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Performance evaluation of a landfill leachate recirculation treatment system using quadric model

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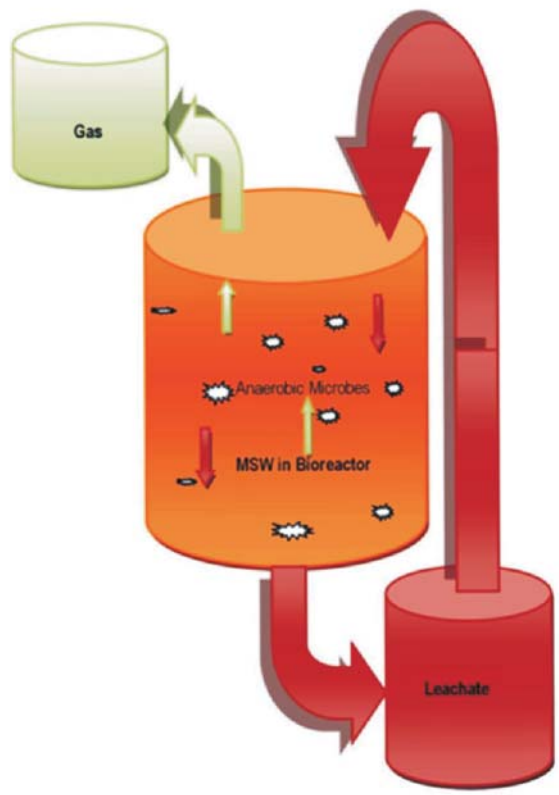
Abstract

Aim : The present research was carried out to study the effects of recirculation of leachate in cylindrical shaped anaerobic bioreactor on treatment of leachate as well as stabilization of municipal solid waste. Quadric and regression model were used to study the behavior of operating parameters over time scale and on COD, respectively.

Methodology : 19 kg of solid waste was filled and compacted and in reactor and water was added to it till 20 liters of leachate prepared. The whole unit was sealed air tight and leachate was recirculated @ 28ml/min for 12 hours daily. Physico-chemical characterization of leachate and and solid waste was done by using standards methods of analysis.

Results : Results shows that the parameters like pH (6.69 to 7.74), alkalinity (7100 to 1600 mg l^{-1}), VFA alkalinity ratio (1.44 to 0.33) etc. were within the optimum range of anaerobic degradation. COD is an indicator of organic contamination and a reduction in 96% COD was observed at the end of 29 weeks of leachate recirculation. The quadric model also confirms that the most of organic and inorganic contaminants of leachate were decreased and alkalinity was increased with time. In addition to leachate treatment, a reduction of 26.3% volume of MSW was observed after completion of study.



Interpretation : The performance of Leachate Recirculation Bioreactor was excellent as most of organic and inorganic contaminants were decreased and pH and alkalinity were increased with time. Thus, this technology can be a good solution of MSW problems of countries like India which demands urgent attention in this direction as it treats the leachate as well as stabilize the solid waste.

Introduction

Solid waste generation has increased and its composition has also changed with increase in population, urbanization, modern life style and food habits. Municipal solid waste generation has shown a positive correlation with economic development on a global level. Strategic review and planning can play a significant role in reducing the direct and indirect impact of waste on the environment. No single technology is adequate for complete management of waste and hence, city-specific combination of technologies should be adopted for sustainable waste management (Mor *et.al.,* 2016).

Solid waste disposal is a difficult task as more land is required for ultimate disposal. The conventional and principal method of MSW disposal in developing countries is open dumping and landfilling (Ponmani *et.al.,* 2014). The disposal of solid waste unscientifically leads to uncontrolled dispersion of leachate.

Leachate is a liquid formed when waste breaks down in the landfill and water filters through that waste. This liquid is highly toxic and can pollute land, ground water and water ways (Kirmizakis *et al.,* 2014). Leachate in a landfill may have high concentration of organic matter, inorganic constituents like nutrients and heavy metals and microbes including disease causing agents. The leachate requires treatment to minimize the pollutants to an acceptable level prior to discharge into water course (Aziz *et al.,* 2010). Because of its complex composition, it is difficult to treat in order to meet the effluent standards (Chen *et.al.,* 2014).

Landfill leachate treatment has been given significant attention in past (Bohdziewicz *et al*., 2001; Ahn *et al*., 2002). Due to high concentration of high organic matter and other pollutants, treatment of leachate is a challenging task. The biological reactions played a dominant role in the removal of pollutants (Han *et al.,* 2013). Pohland (1975) conducted one of the first experiments on leachate recirculation. Leachate recirculation is a relatively inexpensive option of treatment and disposal of leachate. The beneficial effects of leachate recirculation are degradation of waste, biogas production, organic load reduction in leachate and settlements of MSW (Reinhart and AL-Yousfi, 1996). It is also effective in waste volume reduction rate of landfill sites (Chan *et al.,* 2002). Leachate recirculation increases the moisture content in a bioreactor and provides distribution of nutrients between methanogens and solids wastes/liquids. Thus, it treats the leachate at faster pace in comparison to conventional landfill at onsite without transferring them off-site for treatment or disposal. Due to heterogeneous nature solid wastes in bioreactor, the leachate may find discrete channels to travel through. It is difficult to insure that the leachate is reacting with all the waste and is thoroughly being treated. In addition to this, other operational and design problems are at risk of environmental exposure if leachate is applied to the surface and requirement of liner, leachate and gas collection and management facilities. *Leachate Recirculation Bioreactor* is a good technique, if applied skillfully (Bhambulkar, 2011).

The present research aimed to observe the effect of leachate recirculation on stabilization of municipal solid waste in cylindrical shaped anaerobic bioreactor. Quadric and regression model were used to study the behavior of operating parameters over time scale and on COD, respectively.

Materials and Methods

Five random samples consisting 7.5 kg of municipal waste each were collected from dumping site at Dhandhoor on NH-10, Hisar. A part of properly mixed freshly collected MSW after determining moisture content was sun dried and milled and sieved through sieve size of < 2mm for estimation of physico-chemical properties, following the methods of Ryan *et al.* (2001).

The Leachate Recirculation Bioreactor setup and dimensions are given in Fig. 1. Nineteen kilograms of properly mixed MSW having 0.057 m^3 volume was added by compaction to Leachate Recirculation Bioreactor. The water was added in the bioreactor to prepare 20 l leachate. The bioreactor and leachate collection container were sealed air tight. Leachate recirculation was done @ 28 ml min^{-1} for 12 hrs daily. A 10 ml and 50 ml leachate samples were collected on daily basis for analysis of temperature, pH, electric conductivity, alkalinity and chemical oxygen demand and on weekly bases for analysis of total dissolve solids, total suspended solids, volatile suspended solids, sodium, potassium, total hardness, calcium, magnesium, chloride, sulphate, phosphate, total Kjeldahl nitrogen and volatile fatty acids, respectively and analyzed for various physico-chemical parameters following the standard methods of APHA (2012). The leachate volume was made up by adding distilled water equal to the volume of leachate samples collected and accordingly dilution factor was used for the calculations.

To capture the behavior of different variables related to operating parameters (physico-chemical properties of leachate) of the study in relation to time, different regression models such as linear, logarithmic and growth were employed to get the best fit of the model using SPSS 16 software. The data of above mentioned all physico-chemical properties of leachate collected on daily and weekly basis was converted to log scale and used for statistical analysis. Based on the results obtained, quadric model was found best fit to study the change in operating parameters over time scale. Thus the results of quadric model were used in the present study.

The regression model determines the relationship between dependent variable Y and independent variable X. The effects of operating parameters on COD were studied by regression modeling.

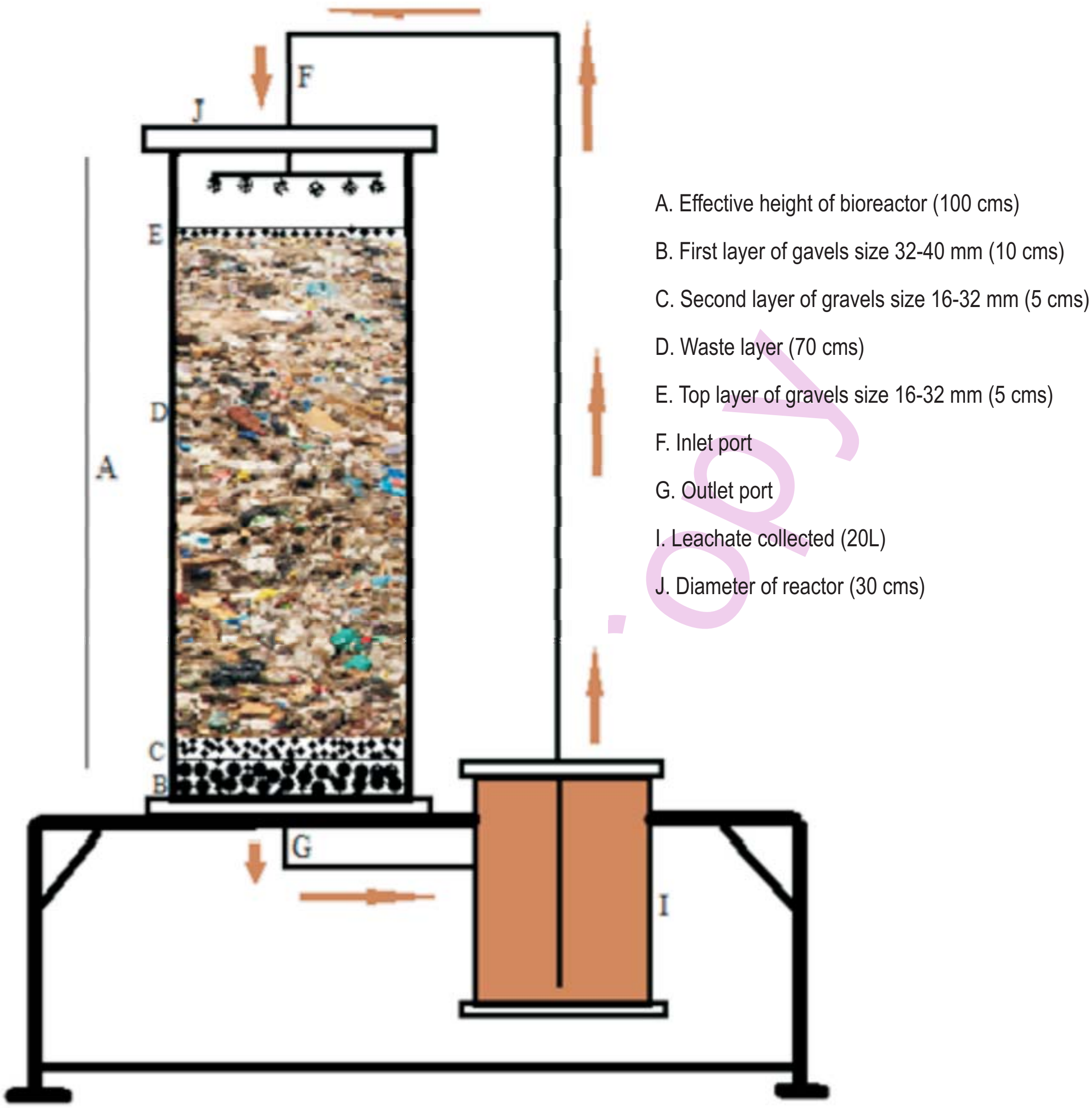


Fig. 1: Schematic diagram of leachate recirculation bioreactor

Results and Discussion

High TOC level of 48.3 mg g^{-1} of MSW indicated that biodegradable organics constituted the major composition of MSW. Mor et al., 2016 also observed highest content (52%) of biodegradable organic fraction in MSW of Chandigarh city. After treatment, the pH, EC, total organic carbon, phosphate and TKN of MSW decreased from 7.8 to 7.3, 2.8 to 2.3 mS cm^{-1}, 48.3 to 27.4 mg g^{-1}, 2.3 to 1.2 mg g^{-1}, and 35 to 15 mg g^{-1}, respectively (Table 1). A 43% reduction in TOC was observed after the study, whereas reduction in phosphate and TKN were 48% and 57%, respectively. The initial volume of solid waste used in bioreactor for leachate preparation was 0.057 m^3. However, at the end of the study it was reduced to 0.042 m^3.

To carry out the leachate recirculation study, 20 l volume of leachate was prepared from MSW in bioreactor, which decreased to 18.5 l after recirculation study due to evaporative loss. The results of change in leachate quality with time is shown in Table 2. The minimum temperature of 9.8°C was observed in February and maximum of 35°C was observed in April. The pH ranged from 6.69 to 7.74. Initially, the pH of the reactor decreased from 7.10 to 6.69 in the 2nd week of recirculation, which might be due to acidogenesis and formation of volatile fatty acids (Bohdziewicz and Kwarciak, 2008). After that an increase in pH was observed. This increase in pH may be due to onset of methanogenic activity which results in increase in methane gas production and decrease in hydrogen, carbon dioxide and volatile fatty acid production (Murphy *et al.,* 1995). When methane

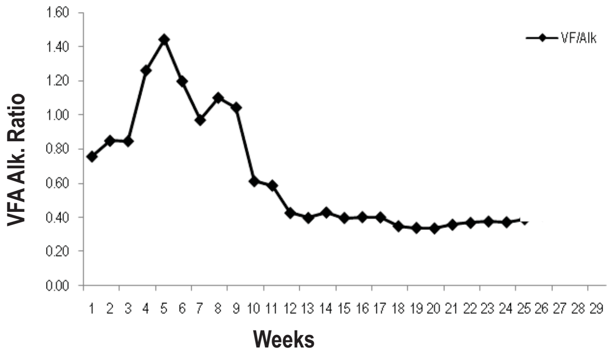


Fig. 2 : VFA Alkalinity ratio of leachate during study period

production was stabilized, the pH ranged between 6 to 8 (Ehrig, 1983). During the study period leachate conductivity increased from 9.22 to 11.45 mS cm^{-1} upto 9th week of leachate recirculation and then it started decreasing with time. At the end of study it was 8.46 mS cm^{-1}. The TDS, TSS and VSS varied from 8560 mg l^{-1} to 2780 mg l^{-1}, 1170 mg l^{-1}to 460 mg l^{-1} and 1050 mg l^{-1} to 180 mg l^{-1}, respectively. The maximum reduction of TDS, TSS and VSS observed were 67%, 60% and 85%, respectively. Biodegradation of organic matter over time resulted in decrease in TDS concentration. As compared to other solids, TSS removal was lower, as TSS takes longer time to decompose and disintegrate (Sartaj *et al*., 2010).

The results of leachate recirculation study reflect the decreasing trend of sodium and potassium concentration during the study period. Initially hardness, calcium and magnesium values were increased and after attaining maximum, they decreased. The decrease in concentration of calcium and magnesium might be due to their precipitation to $CaCO_3$ and $Mg(OH)_2$ (Erses and Onay, 2003; Erses *et al*., 2008).

A decrease in chloride level during study period may be due to the quick anaerobic degradation of municipal solid waste in the lab scale (Sponza and Agdag, 2004). The initial sulphate concentration in leachate sample was 331 mg l^{-1}, which was reduced to 138 mg l^{-1} (64% reduction) at the end of the study period. Sulphide production can cause serious operational problems in anaerobic reactor that treat waste water with high sulphide concentration (Lens *et al*., 1998). At the end of the study, the phosphate content was reduced to 11.52 mg l^{-1} (75% reduction), which might be due to assimilation of phosphate by microorganisms. The total Kjeldahl nitrogen in leachate sample increased to maximum (1295 mg l^{-1}) on 7th week of recirculation. After attaining maximum, a gradual decrease was observed. In nitrification and denitrification process during anaerobic decomposition of organic waste, NH^{4+} is converted to nitrogen gas and is lost to the atmosphere (Kuai and Verstraete, 1998; Elangovan and Sekar, 2015).

VFA is an important parameter because of the methanogenic stage and degree of stability of anaerobic

Table 1: Physico-chemical properties of MSW before leachate preparation and after completion of leachate treatment study

Parameters	Before treatment	After treament
Moisture content (%)	28.1	33.2
pH	7.8	7.3
EC (mS cm^{-1})	2.8	2.3
TOC (mg g^{-1})	48.3	27.4
Calcium (mg g^{-1})	15.0	6.8
Magnesium (mg g^{-1})	2.3	2.0
Sulphate (mg g^{-1})	6.0	4.7
Phosphate (mg g^{-1})	2.3	1.2
TKN (mg g^{-1})	35.0	15.0

degradation process (Sponza and Agdag, 2004). In the present study, VFA increased from 4843 to 8280 mg l^{-1}. This increase in VFA concentration may be as a result of accumulation of organic acids due to hydrolysis and acidogenesis. Later, VFA showed a decreasing trend and at the end of the study a 91% reduction was observed, which might be due to onset of methanogenesis.

The alkalinity of water is a measure of its capacity to neutralize acids and is primarily due to the salts of weak acids (Quasim and Chiang, 1994). The initial alkalinity level in leachate sample was 6400 mg l^{-1}, which reduced to 1600 mg l^{-1} after completion of the experiment. This decrease in alkalinity might be due to dissolution and precipitation of metals carbonates (Bhambulkar, 2011). Except for last three days, alkalinity of the bioreactor was within the optimum range of anaerobic degradation. Alkalinity greater than 2000 mg l^{-1} in the bioreactor indicates optimum condition for methanogenesis (Bilgli *et al*., 2007).

It is essential that the reactor content provide enough buffering capacity to neutralize any eventual VFA accumulation to prevent build up of localized acid zones in the digester (Kanat *et al*., 2006). The degradation of protein by anaerobic treatment results in generation of alkalinity due to the reaction of ammonia with CO_2 and water. Initially, VFA alkalinity ratio increased from 0.76 to 1.44. After that it was gradually decreased and reached to minimum of 0.33 (Fig. 2). The VFA Alkalinity ratio was observed within the limits of optimum condition of anaerobic degradation *i.e.,* less than 0.8 (Ehrig, 1983; Vlissidis and Zauboulis, 1993). This clearly demonstrates that performance of the reactor was excellent as VFA alkalinity ratio approached to less than 0.8.

Chemical oxygen demand is a critical indicator of presence of biodegradable organics matter in leachate (Bhambulkar, 2011). The COD of leachate in the bioreactor increased significantly in the beginning *i.e.,* 12747 mg l^{-1}, which might be due to hydrolysis and leaching of soluble organic and inorganic compound from solid waste into leachate. After attaining maximum, COD reduction was observed. The anaerobic decomposition of simple organic compound into methane, carbon dioxide etc. is responsible for COD reduction. A 96% reduction in COD indicates that Leachate Recirculation Bioreactor

Table 2 : Change in leachate quality with time during their treatment in Leachate Recirculation Bioreactor

Week	Temp.	pH	EC	TDS	TSS	VSS	Na	K	TH	Ca	Mg	Cl	SO_4	PO_4	TKN	VFA	Alk.	COD
1	26.82	7.10	9.22	7550	1170	1050	719	1160	3100	840	243	1402	331	46.19	760	4843	6400	12640
2	26.35	6.69	9.77	7790	970	950	757	1000	4000	880	437	1251	393	31.21	690	5152	6067	12747
3	24.18	6.75	11.12	8560	1060	1010	693	960	4000	720	535	1201	334	27.61	715	5280	6233	10748
4	21.23	6.84	11.20	8340	980	950	712	940	2500	520	292	1051	309	27.39	780	7362	5833	10173
5	20.37	6.81	10.73	8190	930	920	737	920	3100	520	437	951	298	23.20	885	8280	5733	9075
6	20.58	7.16	10.83	7360	830	810	733	1040	4200	840	510	851	244	22.40	1120	7132	5950	8150
7	19.18	7.31	10.45	6030	820	790	612	920	2800	480	389	601	269	22.25	1295	6894	7100	6400
8	18.48	7.38	10.05	6600	880	860	711	960	3300	440	535	701	258	22.69	1230	6243	5667	5607
9	17.57	7.26	11.45	5030	840	820	728	960	2800	440	413	751	227	22.10	1125	5846	5600	5343
10	16.43	7.36	11.02	5930	820	760	693	880	3500	680	437	651	204	19.82	1065	3284	5367	4547
11	13.65	7.20	11.12	5490	870	780	611	960	1700	320	219	651	200	15.64	965	3185	5433	3640
12	12.37	7.35	11.10	6020	820	710	606	920	2100	240	365	601	193	14.13	925	2139	5033	2747
13	10.60	7.63	10.59	4800	790	680	568	920	2200	360	316	651	182	13.66	850	2034	5133	2250
14	11.18	7.32	10.56	5150	770	620	519	840	1800	240	292	651	211	13.81	740	2214	5167	1925
15	15.55	7.08	10.82	4520	740	560	503	760	2100	360	292	601	185	13.73	705	2018	5100	1782
16	12.15	7.13	10.87	4290	730	540	485	730	2200	440	267	701	189	16.74	625	1938	4833	1533
17	10.77	7.48	10.65	4820	780	550	445	650	2100	360	292	651	160	13.00	610	1892	4733	1298
18	9.95	7.53	10.80	4380	680	470	392	680	2000	320	292	551	164	12.26	565	1739	5000	1302
19	9.87	7.46	10.51	4530	660	450	334	590	1800	320	243	601	156	13.88	490	1632	4833	1252
20	11.12	7.53	10.77	4250	640	410	283	520	1500	280	194	501	158	15.46	415	1529	4567	1217
21	11.77	7.47	10.71	4120	610	340	247	450	1400	240	194	551	147	14.29	325	1603	4500	1158
22	12.98	7.42	10.72	3890	580	310	208	440	1200	200	170	501	143	14.13	360	1407	3833	1062
23	14.37	7.58	10.26	3540	620	340	259	390	1100	200	146	450	152	13.28	420	1238	3300	925
24	16.95	7.46	10.06	3260	550	270	238	350	1000	160	146	450	149	12.93	315	1126	3033	895
25	19.20	7.65	9.73	2970	520	240	202	320	900	160	122	410	147	12.27	285	1049	2700	770
26	24.68	7.74	9.29	2820	490	210	179	270	800	120	122	400	141	11.98	230	912	2200	637
27	27.37	7.52	9.26	2810	480	210	171	260	800	120	122	350	142	11.92	220	895	1850	585
28	30.48	7.55	8.66	2790	470	190	168	250	700	100	109	325	139	11.79	210	840	1767	555
29	35.10	7.56	8.46	2780	460	180	162	230	700	100	109	300	138	11.52	210	750	1600	520

Note : All parameters are measured in mg l^{-1} except temperature in ^{0}C, pH and EC in mS cm^{-1}

Table 3 : Quadric model showing change in variables with time

Variable (Y)	α	β	Υ	R^2	F	p
Temperature	3.680	-0.162	0.005	0.847	72.162	0.000
	(41.182)	(-11.802)	(11.995)			
pH	1.914	0.008	0.000	0.691	29.062	0.000
	(142.822)	(3.807)	(-2.099)			
Electric conductivity (EC)	2.266	0.022	-0.001	0.767	42.891	0.000
	(97.235)	(6.175)	(-7.660)			
Total dissolve Solids (TDS)	9.067	-0.036	0.000	0.948	238.197	0.000
	(179.989)	(-4.621)	(-0.670)			
Total suspended Solids (TSS)	6.956	-0.017	0.000	0.958	296.745	0.000
	(214.612)	(-3.444)	(-2.486)			
Volatile suspended Solids (VSS)	6.925	-0.011	-0.002	0.990	1323.575	0.000
	(201.263)	(-2.035)	(-10.447)			
Sodium (Na)	6.650	-0.003	-0.002	0.965	361.742	0.000
	(103.926)	(-0.292)	(-6.216)			
Potassium (K)	6.884	0.021	-0.003	0.983	743.887	0.000
	(166.659)	(3.282)	(-12.471)			
Total hardness (TH)	8.182	-0.012	-0.002	0.922	152.937	0.000
	(85.693)	(-0.803)	(-3.442)			
Calcium (Ca)	6.643	-0.039	-0.001	0.877	92.595	0.000
	(47.852)	(-1.844)	(1.469)			
Magnesium (Mg)	5.946	0.019	-0.002	0.855	76.868	0.000
	(49.811)	(1.042)	(-3.996)			
Chloride (Cl)	7.110	-0.051	0.000	0.890	105.533	0.000
	(89.366)	(-4.144)	(0656)			
Sulphate (SO_4)	5.987	-0.071	0.001	0.965	357.221	0.000
	(165.270)	(-12.814)	(6.766)			
Phosphate (PO_4)	3.671	-0.094	0.002	0.906	125.656	0.000
	(54.696)	(-9.160)	(5.762)			
Total kjeldhal nitrogen (TKN)	6.669	0.049	-0.004	0.919	146.622	0.000
	(65.952)	(3.177)	(-7.149)			
Volatile fatty acid (VFA)	9.023	-0.082	$-6.669E^{-5}$	0.906	125.734	0.000
	(63.221)	(-3.740)	(-0.094)			
Alkalinity (Alk)	8.594	0.038	-0.003	0.944	217.669	0.000
	(141.965)	(4.101)	(-8.922)			
Chemical oxygen demand (COD)	9.844	-0.177	0.002	0.988	1054.966	0.000
	(137.583)	(-16.084)	(5.211)			

performance was excellent. The reason for this decrease may be the quick degradation of the solid wastes in the lab scale anaerobic reactor (Sponza and Agdag, 2004). Similar trends of COD reduction were reported by Sanphoti *et al.,* (2006) and Gawalpanchi *et al.* (2007). Thus, leachate recirculated bioreactor is an effective, faster and good option for MSW management (Snehlata *et al.,* 2015 and Nain and Lohchab, 2015).

To capture the change in operating parameters over time, by using regression analysis, the quadric regression model was identified/selected on the basis goodness of fit criteria (R^2). The estimated results of the model are presented in Table 3. The R^2 value of 0.691 or more and p value (significance F) close to 0 of the quadric model showed that this model was best fit.

The quadric model showed that temperature, SO_4, PO_4 and COD decreased with time however, in diminishing amount. The rate of decrease in temperature, SO_4, PO_4 and COD were 16.2% per unit time with diminishing amount of 0.5%, 7.1% per unit time with diminishing amount of 0.1%, 9.4% per unit time with diminishing amount of 0.2% and 17.7% per unit time with diminishing amount of 0.2%, respectively (Table 3). Whereas, TDS, TSS and chloride are showing decreasing trends with per unit time but acceleration of change is zero. The amounts of decline per unit of time were 3.6%, 1.7% and 5.1% for TDS, TSS and chloride, respectively. The VSS, Na, TH, Ca and VFA were declined with time with increasing acceleration. The VFA has shown highest amount of decline with time but increase in acceleration was lowest.

The quadric model showed that EC, K, Mg, TKN and alkalinity increased with time. The amount of increase was highest in case of TKN (4.9%) with highest diminishing rate of 0.4%. The second highest amount of increase was observed in case of alkalinity. The rate of increase of pH with time was 0.8% though the change of acceleration was zero.

Table 4 : Regression model showing effect of independent variables on COD

Independent variable (X)	α	β	r^2	F	p
Temperature	6.403 (4.171)	0.473 (0.877)	0.028	0.769	0.388
pH	51.338 (8.579)	-21.908 (-7.287)	0.663	53.105	0.000
Electric conductivity (EC)	-5.758 (-1.057)	5.777 (2.478)	0.185	6.142	0.000
Total dissolve solids (TDS)	-16.124 (-12.146)	2.814 (17.991)	0.923	323.681	0.000
Total suspended solids (TSS)	-17.564 (-9.756)	3.845 (14.064)	0.880	197.797	0.000
Volatile suspended solids (VSS)	-3.109 (-3.937)	1.739 (13.787)	0.876	190.093	0.000
Sodium (Na)	-2.666 (-3.008)	1.727 (11.785)	0.837	138.891	0.000
Potassium (K)	-3.958 (-3.289)	1.816 (9.749)	0.779	95.050	0.000
Total hardness (TH)	-5.274 (-4.604)	1.730 (11.388)	0.828	129.695	0.000
Calcium (Ca)	-0.831 (-1.090)	1.489 (11.304)	0.826	127.790	0.000
Magnesium (Mg)	-1.834 (-1.518)	1.730 (7.955)	0.701	63.288	0.000
Chloride (Cl)	-8.260 (-6.385)	2.489 (12.389)	0.850	153.476	0.000
Sulphate (SO_4)	-9.330 (-10.317)	3.235 (18.906)	0.930	357.424	0.000
Phosphate (PO_4)	0.050 (0.080)	2.725 (12.295)	0.848	151.157	0.000
Total kjeldhal nitrogen (TKN)	-1.832 (-1.439)	1.507 (7.544)	0.678	56.907	0.000
Volatile fatty acid (VFA)	-2.676 (-4.762)	1.340 (18.620)	0.928	346.708	0.000
Alkalinity (Alk)	-9.747 (-4.161)	2.088 (7.473)	0.674	55.841	0.000

The quadric model showed that COD had highest amount of decline with time but Sodium has lowest. Whereas, VFA has shown highest amount of increase with time but Magnesium has lowest. Quadric model also shows that pH and alkalinity were increased with time during the study period.

The effects of different operating parameters on COD were studied by cause and effect relationship through regression modeling. Except temperature and EC, all other parameters significantly affected the COD as r^2 values were more than 0.663 and p values (significance F) were close to 0 (Table 4). The 1% increase of TDS, TSS, VSS, Na, K, TH, Ca, Mg, Cl, SO_4, TKN, VFA and alkalinity resulted in 281.4%, 384.5%, 173.9%, 172.7%, 181.6%, 173.0%, 148.9%, 173.0%, 248.9%, 323.5%, 150.7%, 134.0% and 208.8% increase in COD, respectively. The regression models indicate that the 1% increase in pH resulted in 2190.8% decrease in COD.

Above trends of quadric modeling indicate that the organic and inorganic contaminants of leachate were decreased and pH and alkalinity were increased with time. During leachate recirculation a decrease in contaminants were also reported by Pohland *et al.* 1992; Filipkowska (2008); Snehlata et.al., 2015 and Nain and Lohchab, 2015.

High COD reduction of leachate at optimum pH and VFA alkalinity ratio suggests that the *Leachate Recirculation Bioreactor* technique can efficiently and effectively be used to treat leachate as well as stabilizes the MSW.

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References

Ahn, D. H., Y. C. Chung and W. S. Chang: Use of coagulant and zeolite to enhance the biological treatment efficiency of high ammonia leachate. *J. Environ. Sci. Hlth.,* **37**, 163-173 (2002).

APHA: Standard Methods for the Examination of Water and Waste Water. 22nd Edn., American Public Health Association, Washington DC (2012).

Aziz, S. Q., H. A. Aziz, M. S. Yusoff, M. J. K. Bashir and M. Umar: Leachate characterization in semi-aerobic and anaerobic sanitary landfills: A comparative study. *J. Environ. Manag.*, **91**, 2608-2614 (2010).

Bhambulkar, A. V.: Effect of leachate recirculation on landfill. *Int. J. Advan Engin. Sci. Technol.,* **11**, 286-291 (2011).

Bilgili, M. S., A. Demir and B. O¨zkaya: Influence of leachate recirculation on aerobic and anaerobic decomposition of solid wastes. *J. Hazard. Mat.,* **143**, 177-183 (2007).

Bohdziewicz, J. and A. Kwarciak A: The application of hybrid system UASB reactor-RO in landfill leachate treatment. *Desalination,* **222**, 128-134 (2008).

Bohdziewicz, J., M. Bodzek and J. Gorska: Application of pressure driven membrane techniques to biological treatment of landfill leachate. *Process Biochem.,* **36**, 641-646 (2001).

Chan, G. Y. S., L. M. Chu and M. H. Wong: Effects of leachate recirculation on biogas production from landfill co-disposal of municipal solid waste, sewage sludge and marine sediment. *Environ. Poll., **118***, 393-399 (2002).

Chen, C. K., S. L. Lo and T. Y. Chen: Regeneration and reuse of leachate from a municipal solid waste landfill. *J. Environ. Biol.*, **35**, 1123-1129 (2014).

Ehrig, H.J.: Quality and quantity of sanitary landfill leachate. *Waste Manag. Res.,* **1**, 53-68 (1983).

Elangovan, C. and A. S. S. Sekar: Performance evaluation of upflow anaerobic sludge blanket reactor process for dairy wastewater treatment. *J. Environ. Biol.*, **36**, 1305-1310 (2015)

Erses, S. and T. T. Onay: *In situ* heavy metal attenuation in landfills under methanogenic conditions. *J. Hazard. Mat.,* **99,** 159-175 (2003).

Erses, S., T. T. Onay and O. Yenigun: Comparison of aerobic and anaerobic degradation of municipal solid waste in bioreactor landfills. *Biores. Technol.,* **99**, 5418–5426 (2008).

Filipkowska, U.: Effect of recirculation method on quality of landfill leachate and effectiveness of biogas production. *J. Environ. Stud.,* **17**, 199-207 **(2008).**

Gawalpanchi, R. R., V.A. Mhaisalkar, S. Hiraou and A.D. Bhida: Treatment of leachate by recirculation through a bioreactor. In: Proceedings of the International Conference on Sustainable Solid Waste Management, Chennai, India, p. 460-465 (2007).

Han, Z., D. Liu and Q. Li: A removal mechanism for organics and nitrogen in treating leachate using a semi-aerobic aged refuse biofilter. *J. Environ. Manag.*, **114**, 336-342 **(**2013).

Kanat, G., A. Demir, B. Ozkaya and M.S. Bilgili: Addressing the operational problems in a composting and recycling plant. *Waste Manag.,* **26**, 1384-1391 (2006).

Kirmizakis, P., C. Tsamoutsoglou, B. Kayan and D. Kalderis: Subcritical water treatment of landfill leachate: Application of response surface methodology. *J. Environ. Manag.*, **146**, 9-15 (2014).

Kuai, L. and W. Verstraete: Ammonium removal by the oxygen-limited autotrophic nitrification-denitrification system. *Appl. Environ. Microbiol.*, **64**, 4500-4506 (1998).

Lens, P.N.L., A. Visser, A.J.H. Janssen, P.L.W. Hulshoff and G. Lettinga: Biotechnological treatment of sulphate-rich wastewaters. *Crit. Rev. Environ. Sci. Technol.,* **28**, 41-88 (1998).

Mor, S., K. Kaur and R. Khaiwal: SWOT analysis of waste management practices in Chandigarh, India and prospects for sustainable cities. *J. Environ. Biol.*, **37**, 327-332 (2016).

Murphy, R. J., D. E. Jones and R. I. Stessel: Relationship of microbial mass and activity in biodegradation of solid waste. *Waste Manag. Res.,* **13,** 485-497 (1995).

Nain, A. and R. K. Lohchab: Anaerobic treatment of MSW of Hansi in leachate recirculation bioreactor. *Annals of Biology*, **31**, 46-50 (2015).

Pohland, F. G., W. H. Cross, J. P. Gould and D. R. Reinhart: The behaviour and assimilation of organic priority pollutants codisposed with municipal refuse. Vol.1, EPA Co-operation Agreement CR 812158, Cincinnati, Ohio (1992).

Pohland, F. G.: Sanitary Landfill Stabilization with Leachate Recycle and Residual Treatment, U.S. Environmental Protection Agency, EPA 600/2-75-043, Cincinnati, Ohio (1975).

Ponmani, S., C. Udayasoorian, R. M. Jayabalakrishnan and V. Kumar: Vermicomposting of paper mill solid waste using epigeic earthworm Eudrilus eugeniae. *J. Environ. Biol.*, **35**, 617-622 (2014).

Quasim, S. R. and W. Chiang: Sanitary landfill leachate. USA: Techonomic publishing company, ISBN **1**-56676-129-8 (1994).

Reinhart, D. R. and A. B. Al-Yousfi: The impact of leachate recirculation on municipal solid waste operating characteristics. *Waste Manag. Res.,* **14**, 337-346 (1996).

Ryan, J., G. Estefan and A. Rashid: Soil and plant analysis laboratory manual. 2nd Eds., ICARDA, Syria (2001).

Sanphoti, N., S. Towprayoon, P. Chaiprasert and A. Nopharatana: The effects of leachate recirculation with supplemental water addition on methane production and waste decomposition in a simulated tropical landfill. *J. Environ. Manag.*, **81**, 27–35 (2006).

Sartaj, M., M. Ahmadifar and A.K. Jaashni: Assessment of *in-situ* aerobic treatment of municipal landfill leachate at laboratory scale. *Iranian J. Sci. Technol., Transac. B. Engin., **34**, 107-116* (2010).

Snehlata, R. Lohchab and A. Nain: Anaerobic treatment of MSW using leachate recirculation bioreactor: A case study of Rohtak City. *Nature Environ. Poll. Technol.*, **14** , 919-922 (2015).

Sponza, D.T. and O.N. Agdag: Impact of leachate recirculation and recirculation volume on stabilization of municipal solid waste in simulated anaerobic bioreactors. *Process Biochem., **39**, 2157-2165* (2004).

Vlissidis, A. and A.J. Zouboulis: Thermophilic anaerobic digestion of alcohol distillery wastewaters. *Biores. Technol.,* **43**, 131-140 (1993).