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ENHANCED IN-SITU REDUCTION OF LEACHATE PARAMETERS DUE TO AERATION AND LEACHATE RECIRCULATION IN PILOT SCALE MSW BIOREACTOR LANDFILL MODELS IN TROPICAL CLIMATE

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ABSTRACT

The processes for optimizing toxicity removal of leachate from pilot scale Municipal Solid Waste bioreactor landfills were attempted. Landfill models were simulated in Fibre Reinforced Plastic tanks of size 1.5m x 1.0m x 1.0m by applying interventions like aeration and leachate recirculation. It was found that the Chemical Oxygen Demand and Biochemical Oxygen Demand values increased till 46*th* week after which the values started reducing. On 89*th* week after closure of landfill, the aerobic landfill model showed the minimum values for COD (10,200 mg/l) and both anaerobic and aerobic models with leachate recirculation had the lowest BOD (4934 mg/l). By 116*th* week the least concentrations of COD and BOD were in anaerobic landfill model with leachate recirculation (64 and 22 mg/l). Ammonia Nitrogen was the least in aerated model with leachate recirculation by 116th week from closure (281 mg/l). Conductivity was less in the landfill models with leachate recirculation (4.2 and 5 mS/cm for anaerobic and aerobic respectively).

KEY WORDS : Municipal Solid Waste, Landfill, Leachate, In situ bioremediation

INTRODUCTION

Leachate is a mixture of aqueous effluent generated by excess rainwater percolating through the municipal solid waste in landfill which contains a high concentration of organic and inorganic contaminants including humid acids, ammonia nitrogen, heavy metals, xenobiotics, chlorinated organic and inorganic salts. (Abbas *et al.*, 2009; Aluko *et al.,* 2003; Manandhar *et al.,* 2012; Taneja 2011; and Wiszniowski *et al.,* 2006). However, the content of heavy metal in leachate is comparatively low as a result of the attenuation process taking place in the disposed waste (Manandhar *et al.,* 2012 and Renou *et al.,* 2008). Due to the toxicity and presence of pollutants such as COD and NH_3-N or Total nitrogen, the leachate should be treated before it is released into the environment (Wiszniowski *et al.* 2006 and Zhao, 2018)). By studying the water balance of the landfill, the potential for the

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formation of leachate can be assessed (Iqbal *et al.*(2015). There are many technologies used for treating leachate such as biological, chemical, and physical methods. The biological method of nitrification/denitrification is probably the most efficient and cheapest process to eliminate nitrogen from leachate (Wiszniowski *et al.*, 2006). The quality and quantity of leachate depend on many factors such as waste components, the biological, chemical, and physical condition of waste, seasonal variation, waste type, age etc. (Abbas *et al.*, 2009), Manandhar *et al.*, 2012 and Youcai, 2013). Other factors affecting the leachate quantity are water intrusions (like rain, snow, and groundwater) and landfill operations (compaction, pre-treatment, and daily cover (Sekman *et al.*, 2011). Leachate from old landfills is highly contaminated with ammonia, and COD in old landfill is comparatively low compared to new landfills (1). The characteristics of leachate can be determined by measuring pH, oxidation-reduction potential, total dissolved solids, conductivity, chloride, COD, BOD, ammonia nitrogen, and BOD/COD ratio (Bilgili *et al.* (2007), Kjeldsen *et al.* (2002), Taneja, 2011). Recirculation of leachate is the best method for optimizing gas generation because it encourages the biodegradation of waste by raising moisture content and stimulates microbial activity (Mehta *et al.*, 2002).

MATERIALS AND METHODS

The study is based on experimental work. Pilot scale landfill models were simulated in 1.5mx1.0mx1.2m fibre glass tanks. Four sets of models were prepared which represents various landfill bioreactor processes like:

a. Anaerobic + moisture addition – this model is kept as control in which the only intervention is addition of moisture. In this model toxicity removal potential of indigenous anaerobic microorganisms is achieved.
b. Anaerobic + moisture addition + leachate recirculation (LR) - this model is kept anaerobic with intervention in the form of moisture addition and leachate recirculation
c. Aerobic + moisture addition – Controlled amount of air is pumped into the system which achieves toxicity removal through aerobic indigenous microorganisms
d. Aerobic + moisture addition + leachate recirculation – Toxicity removal potential of aerobic indigenous microorganisms is assessed when leachate is recirculated.

Experimental Set Up

The tanks were fabricated in fibre glass with provisions for landfill gas and leachate collection without external contamination, moisture/leachate addition and ports for aeration of the system. Leachate collection system included a network of perforated pipes connected to the main pipe and laid horizontally within the bottom gravel layer which connects to the outlet valve on one side of the tank at bottom 5 cm. The diagrammatic figures of the leachate collection and gas collection system are given in Figure 1.

Aeration system included a zero air cylinder fitted with a pressure regulator and connected to the

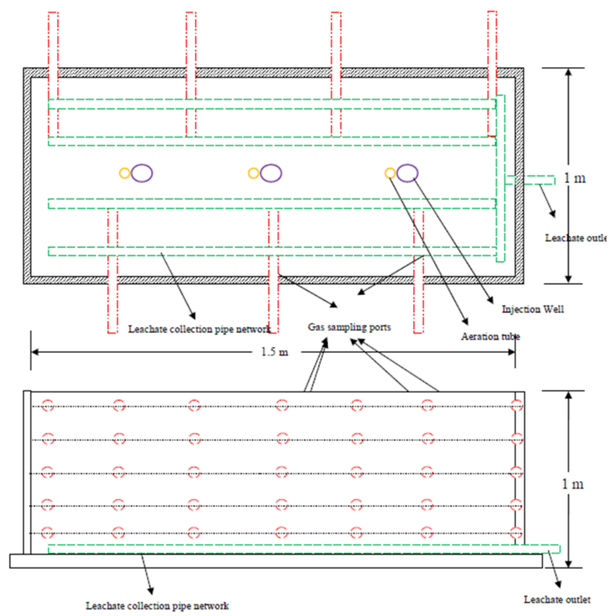

Fig. 1. Diagrammatic representation of Leachate collection system and LFG collection ports

Fig. 2. Zero air with pressure flow regulator

aeration tubes fitted in the aerobic models. Each model is fitted with 3 vertical pipes with perforations (from the topmost soil layer at 90cm height to the middle (50 cm) of the tanks) and spaced equidistant from each other along the length (1.5m) of the tank. Moisture addition was achieved through a network of perforated pipes laid horizontally at the topmost soil layer of the landfill models with inlet pipes projecting out of the landfill models. The field set up for aeration is given in Figure 2.

The models were prepared in the exactly same manner in which a landfill is made. The bottom layer comprised of fine gravel of 10 cm thick in which a pipe system was laid to collect and transport leachate to the outlet fitted with a valve. The next layer was coarse river sand of 5cm to filter out the solids from entering the leachate collection system on top of which the first soil layer of 5cm was laid. These three layers formed the base of the landfill models. The Municipal Solid Waste (MSW) layer of 10 cm thickness was laid on this base layer which was then topped by 5cm soil layer. The 5cm soil layer and 10 cm thick MSW layer were alternated till the landfill reached 90 cm height. The final cover was made with Benton clay layer of 10 cm in two layers with a PTFE sheet in between. The diagrammatic representation of the landfill model is given in Figure 3 and the set up in the field is given in Figure 4.

MATERIALS

Municipal Solid Waste

The typical composition of Municipal Waste in

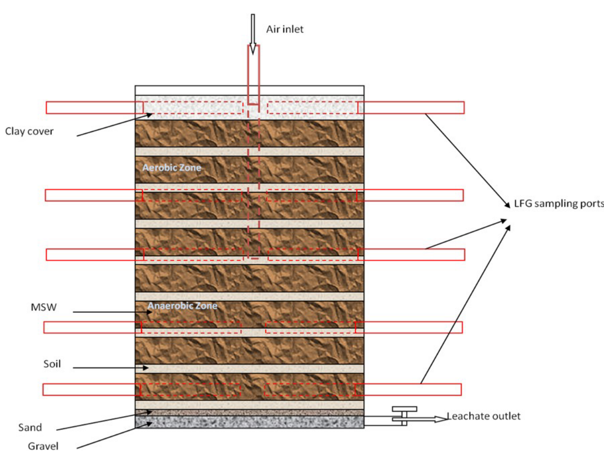

Fig. 3. Diagrammatic representation of the landfill model – a lateral side view

Fig. 4. Experimental set up

Kerala as published by State of the Environment (2002), Government of Kerala was adopted as the basis for the Municipal Solid Waste used in the landfill models.

Table 1. Typical Composition of Municipal Waste in Kerala

Typical Composition	Typical Sp wt (kg/m^3)	Typical Composition
Food wastes	290.717	9.09%
Paper	88.995	2.25%
Plastics	65.263	2.79%
Textiles	95.326	3.00%
Glass	195.789	1.30%
Other Metal(Copper, Zinc, Chromium, Iron, steel)	320.382	1.02%
Tin cans	88.995	0.10%
Aluminium	160.191	0.60%
Rubber	130.526	2.11%
Battery, car battery	3000	0.05%
Unclassified (inert etc.)	100	11.1%

Source: Padmalal and Reghunath (2002).

Table 2. Characteristics of cover soil

Gravel (> 2 mm)	4.36%
Total sand (2 mm-0.05 mm)	74.92%
Sand Fraction	
a. Very coarse (2mm-1 mm)	10.20%
b. Coarse (1mm-0.5 mm)	20.81%
c. Medium (0.5 mm-0.25 mm)	20.50%
d. Fine (0.25 mm-0.1 mm)	12.80%
e. Very fine (0.1 mm-0.05 mm)	10.61%
Silt (0.05 mm-0.002 mm)	11.47%
Clay (<0.002 mm)	9.25%

Cover Soil

The cover soil was procured from a materials contractor in Trivandrum. The soil was assessed for its characteristics and quality in terms of nutrients and presence of heavy metals. Tables 2, 3 and 4 gives the characteristics, nutrients present and heavy metal concentrations in cover soil.

Zero Air

Zero air for aeration was procured from laboratory gas suppliers in Trivandrum. It was obtained in cylinders and the quality was of laboratory standard with moisture and hydrocarbons removed. The zero air cylinders were fitted with pressure regulators and connected to all of the 12 aeration tubes in 4 landfill models. The regulator controls the pressure and hence the amount of air flowing from the cylinder and the valves in the aeration are used to restrict or open air flow into the models.

Method

The study was conducted in 3 phases: acclimatizing, introducing air and recirculating leachate, and varying aeration rates.

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Table 3. Nutrients in cover soil

Organic Carbon	0.19%
Organic Matter	0.33%
Total Nitrogen	0.23%
Moisture Content	13.09%

Table 4. Heavy metals in cover soil (ppm)

Iron	26.00
Manganese	23.75
Copper	1.65
Zinc	1.45
Lead	1.00
Cadmium	0.10
Nickel	0.65
Chromium	0.05

Phase 1: Acclimatizing the Models

The landfill models were set up and all the inlets and outlets kept closed for the first 10 days for all the landfill models to become stable. The only intervention was in the form of moisture addition of 500ml/day to all the models.

Phase 2: Aeration

Two of the landfill models were aerated from 15 th week onwards. Aeration at the rate of about 15 ml/min was given to the two aerobic models continuously during the acclimatization period of 30 days, and then increased in increments to 25ml/min for 10 minutes every 24 hours.

Phase 3: Leachate recirculation

Recirculation of leachate (500 ml every day) commenced after two months of closure of landfill models for two of the models, one anaerobic and one aerobic.

RESULTS AND DISCUSSION

Leachate generation started after two months of final cover placement, and was monitored. The parameters which were analysed include Biochemical Oxygen Demand (BOD), Ammonia-Nitrogen (NH_3-N), pH, conductivity and heavy metals copper (Cu), chromium (Cr), iron (Fe), zinc (Zn) and nickel (Ni). Table 5 shows the characteristics of initial leachate. Charts 1 to 4 shows the COD and BOD values and its reduction in percentage from the control model. Charts 1 to 10 show the leachate parameters ammonia, pH and conductivity during the active bioreactors phase in the initial years and after stabilization of the MSW in the landfills during the end of the study after two years. Table 6 to 9 shows these leachate parameters at the initial phase of study (10*th* week), near to one year (46*th* week) when the leachate parameters increases to a maximum, near to two years (89*th*

Table 5. Range of Parameters in initial leachate

Parameter	Measured range in samples	Typical range reported in field
pH	7.06-8.18	4.5-9
Conductivity(mS/cm)	12-22 (DW-0.091)	0.48- 72.5
NH3-N (mg/l)	48-55	50-2,200
Heavy Metals (mg/l)	Trace	Cr - 0.02 - 1.5
	Cu - 0.005 - 10	
	Ni - 0.015 - 3	
	Zn - 0.03 - 1,000	
	Fe - 3 - 5,500	

week) when the leachate parameters start to decrease and after two years (116*th* week) near to end of the study.

Inference

It can be observed that the previous day's atmospheric temperature has a positive influence on all the leachate parameters. Most of the leachate parameter values increased till 46*th* week after closure and then started declining slowly till 89*th* week in all the models. Drastic reduction in the leachate parameters were found after 89*th* week in all the models. Some of the parameters showed higher reduction in aerated models than anaerobic models. The heavy metals became undetectable in leachate after the initial weeks.

COD (Chart 1&2): it can be seen that in both anaerobic models, COD of leachate increased from 10*th* week (10,000 and 8560 mg/l for control and anaerobic + LR) to 46*th* week (13,230 and 14,100 mg/l) and then decreased slightly (10,360 and 10,280 mg/l by 89*th* week). In the aerobic models, COD of leachate increased from 10*th* week to 54*th* week and then decreased slightly till 89*th* week. By 116*th* week, COD has reduced near to permissible levels in all models with the values for the anaerobic models being 232 and 64 mg/l. The models where leachate was recirculated showed the maximum reduction in COD values.

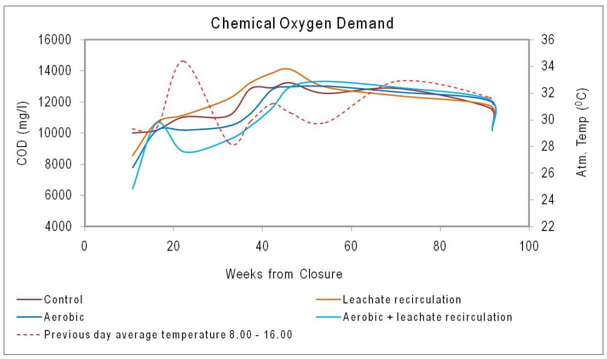

Chart 1. COD values over time from closure

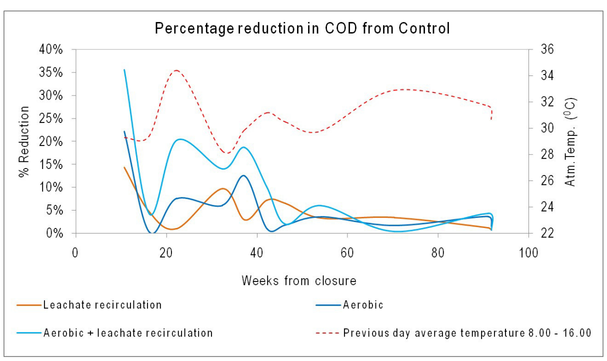

Chart 2. Percentage reduction in COD over time from closure

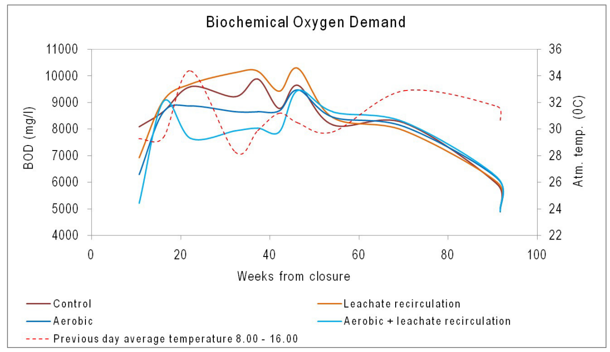

Chart 3. BOD values over time from closure

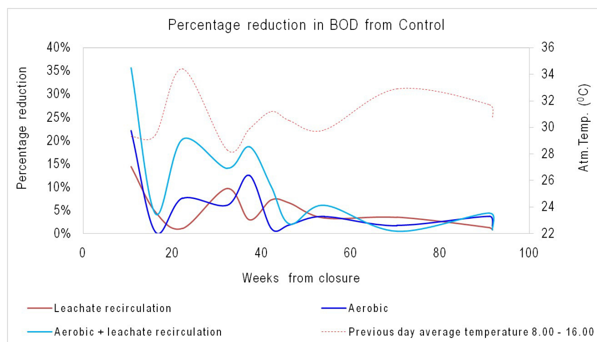

Chart 4. Percentage reduction in BOD over time from closure

BOD (Charts 3 & 4): In all the models, BOD of leachate increased from 10*th* week to 46*th* week and then decreased. By 116*th* week, BOD has reduced substantially in all models; the maximum reduction was in the models where leachate was recirculated.

pH (Charts 5 & 6): pH in all the models ranged between 7 and 8.8 in all models by 22*nd* week after closure which then decreased and to a range between 7 and 8 by 32*nd* week except in anaerobic

Table 6. Chemical Oxygen Demand (mg/l)

Model	10th week	46th week	89th week	116th week
Control	10,000	13,230	10,360	232
Anaerobic + LR	8560	14,100	10,280	64
Aeration	7784	13020	10200	320
Aeration + LR	6440	13320	10280	104

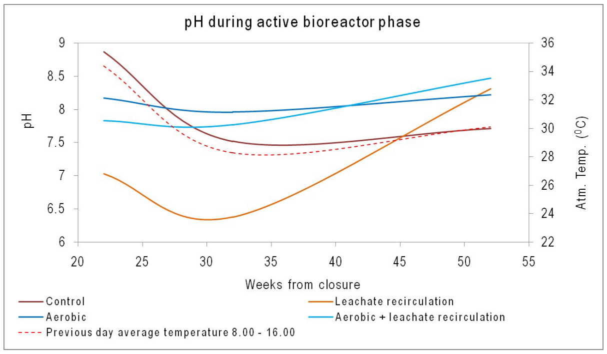

Chart 5. pH overtime from closure during active phase

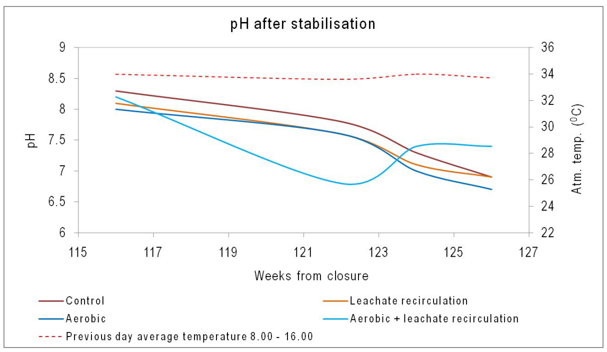

Chart 6. pH overtime from closure after stabilization of MSW

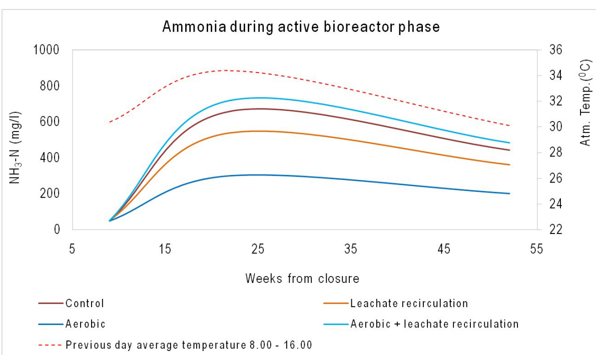

Chart 7. Ammonia over time from closure during active phase

model with leachate recirculation where the pH reduced to 6.5. By the end of one year pH values increased slightly in all the models to a range between 7.7 and 8.5. By 116th week, pH of leachate from all the models became in the range 8 to 8.3 and by 124th week these became in the neutral range from 6.7 to 7.8.

NH_3-N (Charts 7 & 8). The ammonia nitrogen in the leachate on 9th week after closure of landfill was around 50mg/l in all the models the concentration of which increased till 116th week except for aerobic

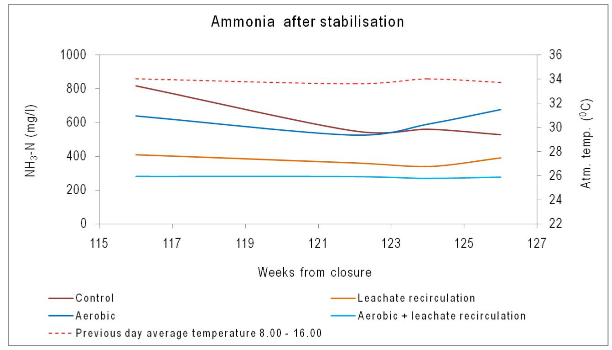

Chart 8. Ammonia over time from closure after stabilization of waste

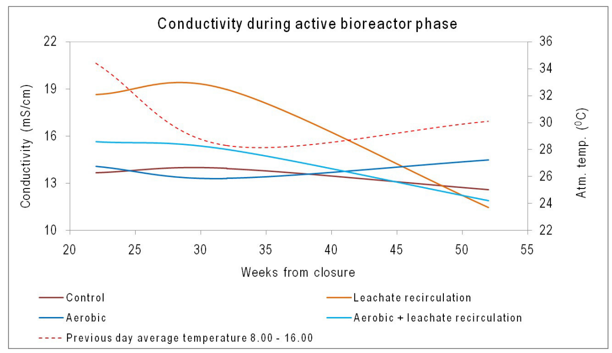

Chart 9. Conductivity over time from closure during active phase

model with leachate recirculation where the concentration peaked in one year and then decreased.

Conductivity (Charts 9 & 10): Conductivity decreased gradually with time in all the models till 38th week and then decreased substantially by 116th week, except in control model where it increased gradually till 38th week and then decreased substantially.

Table 7. Ammoniacal Nitrogen during active bioreactor phase (mg/l)

Model	9th week	38th week	116th week
Control	48.63	442.20	817
Anaerobic + LR	51.36	361.80	409
Aeration	48.63	201.00	638
Aeration + LR	49.54	482.40	281

CONCLUSION

Findings

1. The COD values decreased maximum in anaerobic model with leachate recirculation. Both the models with leachate recirculation

Table 8. Biochemical Oxygen Demand (mg/l)

Model	10th week	46th week	89th week	116th week
Control	8100	9658	4973	66
Anaerobic + LR	6934	10293	4934	22
Aeration	6305	9479	4896	80
Aeration + LR	5216	9461	4934	28

Table 9. Conductivity during active bioreactor phase (mS/cm)

Model	9th week	38th week	116th week
Control	12.36	13.94	8.4
Anaerobic + LR	21.74	18.95	4.2
Aeration	15.63	13.31	8.6
Aeration + LR	18.11	15.15	5

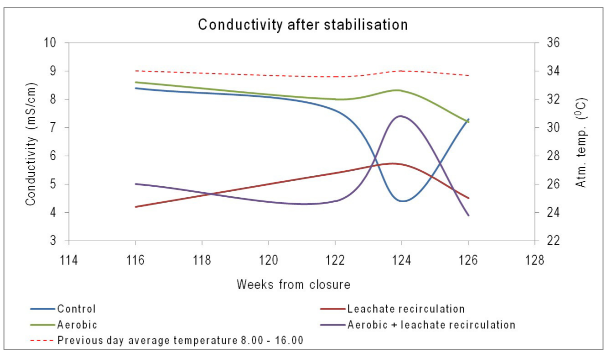

Chart 10. Conductivity over time from closure after stabilization of waste

showed considerable reduction in COD values by 116*th* week (64 and 104*mg/l*).

2. The BOD values also decreased maximum in anaerobic model with leachate recirculation. As like COD, both the models with leachate recirculation showed considerable reduction in COD values by 116*th* week (22 and 28*mg/l*).
3. The concentration of NH_3-N was the most reduced in aerated model with leachate recirculation by 116*th* week (281*mg/l*).
4. Conductivity was lower in models with leachate recirculation by 116*th* week and after though the values were higher in the initial phase.
5. pH was found to be mostly in the alkaline range of 8 – 8.7 in all the models till 116*th* week and by 124*th* week and after these were in the neutral range from 6.7 to 7.8.
6. The pollutants in the leachate was higher in models with leachate recirculation during the initial years, this may be due to the enhanced metabolic processes in these causing generation of intermediary compounds which gets into the leachate.
7. All the parameters in all the models reduced substantially by the end of two years. This may be due to decreased metabolic process as and when the wastes get stabilized.

CONCLUSION

In the initial period, aeration helped in generating leachate with lower parameters. This would help in generating treatable leachate when compared with anaerobic models which generates leachate with higher pollutants which is difficult to treat. Models with leachate recirculation generated leachate with higher pollutants than models without leachate recirculation during the initial years, but the pollutants reduced significantly by the end of two years. It can be concluded that in the long run, more than aeration, leachate recirculation plays a significant role in reducing the leachate parameters in MSW landfills.

Hence aerated landfill model with leachate recirculation would be a feasible technique to reduce the pollutants in the generated leachate which can then be collected and treated easily.

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REFERENCES

Abbas, A.A., Jingsong, G., Ping, L.Z., Ya, P.Y. and Al-Rekabi, W.S. 2009. Review on LandWll leachate treatments. *Journal of Applied Sciences Research.* 5(5) : 534-545.

Aluko, O.O., Sridhar, M.K. and Oluwande, P.A. 2003. Characterization of leachates from a municipal solid waste landfill site in Ibadan, Nigeria. *Journal of Environmental Health Research.* 2(1): 32-37.

Bilgili, M.S., Demir, A. and Özkaya, B. 2007. Influence of leachate recirculation on aerobic and anaerobic decomposition of solid wastes. *Journal of Hazardous Materials*. 143(1-2): 177-183.

Iqbal, H., Anwar Baig, M., Usman Hanif, M., Usman Ali, S. and Flury, M. 2015. Leaching of Metals, Organic Carbon and Nutrients from Municipal Waste under Semi-Arid Conditions. *International Journal of Environmental Research.* 9(1) : 187-196.

Kjeldsen, P., Barlaz, M.A., Rooker, A.P., Baun, A., Ledin, A. and Christensen, T.H. 2002. Present and long-term composition of MSW landfill leachate: a review. *Critical Reviews in Environmental Science and Technology.* 32(4) : 297-336.

Manandhar, D.R., Hogland, W., Krishnamurthy, V. and Khanal, S.N. 2012. Estimation of leachate from a pilot scale lysimeter. *Kathmandu University Journal of Science, Engineering and Technology*. 8(2): 93-100.

Mehta, R., Barlaz, M.A., Yazdani, R., Augenstein, D., Bryars, M. and Sinderson, L. 2002. Refuse decomposition in the presence and absence of leachate recirculation. *Journal of Environmental Engineering*. 128(3): 228-236.

Padmalal, D. and Reghunath, R. 2002. Urban Solid wastes of Kerala. In: Jayakumar et al. (Edited) State of the Environment Report of Kerala, p. 93-97; STEC, Government of Kerala, Thiruvananthapuram.

Renou, S., Givaudan, J.G., Poulain, S., Dirassouyan, F. and Moulin, P. 2008. Landfill leachate treatment: Review and opportunity. *Journal of Hazardous Materials.* 150(3): 468-493.

Sekman, E., Top, S., Varank, G. and Bilgili, M.S. 2011. Pilot-scale investigation of aeration rate effect on leachate characteristics in landfills. *Fresenius Environmental Bulletin.* 20(7).

Taneja, R.K. 2011. *Study of Municipal Landfill Leachate: Recycling and Treatment Using UASBR with posttreatment by Constructed Wetland* (Doctoral dissertation, Indian Institute of Technology Delhi New Delhi.

Wiszniowski, J., Robert, D., Surmacz-Gorska, J., Miksch, K. and Weber, J.V. 2006. Landfill leachate treatment methods: A review. *Environmental Chemistry Letters*. 4: 51-61

Youcai, Z. 2018. Chapter 1 - Leachate generation and characteristics. In: Zhao Youcai (authored) Pollution control technology for leachate from municipal solid waste, Butterworth-Heinemann, pp.1-30.

Youcai, Z. 2018. Chapter 2-Physical and chemical treatment processes for leachate. In: Zhao Youcai (authored) *Pollution Control Technology for Leachate from Municipal Solid Waste.* Butterworth-Heinemann, pp. 31-183.