly methane (CH_4) and carbon dioxide (CO_2) were duly reported.

MATERIALS AND METHODS

Materials: Municipal Solid Waste (MSW) was synthesized using waste components which represents the average composition of municipal solid waste in Malaysia as shown in Table 1. The entire waste components were collected from within the University Teknologi PETRONAS campus, Malaysia. Prior to thoroughly mixing all the components of the solid waste, they were manually reduced in size (averaging between 1 and 2 cm). Size reduction of the solid waste was done in order to ease up the packing operation and also to expedite the degradation process, hence allowing for a more rapid stabilization (Hentrich *et al*., 1979). The synthetic waste was comprised of (by wet weight) food waste (86%), newspaper (3.72%), corrugated paper (1.02), plastics (0.83%), glass (0.68%), metal cans (2.19%), wood (3.10%), lawn clippings (0.68%) and cloth materials (1.02%). The initial moisture content of the synthesized waste was 81.525%. The landfill reactor was initiated by filling it up with rainwater for moisture content adjustment and initial leachate production.

Design of experiment and operation: A High Density Polyethylene Drum (HDPE) was acquired and constructed to simulate an anaerobic landfill bioreactor. The reactor set up comprised of a bottom part which contained sand of varying sizes. It was fabricated from a PVC pipe column of 109 cm height and 10.9 cm in internal diameter. The dimension of the HDPE (simulated landfill bioreactor) is thus, height 97 cm and internal diameter of 48.3 cm. Figure 1 shows the structure of the fabricated laboratory landfill bioreactor. The landfill bioreactor had a working volume of

Table 1: Composition of MSW in simulated landfill bioreactor

Waste components	Wet weight (%)	Moisture content (%)	Wet mass (kg)
Plastic	0.83	0.15	0.55
Metal	2.19	1.75	1.45
Wood	3.10	4.64	2.05
Corrugated paper	1.02	3.15	0.675
Rag	1.02	0.59	0.675
Lawn clippings	0.68	15.29	0.45
Food waste	86.76	55.24	57.24
Newspaper	3.72	0.67	2.56
Glass	0.68	0.015	0.45
Total	100.00	81.525	66.10

MSW: Municipal solid waste

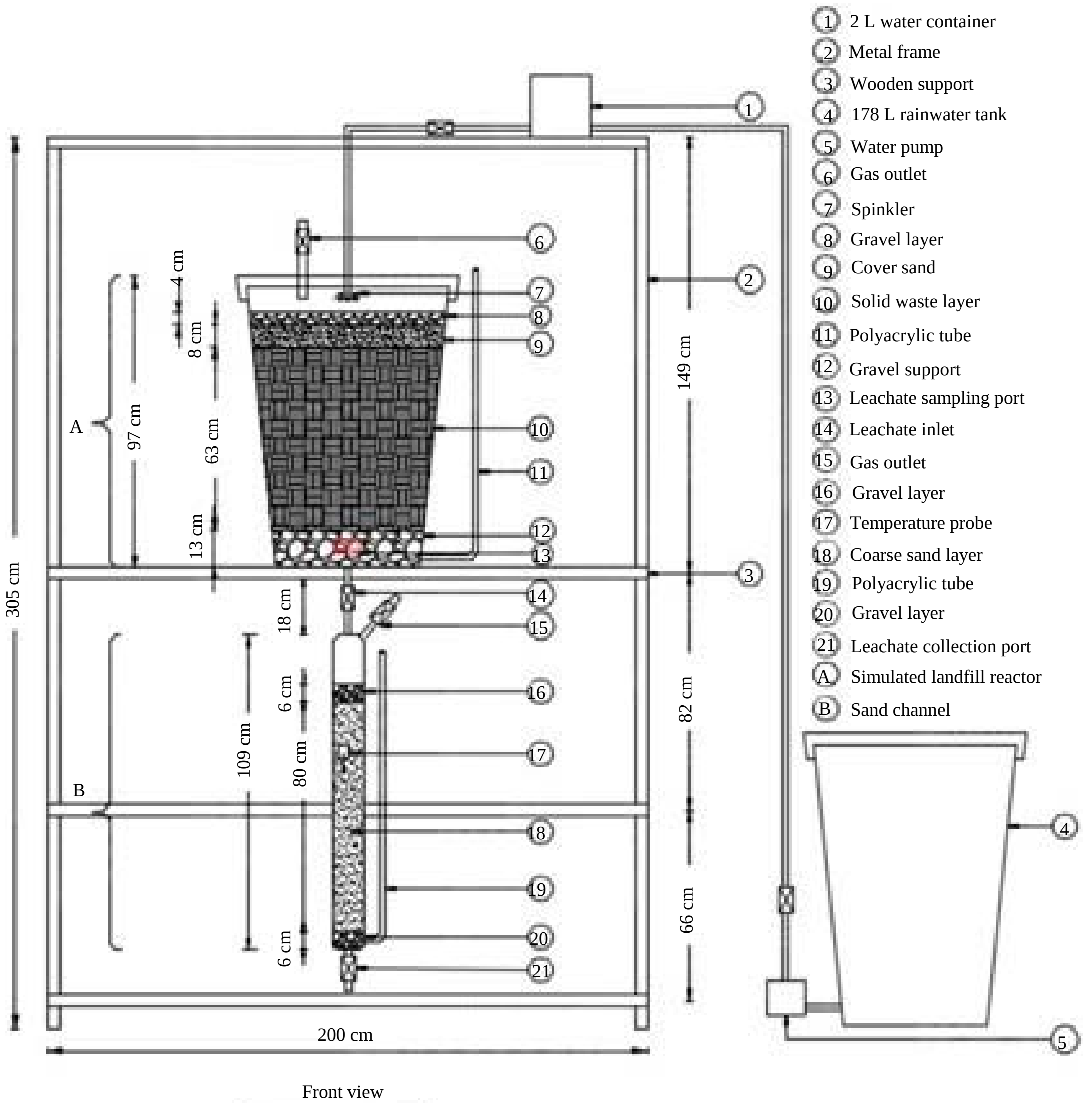

Fig. 1: Schematic representation of the simulated landfill bioreactor and sand channel

178 L with a head space of 24% v/v. The lab scale landfill reactor had an underlying bottom layer of gravel with an average size diameter of 1 cm to a height of 13 cm which served as both a support and drainage layer. The synthesized solid waste was placed on top of the gravel. A total of 66.1 kg of solid waste was packed into the reactor. The bulk density of the solid waste was 371.3 kg m^{-3}. A sand layer to a thickness of 8 cm which served as cover material was placed on top of the solid waste. Above the sand layer, a gravel layer was placed which served as the final cover. It had a thickness of 4 cm. The final cover layer enhanced proper distribution and also aided the reduction of the splattering effect of water as it is being introduced into the reactor from the top. The reactor had two openings at the top cover, one opening was used for water inlet and the other served as gas outlet. The reactor also had a temperature monitoring probe connected to it, a leachate sampling tap at the lower part and a bottom opening from where leachate drained through a 0.5 PVC pipe into the sand channel. Two water tanks containing rainwater were used to feed the reactor with

rainwater. The bigger water tank, 178 L placed on the floor was connected to a water pump. Rainwater was pumped from the bigger water tank into a smaller one, 2 L placed slightly above the reactor, from where rainwater was fed into the reactor. The leachate generated was not recirculated. The reactor was supported by a wooden platform, embedded in a steel frame. The sand channel was packed with an underlying bottom and final top layer of quartz pebble of about 1 cm diameter size to an approximate height of 6 cm, respectively. A layer of loosed sand which comprised of sands of 1.9 and 1.6, 650 and 450 μm diameter size was placed to a thickness of 80 cm on top of quartz pebble with the finer grains above the coarse grains. Quartz pebbles were used because they are inert, hence any form of chemical reactions between them and the leachate would not occur. They served as support to the loosed sand placed on them as well as to enhance elutriation of the particles during leachate sampling. The sand channel had a port installed at the top of it for gas collection and a leachate sampling tap at the bottom for collecting and monitoring leachate quality, pH, COD, BOD, NH_3-N.

Both the simulated landfill bioreactor and the sand channel had a clear polyacrylic plastic tube attached to them for monitoring leachate level within the reactor and sand channel.

Collection of samples and analysis: On a weekly basis 1 L of leachate samples were collected from both the lab scale landfill bioreactor and the sand channel. Leachate collected were analyzed for pH (sensION+MM340 GLP Benchtop pH/ISE meter), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (COD), ammonia nitrogen (NH_3-N) and nitrate. Dichromate digestion spectrophotometric method was used in the COD measurement. The BOD_5 was obtained using the dilution method, while ammonia-nitrogen was analyzed using Nessler's reagent colorimetric method. The calibration investigative samples were conducted as well as the blanks and replicates, as pertinent.

Collection of gas sample was done using 3 L Tedlar gas sampling bags. The constituent component of the recovered gas (methane, carbon dioxide and oxygen) and their concentrations were determined using gas chromatography (Shimadzu GC-2010 plus, Kyoto, Japan) furnished with a Thermal Conductivity Detector (TCD). Gas samples were collected from both the simulated landfill bioreactor and the sand channel.

Operation of bioreactor: Rainwater was slowly introduced into the laboratory landfill bioreactor from the top. Rainwater was pumped using an electrical cast iron centrifugal clean water pump (CPM146), Xuje, China. Rainwater was introduced until it covered the entire waste in the reactor. The transparent polyacrylic pipe attached vertically by the side of the reactor was used to monitor the water level and pressure inside the reactor. The pipe was open ended and was affixed at the lower part of the reactor to the same height as that of the top water tank. The reactor was kept saturated as the water level remained above the solid waste layer throughout the experiment. Leachate formed in the bioreactor drained into the sand channel. The amount of leachate drained into the sand channel (1 L) during the weekly collection and analysis of leachate sample was refilled back into the reactor. Leachate samples were analyzed for COD, BOD_5, NH_3-N, nitrate, pH, Eh weekly for the entire period the experiment was carried out (18 months).

Sand channel monitoring: The sand channel was initially loaded with rainwater to the last layer of sand. Monitoring the level of water in the sand channel was done with the aid of a transparent polyacrylic pipe installed the same way as the landfill bioreactor. A 1 L of leachate sample was collected from the sampling tap weekly for analysis. Parameters analyzed included COD, BOD_5, NH_3-N, nitrate, pH, Eh. The reactor was run and operated for a total period of about 18 months.

RESULTS AND DISCUSSION

Variations in the pH of leachate samples collected from the simulated landfill bioreactor and sand channel: Within the first week of monitoring the reactor, the pH values of both the simulated landfill bioreactor and the sand channel dropped to around 4 but after the first month, the pH of the sand channel had increased to about 6.3, while the pH of the simulated landfill bioreactor remained at 5 in the first month (Fig. 2). A similar observation was reported elsewhere (Xu *et al*., 2015). However, it experienced a hike as the experimental period progressed but nonetheless, the reactor remained acidic throughout the experiment with the maximum pH value at 6.2 in the month of February. This eventually would result in a longer duration of time required for the organic fraction of the waste to stabilize, especially as methane forming anaerobes are quite sensitive to acidity (Bolzonella *et al*., 2003). Methane gas was seen to be generated in the simulated landfill bioreactor, with concentrations ranging between 3% to a maximum of 25% despite the low pH signifying acidity throughout the experiment. This can be associated with the presence of hydrogenotrophic methanogens found in organic solid wastes (Paulo *et al*., 2003). Hall *et al*. (1995) described the phenomenon called "Acid habituation" or "The adaptive acid tolerance response" as the reason for the resistance of anaerobes in organic solid wastes. Also, according to Speece (1996), alkalinity from ammonium bicarbonate within cells can keep their pH to near neutral. On the contrary, the pH value of the sand channel became 7.3 in the 2 month and remained fairly constant throughout the experiment, with the maximum at 7.9 in the month of June.

Variations in the COD of leachate samples collected from the simulated landfill bioreactor and sand channel: There was a rapid increase in the amount of COD in the simulated landfill bioreactor within the 1st month of initiation. The COD value came up to almost 26,000 mg L^{-1} (Fig. 3). This can be attributed to the hydrolysis of organic matter occurring in the reactor (Xu *et al*., 2015). The COD concentration decreased by the second month and thereafter increased steadily until it reached almost 48,000 mg L^{-1} in the 12th month. By the 20th month, it had decreased to about 34,000 mg L^{-1}. Contrarily, the amount of COD in the sand channel increased until it reached a maximum value of about 32,000 mg L^{-1} after 11 months of operation and then began to decrease. By the 20th month of the sand channel operation, the COD was about 5,800 mg L^{-1}.

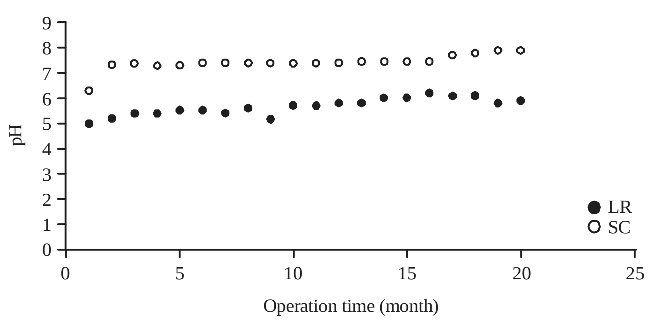

Fig. 2: pH for both simulated landfill reactor and sand channel for 20 months

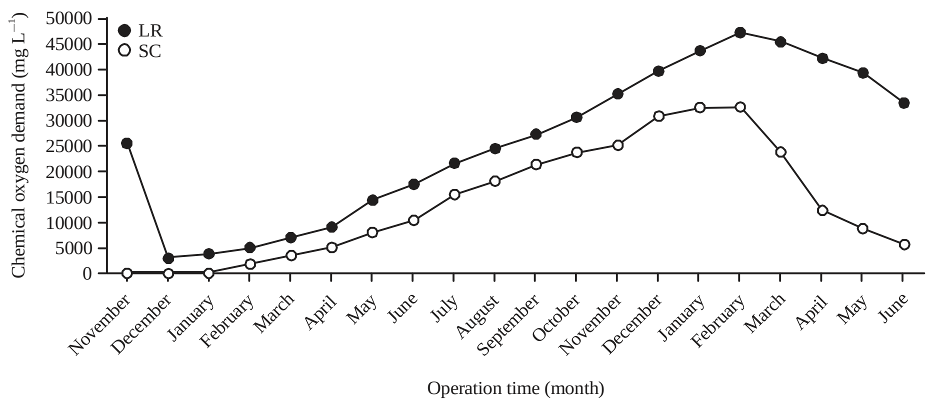

Fig. 3: Variations of chemical oxygen demand concentration in the simulated landfill reactor and sand channel

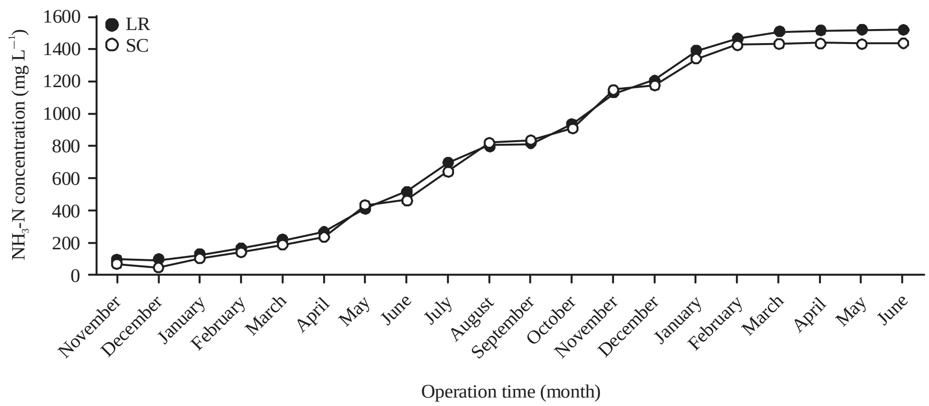

Fig. 4: Variations of ammonia concentration in leachate in the simulated landfill reactor and sand channel

COD reduction may have been due to a possible rapid decomposition of the organic fraction of the solid waste in the reactors (Agdag and Sponza, 2005). The effect of the occurrence of alkalinity in the sand channel was seen to have influenced the reduction of the COD amount. This clearly shows that as the leachate in the reactor becomes more alkaline in nature, there is enhanced anaerobic degradation of the organic fraction of the solid waste and at this stage, methanogenesis is said to have occurred, where there is a quick conversion of the organic matters into methane (Agdag and Sponza, 2005). However, because the simulated landfill bioreactor remained acidic and was not a convenient environment for methanogenic bacteria to thrive, degradation of organic materials was observed to be slow and low as well as described by Agdag and Sponza (2005), who recorded that methanogenic bacteria are more efficient when the condition of pH is almost neutral, with 6.5-8.2 being the commonly accepted optimum range.

Variations in the ammonia (NH_3-N) of leachate samples collected from the simulated landfill bioreactor and sand channel: The variations in concentration of ammonia (NH_3-N) are shown in Fig. 4. Ammonia (NH_3-N) which is a product of the degradation of protein, usually accumulates in anaerobic environments due to the lack of biological nitrification-denitrification operation (Valencia *et al*., 2011). Hence, the concentration of NH_3-N in both the simulated landfill bioreactor and the sand channel accrued continuously throughout the experiment. The maximum concentration for both reactors at the end of the experiment were 1509.56 and 1435 mg L^{-1}, respectively. The disparity in ammonia concentration between the simulated landfill reactor and the sand channel was observed to be very infinitesimal. NH_3-N removal from the sand channel was very low and this can be associated with the usage of NH_3-N through ingestion of anaerobic bacteria (Yalmaz and Ozturk, 2001).

Concentration of methane gas (CH_4) recovered from the simulated landfill bioreactor and sand channel: There was a steady increase in methane gas production percentage from the onset of the operation of the reactor, until it reached the highest percentage in the 16th month for both the simulated landfill bioreactor and the sand channel. The highest percentage of methane gas generation in the sand channel was 58% in contrast to the 25% peak methane gas generation in the landfill reactor. The high cumulative methane gas generation in the sand channel can be associated with the rapid and steady degradation of the organic fraction of the municipal solid wastes in the reactor via rapid methanogenesis occurring on the 16th month Agdag and Sponza (2005).

A constant decline was observed in the percentage of methane gas recovered from both the simulated landfill bioreactor and the sand channel after 16 months of operation and by the 20th month gas recovered had significantly decreased (Fig. 5). This can be attributed to termination in the anaerobic degradation of the organic fraction of the solid waste (Agdag and Sponza, 2005). Methane gas percentages in the sand channel which showed early leachate stabilization by attaining a neutral pH indicates that neutrality and alkalinity both positively affect the efficiency in terms of degradation of the organic solid waste in the sand channel as a result of the high methane gas generated in it (Agdag and Sponza, 2005).

Leachate quality before and after passing through the sand channel: The leachate characteristics before and after passing through the sand channel is presented on Table 2. It shows the maximum values for the simulated landfill bioreactor and the value after passing through the sand channel.

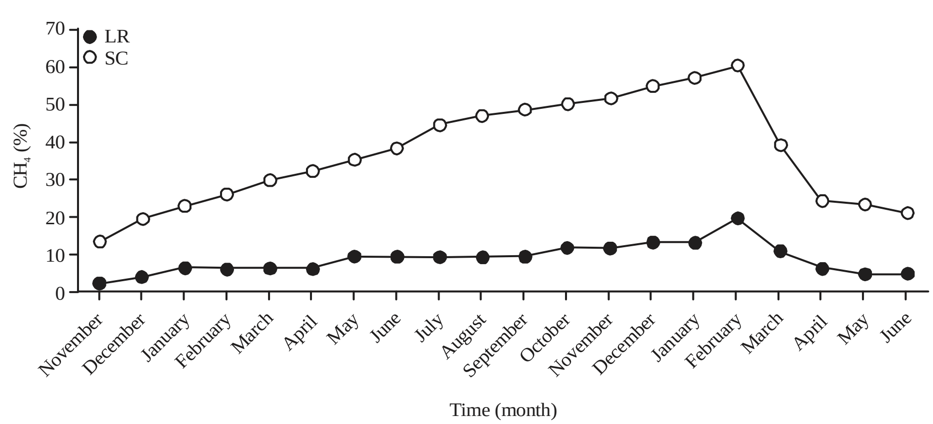

Fig. 5: Methane gas recovery rate percentage for 20 months operation period

Table 2: Leachate characteristics in simulated landfill bioreactor and sand channel

Parameters	Leachate characteristics	
	Leachate from the simulated landfill bioreactor	Leachate from sand channel
COD (mg L^{-1})	47172.25	5732.0
BOD_5 (mg L^{-1})	21227.5	2107.0
Ammonia (NH_3-N) (mg L^{-1})	1509.6	1435.0
pH	6.2	7.9

COD: Chemical oxygen demand, BOD: Biochemical oxygen demand

The table clearly shows the efficiency derived in terms of reduction in concentration of the organic pollutant in the leachate after it passed through the sand channel. The peak pH value for the simulated bioreactor was 6.2 depicting that the reactor remained in the acidic phase throughout the experimental period.

CONCLUSION

In this study, the performance of a novel sand channel operating under saturated condition and kept under anaerobic condition was accessed in terms of leachate treatment (reduction of organic load in leachate) and biogas generation. Leachate was generated from an anaerobic lab scale landfill bioreactor with a maximum pH of 6.2, COD and BOD_5 of 47172.25 and 21227.5 mg L^{-1}, respectively. This highly concentrated leachate was treated to generate methane gas in a sand channel. Methanogenesis was quickly established in the sand channel by a slow continuous and systematic introduction of the leachate into the sand channel over a period of 20 months. After passing through the sand channel the leachate was observed to have reduced greatly in concentration with a final COD and BOD_5 of 5732 and 2107 mg L^{-1}. The constituent composition of methane gas collected from the sand channel and the simulated landfill bioreactor were 77 and 25%, respectively. The sand channel was very efficient in leachate treatment and methane gas generation. Having a sand layer under young landfills increases their potential to treat leachate and also generate methane gas which can be recovered and used as an alternative source of clean energy as demonstrated in this study.

ACKNOWLEDGMENT

The authors are grateful to the Universiti Teknologi PETRONAS (UTP) management for sponsoring this study through the Graduate Assistantship (GA) scheme and the Fundamental Research Grant Scheme (FRGS) grant number 0153AB-C56.

REFERENCES

Agdag, O.N. and D.T. Sponza, 2005. Effect of alkalinity on the performance of a simulated landfill bioreactor digesting organic solid wastes. Chemosphere, 59: 871-879.

Aziz, H.A., Z. Daud, M.N. Adlan and Y.T. Hung, 2009. The use of polyaluminium chloride for removing colour, COD and ammonia from semi-aerobic leachate. Int. J. Environ. Eng., 1: 20-35.

Aziz, S.Q., H.A. Aziz, M.S. Yusoff and M.J.K. Bashir, 2011. Landfill leachate treatment using powdered activated carbon augmented Sequencing Batch Reactor (SBR) process: optimization by response surface methodology. J. Hazard. Mater., 189: 404-413.

Aziz, H.A. and S.S. Abu Amr, 2015. Performance of combined ozone and Fenton process in treating different leachate concentrations. IAFOR J. Sustain. Energy Environ., 2: 3-14.

Bashir, M.J.K., H.A. Aziz and M.S. Yusoff, 2011. New sequential treatment for mature landfill leachate by cationic/anionic and anionic/cationic processes: Optimization and comparative study. J. Hazard. Mater., 186: 92-102.

Bolzonella, D., P. Battistoni, J. Mata-Alvarez and F. Cecchi, 2003. Anaerobic digestion of organic solid wastes: Process behaviour in transient conditions. Water Sci. Technol., 48: 1-8.

Christensen, T.H., P. Kjeldsen, P.L. Bjerg, D.L. Jensen and J.B. Christensen *et al*., 2001. Biogeochemistry of landfill leachate plumes. Applied Geochem., 16: 659-718.

D'Alessio, M., B. Yoneyama and C. Ray, 2015. Fate of selected pharmaceutically active compounds during simulated riverbank filtration. Sci. Total Environ., 505: 615-622.

Deng, Y. and C.M. Ezyske, 2011. Sulfate Radical-Advanced Oxidation Process (SR-AOP) for simultaneous removal of refractory organic contaminants and ammonia in landfill leachate. Water Res., 45: 6189-6194.

Foul, A.A., H.A. Aziz, M.H. Isa and Y.T. Hung, 2009. Primary treatment of anaerobic landfill leachate using activated carbon and limestone: Batch and column studies. Int. J. Environ. Waste Manage., 4: 282-298.

Ghangrekar, M.M. and U.J. Kahalekar, 2003. Performance and cost efficacy of two-stage anaerobic sewage treatment. J. Inst. Eng., 84: 16-22.

Gottinger, A.M., D.W. McMartin, D. Price and B. Hanson, 2011. The effectiveness of slow sand filters to treat Canadian rural prairie water. Can. J. Civil Eng., 38: 455-463.

Hall, H.K., K.L. Karem and J.W. Foster, 1995. Molecular responses of microbes to environmental pH stress. Adv. Microb. Physiol., 37: 229-272.

Hentrich, R.L., J.T. Swartzbough and J.A. Thomas, 1979. Influence of Municipal Solid Waste Processing on Gas and Leachate Production. In: Municipal Solid Waste, Wanielista, M.P. and J.S. Taylor (Eds.). Municipal Environmental Research Laboratory, Office of Research and Development, U. S. Environmental Protection Agency, Washington, DC.

Ilhan, F., U. Kurt, O. Apaydin and M.T. Gonullu, 2008. Treatment of leachate by electrocoagulation using aluminum and iron electrodes. J. Hazardous Mater., 154: 381-389.

Lwesya, G.G. and Y. Li, 2010. Treatment of light contaminated surface water using slow sand filtration in China. J. Am. Sci., 6: 47-57.

Machdar, I., Y. Sekiguchi, H. Sumino, A. Ohashi and H. Harada, 2000. Combination of a UASB reactor and a curtain type DHS (downflow hanging sponge) reactor as a cost-effective sewage treatment system for developing countries. Water Sci. Technol., 42: 83-88.

Marchioretto, M. and M. Reali, 2001. Ozonation followed by coagulation/flocculation and flotation as post-treatment of the effluent from an anaerobic baffled reactor treating domestic sewage. Water Sci. Technol., 43: 99-106.

Mohajeri, S., H.A. Aziz, M.H. Isa, M.A. Zahed and M.N. Adlan, 2010a. Statistical optimization of process parameters for landfill leachate treatment using electro-Fenton technique. J. Hazard. Mater., 176: 749-758.

Mohajeri, S., H.A. Aziz, M.H. Isa, M.J.K. Bashir, L. Mohajeri and M.N. Adlan, 2010b. Influence of Fenton reagent oxidation on mineralization and decolorization of municipal landfill leachate. J. Environ. Sci. Health Part A: Toxic/Hazard. Subst. Environ. Eng., 45: 692-698.

Moravia, W.G., M.C.S. Amaral and L.C. Lange, 2013. Evaluation of landfill leachate treatment by advanced oxidative process by Fenton's reagent combined with membrane separation system. Waste Manage., 33: 89-101.

Naumczyk, J., I. Prokurat and P. Marcinowski, 2012. Landfill leachates treatment by H_2O_2/UV,O_3/H_2O_2, modified fenton and modified photo-fenton methods. Int. J. Photoenergy. 10.1155/2012/909157

Pacini, V.A., A.M. Ingallinella and G. Sanguinetti, 2005. Removal of iron and manganese using biological roughing up flow filtration. Water Res., 39: 4463-4475.

Paulo, P.L., G. Villa, J.B. van Lier and G. Lettinga, 2003. The anaerobic conversion of methanol under thermophilic conditions: pH and bicarbonate dependence. J. Biosci. Bioeng., 96: 213-218.

Prakash, K.J., V.K. Tyagi, A.A. Kazmi and A. Kumar, 2007. Post-treatment of UASB reactor effluent by coagulation and flocculation process. Environ. Progr., 26: 164-168.

Primo, O., M.J. Rivero and I. Ortiz, 2008. Photo-Fenton process as an efficient alternative to the treatment of landfill leachates. J. Hazard. Mater., 153: 834-842.

Renou, S., J.G. Givaudan, S. Poulain, F. Dirassouyan and P. Moulin, 2008. Landfill leachate treatment: Review and opportunity. J. Hazard. Mater., 150: 468-493.

Sapari, N., S. Mustapha, E. Olisa and H. Jusoh, 2013. Improving the production of gas in landfills by methanogenic sand layer. Proceedings of the IEEE Conference on Clean Energy and Technology, November 18-20, 2013, Lankgkawi, Malaysia, pp: 27-32.

Sato, N., T. Okubo, T. Onodera, A. Ohashi and H. Harada, 2006. Prospects for a self-sustainable sewage treatment system: A case study on full-scale UASB system in India's Yamuna River Basin. J. Environ. Manage., 80: 198-207.

Schiopu, A.M. and M. Gavrilescu, 2010. Options for the treatment and management of municipal landfill leachate: Common and specific issues. Clean: Soil Air Water, 38: 1101-1110.

Shabiimam, M.A. and A.K. Dikshit, 2012. Treatment of municipal landfill leachate by oxidants. Am. J. Environ. Eng., 2: 1-5.

Speece, R.E., 1996. Anaerobic Biotechnology for Industrial Wastewaters. Archae Press, Nashville Tennessee, USA., ISBN-13: 978-0965022606, Pages: 416.

Tawfik, A., G. Zeeman, A. Klapwijk, W. Sanders, F. El-Gohary and G. Lettinga, 2003. Treatment of domestic sewage in a combined UASB/RBC system. Process optimization for irrigation purposes. Water Sci. Technol., 48: 131-138.

Tizaoui, C., L. Bouselmi, L. Mansouri and A. Ghrabi, 2007. Landfill leachate treatment with ozone and ozone/hydrogen peroxide systems. J. Hazard. Mater., 140: 316-324.

Tyagi, V.K., A.A. Khan, A.A. Kazmi, I. Mehrotra and A.K. Chopra, 2009. Slow sand filtration of UASB reactor effluent: A promising post treatment technique. Desalination, 249: 571-576.

Valencia, R., W. van der Zon, H. Woelders, H.J. Lubberding and H.J. Gijzen, 2011. Anammox: An option for ammonium removal in bioreactor landfills. Waste Manage., 31: 2287-2293.

Weber-Shirk, M.L. and R.I. Dick, 1997a. Biological mechanisms in slow sand filters. Am. Water Works Assoc. J., 89: 72-83.

Weber-Shirk, M.L. and R.I. Dick, 1997b. Physical-chemical mechanisms in slow sand filters. Am. Water Works Assoc. J., 89: 87-100.

Xu, Q., Y. Tian, S. Wang and J.H. Ko, 2015. A comparative study of leachate quality and biogas generation in simulated anaerobic and hybrid bioreactors. Waste Manage., 41: 94-100.

Yalmaz, G. and I. Ozturk, 2001. Biological ammonia removal from anaerobically pre-treated landfill leachate in Sequencing Batch Reactors (SBR). Water Sci. Technol., 43: 307-314.