Simulation of Lab-scale Leachate Treatment Bioreactor with Application of Logistic Growth Equation for Determining Design and Operational Parameters

Gnanakaran, M., Ariyawansha, R.T.K., Basnayake B. F. A.

Abstract— A laboratory scale Leachate Treatment Bioreactor (LTB) was needed to determine the optimum design and operational parameters because of poor performance of a full scale unit. In order to increase the lifespan of LTB, coconut comb and rubber tyres were included in the partially decomposed Municipal Solid Waste (MSW) as biofilter material inside the reactor. A composite liner of clay and waste polythene was used to mineralize excess inorganic compounds. The parameter reductions were from 26,000 mg/L to 6,832 mg/L of Total Solids (TS), 6,230 mg/L to 2,930 mg/L of Total Disolved Solids (TDS), 12,000 mg/L to 1182.6 mg/L of Volatile Solids (VS), 14,000 mg/L to 4,410 mg/L of Total Fixed Solids (TFS) and 29,700 mg/L to 3,000 mg/L of Biochemical Oxygen Demand (BOD). The kinetic analysis using the logistic growth equation showed cyclic events and the application of separating the growth and decay of microbes based on the Total Fixed Solids (TFS) gave a mineralization rate of 1.83×10^2 kg /m^3 of leachate/m height of LTB /day for up scaling.

Keywords — Kinetic analysis, Leachate treatment bioreactor, Logistic growth equation, Mineralization, Municipal solid waste, Total fixed solid, Up scaling

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1 INTRODUCTION

In the past decades, the increases in populations, industrial growth with technology development and urbanization have increased solid waste generations. Land filling is one of the most common ways of Municipal Solid Waste (MSW) disposal in developing countries [1] including in Sri Lanka. If poorly managed, a landfill may become a source of hydro-geological contamination [1], [2], [3] due to the risk of leachate infiltrating into the natural environment [4], [5] and groundwater table [3], [6]. Consequently, it causes multiple health problems due to carcinogenic, acute toxicity and geno-toxicity [7], [8] of leachate. Therefore, it is essential to collect and treat the leachate before discharging in order to safeguard the ecosystems [2] and to comply with stringent wastewater discharge standards in different countries.

The characteristics of landfill leachate depend on the type of MSW being dumped, site hydrology, moisture content, seasonal weather variations, age of the landfill, the degree of solid waste stabilization and stage of the decomposition in the landfill [9], [10], [11]. The composition of landfill leachate is a complex [12], high strength wastewater. Substances which are commonly present in leachate include major ions such as NO_3^-, NO_2^-, NH_4^+, SO_4^{3-}, PO_4^{3-} and Cl^-, heavy metals such as Cd, Hg, Ni, Mn, Cu, Zn and Pb [13], a wide range of organic compounds and micro-organisms [2]. Handling of leachate is difficult because of the high concentrations of chemical oxygen demand (COD) and nitrogen [5], [10].

The treatability of landfill leachate depends on its composition and characteristics [14], [15] and treatment method and technologies. Different technologies including biological treatments [12], physico-chemical treatments [16], advanced oxidation processes [17], [18], constructed wetlands [19], [20], [21] and leachate recirculation [22], [23], [24] have been developed in recent years to treat the leachate [10]. Landfill leachate, especially old landfill leachate is very difficult to treat using conventional biological processes [11]. On the other hand, the organic natures of the majority of the leachate pollutants and the high carbonaceous load have led to the application of biological treatment processes [5], [10]. Further biological treatment (suspended/attached growth) is commonly used for the treatment of the bulk of leachate containing high concentrations of biochemical oxygen demand (BOD) because of reliability, simplicity and high cost-effectiveness [10].

A project was commenced to rehabilitate the Gohagoda dumpsite, which is the solid waste disposal site of the Kandy Municipal Council for more than 30 years and establish an integrated solid waste management system [19]. In the process of rehabilitation, an integrated leachate management system was established combining landfill bioreactor technology with clay polythene clay composite liner system developed at University of Peradeniya, termed leachate treatment bioreactor (LTB), along with algae pond, floating wetland and subsurface flow constructed wetlands [19], [21]. As reported by [25] the landfill bioreactor with clay-polythene-clay composite liner is capable of reducing

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the BOD concentration of leachate to less than 500 mg/L or even 250 mg/L. In the process of mineralization in the liner system, the COD reduced to 1,500 mg/L and as the required solid retention time (SRT) is achieved, it can even reach 800 mg/L. Based on that, the LTB was designed to treat high concentrated leachate [19]. A mixture of coconut comb and decomposed waste collected from the dumpsite was used as the biofilter (filling) materials of the LTB. As reported by [21] for a period of two months, salinity removal efficiency was 53.16 ± 29.61% while electrical conductivity (EC) was 54.47 ±3 7.62%, total dissolved solids (TDS) was 55.87 ± 36.51%, total solids (TS) was 79.31 ± 19.7%, volatile solids (VS) was 53.39 ± 2.74%, total suspended solids (TSS) was 68.23 ± 17.02%, volatile suspended solids (VSS) was 53.2 ± 0.34%, BOD was 62.2 ± 36.49%, PO_4^{-3} was 55.79 ± 26.96%, NO_3^- was 41.56 ± 12.64%, NH_4^+ was -101.12 ± 30.3%.

The performance of the LTB was not always satisfactory due to high level of fluctuations of the treated effluents to undergo further treatment in the algae pond, floating wetland and constructed wetland to meet the required effluent discharge standards. Because of increased incidence of fouling LTB, affecting subsequent treatment systems, it was decided to simulate a laboratory scale model of LTB with new biofilter materials which included tyres and waste rubber pieces placed in layers with coconut comb and decomposed wastes with waste polythene. In addition, the recycling regime of treated effluent and water requirements for diluting the high strength leachate, particularly in view of the short dry spells encountered in the wet tropical hilly region was considered in the experimentation to evaluate the performances and the mineralization process.

2 MATERIALS AND METHODS

2.1 Design and fabrication of laboratory scale LTB

The design and fabrication was done at the Engineering workshop of the Department of Agricultural Engineering, Faculty of Agriculture, University of Peradeniya. The LTB consisted of a liner 15 cm thick clay-polythene-clay composite layer, a 5 cm gravel layer, a 5 cm sand layer, main reactor with biofilter materials, cover with the clay-polythene-clay composite liner and vegetation cap (turf), a gas collection system, a leachate collection and a recirculation system and sampling ports as shown in Fig.1. The main body of the reactor was fabricated by using a 100 cm long PVC pipe of 11 cm diameter and an end cap for the bottom. A permeate collecting port of 2 cm diameter was placed on the middle of the end cap. An iron frame was used to erect the main

reactor. Leachate collected from Gohagoda dumpsite was used to feed the LTB.

2.2 Construction of the composite liner

Gravel and river sand were washed to remove impurities. A 1 mm size mesh was placed at bottom of the PVC column and a 5 cm thick gravel layer was placed on the top. Thereafter, river sand layer of 5 cm thick was placed on the top of the gravel layer as shown in Fig.1. Then 10 cm clay layer was placed and it was compacted to 5cm thickness. Collected waste poly-thene was cut into small pieces and mixed well with clay slurry which was prepared by mixing clay and water. After that clay mixed polythene was placed up to 10 cm thick and similar to the first step, it was also compacted to 5 cm. Another 10 cm clay layer was placed and it was compacted to 5 cm thickness. On the top of the composite liner, a 5 cm thick gravel layer was placed. Adjacent to this gravel layer, an orifice of 2 cm diameter was drilled on the wall of the reactor to create a sampling port as shown in Fig.1.

2.3 Pre-processing and filling of filling materials for the reactor

Partially decomposed coconut combs, pieces of used vehicle tyres, rubber pieces and partially decomposed MSW that were collected from Gohogoda solid waste dumpsite were used as the biofilter (filling) materials of the reactor. Coconut combs were chopped into small pieces of about 1.5 cm size and put in to a water bath for 18 hours to remove the tannin. Used vehicle tyres and rubber also shredded into small pieces of about 1 cm and washed thoroughly to remove impurities. The layering of the LTB was with different materials. Firstly, pre-processed coconut combs were filled in to the reactor to occupy 5 cm thickness, followed by 15 cm layer of decomposed solid waste, 5 cm layer of pre-processed pieces of used vehicle tyres/rubber, once again, 15 cm layer of decomposed solid waste, 3 cm layer of pre-processed pieces of used vehicle tyres/rubber, 5 cm layer of pre-processed coconut comb pieces, 2 cm layer of pre-processed pieces of used vehicle tyres/rubber and 5 cm layer of pre-processed coconut comb pieces as shown in Fig.1. While filling the materials, a gas collection pipe of 1cm diameter was placed at the middle of the reactor as shown in Fig.1 and leachate inlet pipe and recircula-tion pipe were connected to the reactor. After filling the materials, on top of that, the clay-polythene-clay composite liner and a turf were placed as the cover. Leachate was fed through a 2 cm diameter pipe with a valve in to the reactor from a storage tank.
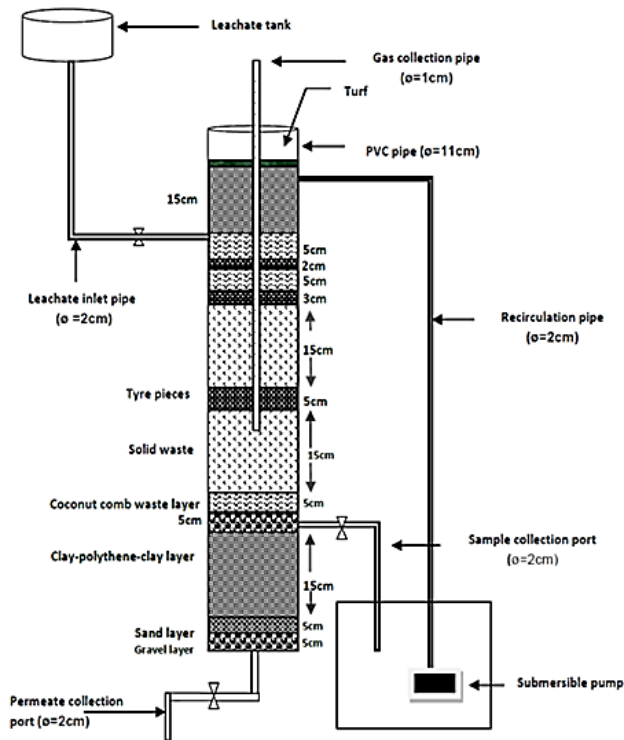
Fig. 1 A schematic diagram of the laboratory scale LTB

2.4 Operational procedure and performance evaluation of the LTB

Operation of the lab-scale LTB was activated by adding 2.7 L of leachate. Leachate feeding rate was 12 mL per minute. Valves were used to control the leachate inflow. Leachate recirculation was done once a day by using a submersible pump. On the 13th day of operation, triple supper phosphate (TSP) was introduced at a rate of 0.04 g/L to the effluent of the reactor then recirculation was done. From 21st day of operation onwards, fresh leachate and fresh water was fed with recirculation of effluent. Daily feeding rate was 60 mL of leachate and 30 mL of fresh water for 40 days. Samples were taken from sampling port daily. The collected samples were analysed for the parameters of pH, electrical conductivity (EC), dissolved oxygen (DO), total dissolved solids (TDS), total solids (TS), volatile solids (VS), total fixed solids (TFS), which is ash and biochemical oxygen demand (BOD) by using standard methods and equipment as given in Table 1. Removal efficiency was calculated by using (1).

$$\text{Re}\,moval\,efficiency\,\% = \left[(I - E)/I\right] \times 100 \qquad (1)$$

Where,
I = Inlet concentration
E = Outlet concentration
[26], [27].

Parameter	Method /Instrument
pH	pH meter
Electrial conductivity and salinity	Conductivity meter-thermo orient model 145 A
Dissolved oxygen (DO)	DO meter
Total dissolved solids (TDS)	Conductivity meter-thermo orient model 145 A
Total solids (TS)	APHA Method 2540-G
Volatile solids (VS)	APHA Method 2540-G
Ash	APHA Method 2540-G
Chemical oxygen demand (COD)	Spectrophotometer (HACH DRB 200)
Biochemical oxygen demand (BOD)	Winkler titration method (APHA 2005)

2.5 Kinetic analysis of the performance of LTB

Most mathematical models are developed based on the black box approach. Lately, logistic growth equation is used to predict the growth and decay of microbes within the treatment system. In the decay process, mineralization takes place of heavy metals, thus reducing the ionic strength of the leachate and it is a good indicator as well as a parameter for the kinetic analysis to determine the performance of the LTB. Logistic growth equation as given in (2) was used to analyze the parameters [28], [29], [30], [31], [32].

$$X_t = \left[\alpha X_0 e^{\alpha t} / \left(\beta X_0 e^{\alpha t} + \alpha - \beta X_0\right)\right] \qquad (2)$$

Where, X_t = biological transformation mass at time t
X_0 = initial value of growth
α = transformation or growth coefficient
β = retardation coefficient

The first derivative

$$dX_t/dt = \alpha X_t - \beta X_t^2 \qquad (3)$$
[29], [30].

Microsoft Excel programme was used to obtain the above coefficients and Xo, α/β. The regression analysis was conducted to obtain R². The program optimizes the value of $\alpha/\beta = c$ to give the optimum R² value.

Distinguish growth phases were identified in the growth curve. And those growth phases were separated and kinetic parameters was determined for each separated growth phases and growth curves were simulated. It has been assumed that the experimental values are differentials of logistic growth curve. Unfortunately the differential of the growth curve cannot be used to describe purely downward trend of the experimental values of TFS content (ash) to make an accurate mathematical prediction of this downward trend. Therefore, negative and positive values of dif-

ferentials of logistic growth curve were separated and cumulative values of each negative and positive value were obtained. Finally, these negative and positive TFS contents (ash) values were applied to logistic growth equation. The difference, which is the differential of summed up negative values and positive values were obtained to predict the likely performance of the laboratory LTB. These predictable results were used to obtain the design parameters for the full scale LTB.

3 RESULTS AND DISCUSSION

The laboratory scale LTB is similar to a leaching column with the addition of recycling of leachate, nutrients, layers of materials and water. The purpose of adding larger quantities of coarse filter materials in layers is to increase the lifespan of the reactor, otherwise as experienced the volume of the reactor gets reduced only with partially decomposed waste within three years. It is a primary treatment step of treating fresh leachate collected from the Gohagoda MSW dumpsite. pH of inlet leachate before being fed in to the LTB was 6.9, EC was 8.7 mS indicating high content of dissolved salts, salinity was 6.3 ‰. DO was very low of 0.29 mg/L indicating the dumpsite was under anaerobic conditions, TDS was 6,230 mg/L, BOD was 29,700 mg/L, TS was 26,000 mg/L and VS was 12,000 mg/L.

3.1 Variation of DO, pH, salinity, EC and TDS

DO concentration of the LTB outlet was very low 0.29 mg/L at the beginning as shown in Fig.2(a) After introducing the leachate and water additions, DO steadily increased up to 4.47 mg/L until 43 days of operation, thereafter it reduced to 2.57 mg/L on 61th day of operation (end of experimentation) in a fluctuating manner. It is likely that the LTB was reaching anaerobic conditions. Salinity values decreased in a fluctuating manner with the time throughout the study period. Salinity values varied between 7.2 ‰ - 2.9 ‰ as shown in Fig.2 (a). At the end of experimentation, it had reduced to 3 ‰. Maximum salinity removal efficiency of 53.6 % was recorded for the later duration from 21st day to end of experimentation.

The growth of microorganisms in anaerobic processes significantly depends on pH value of the system. Most methanogens prefer a narrow pH range and the optimal is reported to be 7 to 8. The optimum pH range for mesophilic digestion is between 6.5 and 8 and the process is severely inhibited, if the pH value falls out of this range [33]. During the study period pH values varied from 6.65 to 7.67 with fluctuations. The LTB was mostly operated at that optimum range.

EC increases when the concentration of ions increases in the solution. In this reactor, EC and TDS values decreased in a fluctuating manner with the time as shown in Fig.2 (b). Throughout the study period, EC values varied from beginning to the end of the study between 13 mS - 5.53 mS. Nutrients like carbon, nitrogen, phosphorus and sulphur are very important for the survival and growth of anaerobic digestion process organisms [34]. Insufficient amount of these nutrients and trace elements can cause inhibition and

instability in anaerobic digestion process [33]. It is reported that in order to maintain optimum methanogenic activity, desirable liquid phase concentration of nitrogen, phosphorus and sulphur should be in the order of 50, 10 and 5 mg/L [35]. Therefore, TSP was added as a nutrient source in to the LTB.

After adding TSP into the influent on the 13rd day of operation, EC (9.62 mS – 8.3 mS) and TDS (5,120 mg/L - 4,800 mg/L) showed some stable conditions until 21st day of operation, when fresh leachate was added with recirculation effluent, resulting an EC increase, reaching 11.93 mS on the 26th day of operation, while TDS increased up to 6,520 mg/L with fluctuations. During the study period, EC removal efficiency of Lab-scale LTB was -0.30±20.68%. TDS removal efficiency was 25.47±16.39%. Warith et al. 2000 [36], Hughes et al., 2005 [37], reported that leachate circulation accelerate the decomposition of waste by distributing moisture, nutrient and bacteria throughout the waste mass more efficiently. Inevitably, on the 61st day of operation, EC of effluent of the LTB did reduce to 5.69 mS and TDS reduced to 2,930 mg/L, which are in terms of efficiency 34.60% and 52.97%, respectively. TDS was the substrate for the methenogens converting carbon sources to methane and carbon dioxide while the mineralization process was taking place accompanied with deposition of these minerals in the liner system, thus achieving one of the objectives of the study.

3.2 Variations of TS (Total solids) and VS (Volatile solids)

TS is a direct indicator of the substrate for microbial growth. TS degradation is accomplished through complex reactions. Gaseous and liquids are the products of these reactions. Methanogen produce methane, carbon dioxide and other trace gasses as they degrade the organic fraction of TS, which had been converted to TDS. Volatile materials in the waste mass are transported out of the reactor with this evolving gas stream [38]. At the beginning, TS was rapidly declining because solid particles were absorbed and adhered to biofilter materials of the LTB. Also, this can be due to increase of the microbial growth. Fig.2(c), shows the variations of TFS contents (ash), TS and VS during experimental period. The temporal variations of TS and VS have been identified having many similarities. VS content is one of the indicative parameters, which can be used to express interactions between microbial growth and substrate utilizations in the biofilm liner. Also, VS levels are often interpreted as being a measure of the organic content, which shows a gradual reduction with time [39]. It is conclusive as reported by [37], leachate circulation accelerate the decomposition of waste by distributing moisture, nutrient and bacteria throughout the waste mass more efficiently.

As shown in Fig.2(c) initial value of the TS was 26,000 mg/L and VS was 12,000 mg/L. TS values reduced from 26,000 mg/L to 6,834.2 mg/L and 26,500 mg/L was observed as highest value of TS. VS also reduced from 12,000 mg/L to 1,182.6 mg/L and 16,000 mg/L was observed as highest VS value. Initial ash content was 14,000 mg/L and it did increase in the initial stages and then reduced to 4,364

mg/L in a fluctuating manner with time. During the study period, TS removal efficiency of Lab-scale LTB was 51.25±19.69% and VS removal efficiency was 61.10±21%, respectively.

3.3 Variations of Biochemical Oxygen Demand (BOD)

BOD is a widely used method for determination of the dissolved oxygen used by microorganisms in the biochemical oxidation of organic matter. Leachate recirculation is an attractive option as it achieves a decrease in the total volume of leachate to be treated or disposed and a reduction in

the degradable components of the leachate. Increase in moisture content along with leachate recirculation has shown increased biological activity, particularly methanogenesis and decomposition [40], [41], [42]. According to Fig.2 (b), BOD values decreased because methanogenic tivities had taken place, whenever anaerobic conditions existed in the reactor. Initially BOD rapidly reduced, as a result from high microbial activities reacting on the leachate. BOD value did reduce from 29,700 mg/L to 3,000 mg/L during the experimental period, thus BOD removal efficiencies of the Lab-scale LTB were 64.47±29.08%.
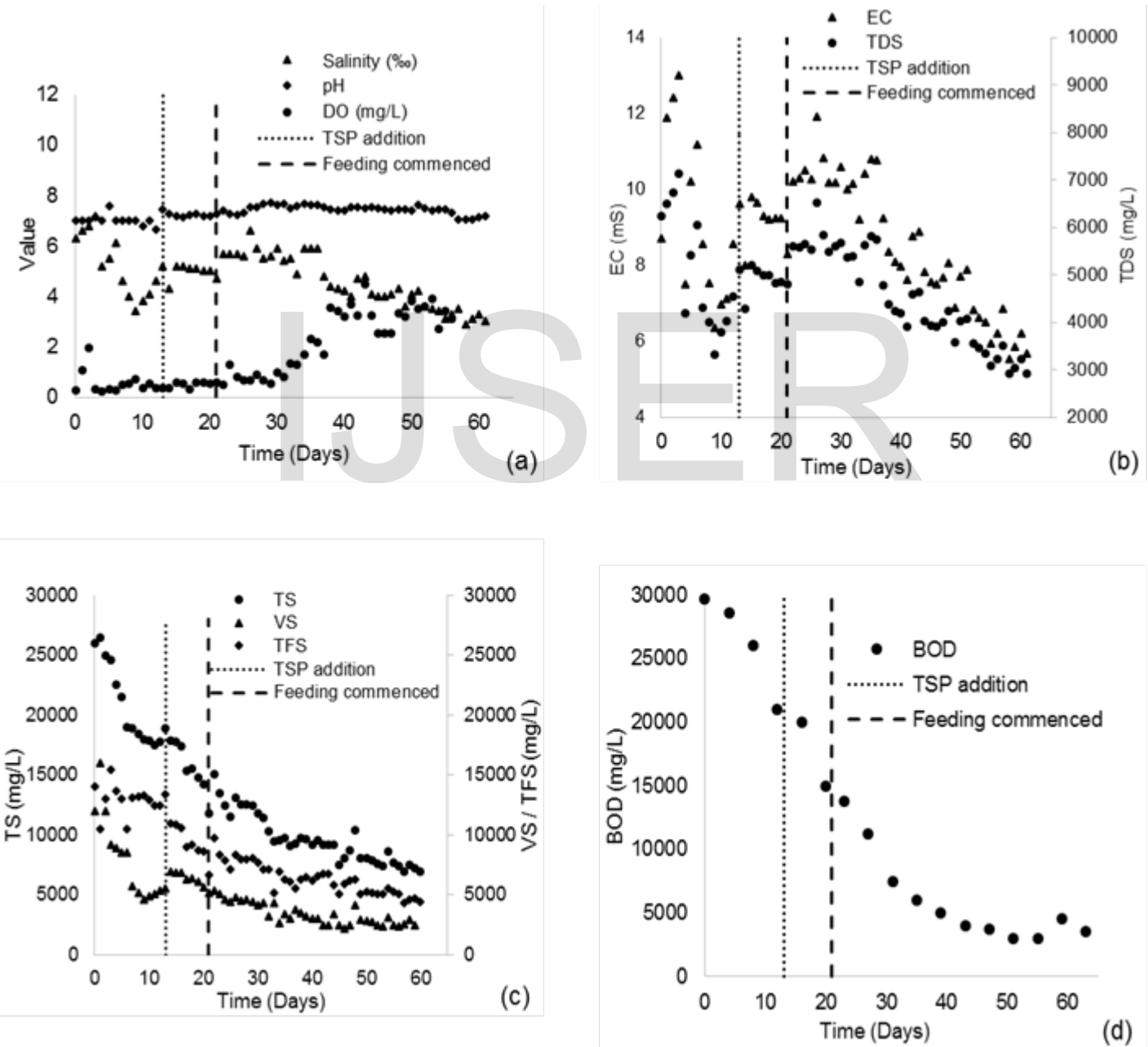

Fig. 1.Variations of analytical parameters with time (a) salinity, pH and DO (b)EC and TDS (c)TFS (Ash), VS and TS (d)BOD

Maximum average removal efficiency of all parameters recorded during 21st day to 61st day period is given in Table 2. The removal efficiency of the LTB on 61st day was much higher than recorded average values of the specified period as given in Table 2 indicating the LTB was performing well at the end of the study period and reaching stable conditions.

TABLE 2.REMOVAL EFFICIENCY OF THE LTB

Descrip-tion	Removal efficiency (%)						
	Salinity	EC	TDS	TS	VS	TFS (Ash)	BOD
First 13 days	18.07±20.28	-6.59±25.89	19.59±19.18	21.19±12.19	36.29±28.17	8.25±9.10	13±15.15
13rd day to 21th day	21.42±4.87	-4.52±7.21	21.72±4.44	40.05±7.97	47.7±5.25	33.49±10.38	41.07±11.90
21st day to 61st day	27.77±16.18	1.85±20.37	27.50±16	63.26±8.05	72±08	55.17±9.24	79.20±12.28
On 61st day	52.38	34.60	52.97	73.71	78.75	68.45	84.85
Minimum*	-14.28	-49.42	-14.45	-1.92	-33.33	-10.29	3.70
Maximum*	53.96	36.44	53.29	73.71	81.81	68.83	89.90
Average*	24.87±16.48	-0.30±20.68	25.47±16.39	51.25±19.69	61.10±21	42.11±21.44	64.47±29.08

Note: * recorded throughout the experimental period

3.4 Kinetic analysis

The rate of mineralization of organics in a biological process depends on the concentration of active cell mass [43]. The maximum cell growth in a process will depend on nutrient availability, gas transfer and toxicity of leachate [43], [44]. Microorganisms can degrade organic compounds to form a mixture of carbon dioxide and methane under anaerobic conditions [43], [45], thus increasing the concentration of the mineral content (TFS), notably the sludge. The sludge too gets mineralized in the biofilter liner systems, thus there was a gradual reduction in the TFS in the LTB as shown in Fig.3. As mentioned before, these are differential values taken daily over the experimental period.
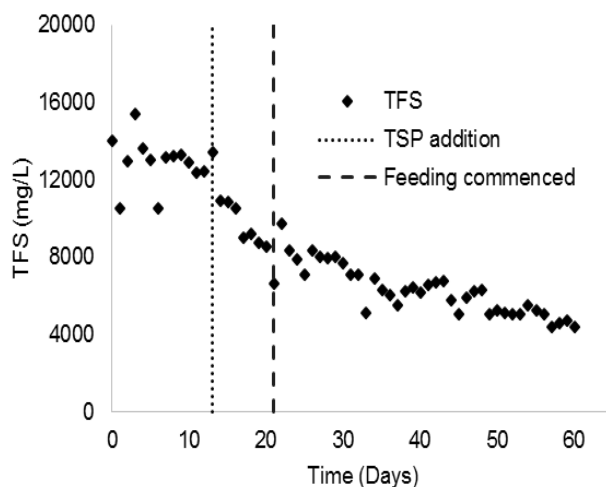

Fig. 3 Variation of TFS (Ash) with time

Once these values were summed up, in other words, increase in cumulative TFS content (ash) of LTB effluent with time seems to follow the classical logistic growth curve. The TFS content (ash) in LTB effluent, showed distinct phases which can be considered as different growth curves with time as shown in Fig. 4. This may be due to interventions during the experimental period. The Fig. 5 shows the differential of cumulative TFS content (ash) variations.

Separate growth curves were identified according to the intervention activities of different phases and the logistic growth equation and the differential of it was used to simulate the TFS content (ash) discharges in each of the phases. Each phase gave different growth parameters to optimize the R^2 value. In the first phase, experimental cumulative curve showed two growth curves as shown in Fig. 4. As shown in Fig. 5(a) during the first phase, dx/dt value reduced from 14 g/L/day to 12.4 g/L/day.

In the second phase, the predictions of logistic growth curve show some slight deviations from the cumulative experimental values as shown in Fig. 4. These deviations are prominent at the beginning and in the latter part of the curve as shown in Fig. 4. R^2 of experimental sum of TFS value vs simulated cumulative TFS value was 0.9975 and y = 1.0147x- 2.5004. It should be noted that during the second phase, dx/dt value of TFS content (ash) reduced from 13.49 g/L/day to 8.58 g/L/day as shown in Fig. 5(a).

In the third phase, the cumulative experimental TFS values were fitted with the perdition of logistic growth curve as shown in Fig. 4. R^2 of experimental sum of TFS value vs simulated cumulative TFS value was 0.9985 and y = 1.0027x. As illustrated in Fig. 5(a), during the third phase, dx/dt value of TFS reduced from 6.6 g/L/day to 4.4 g/L/day.
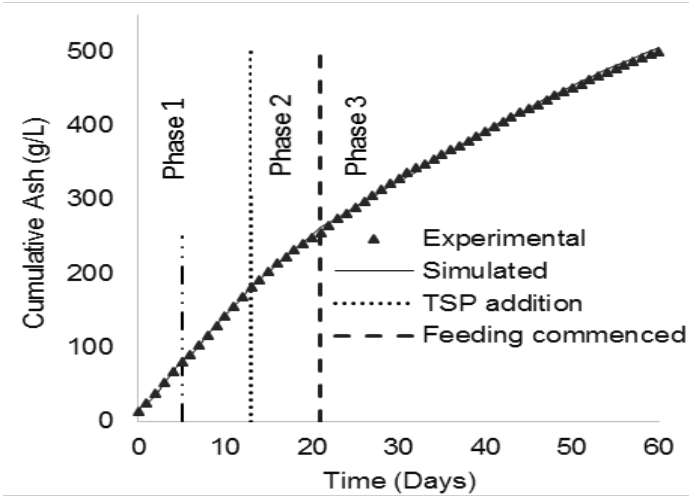
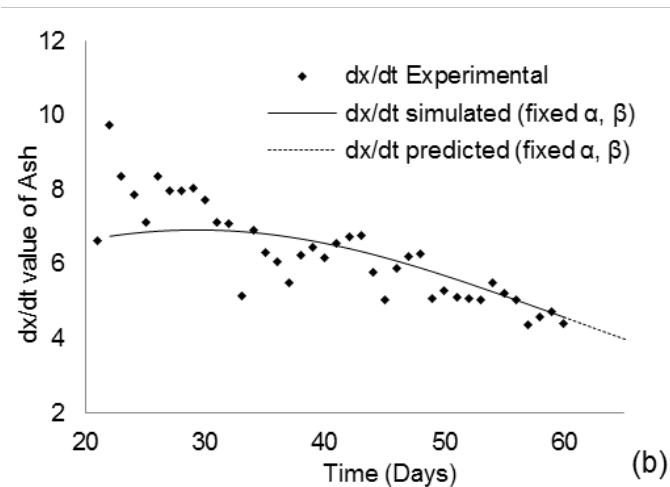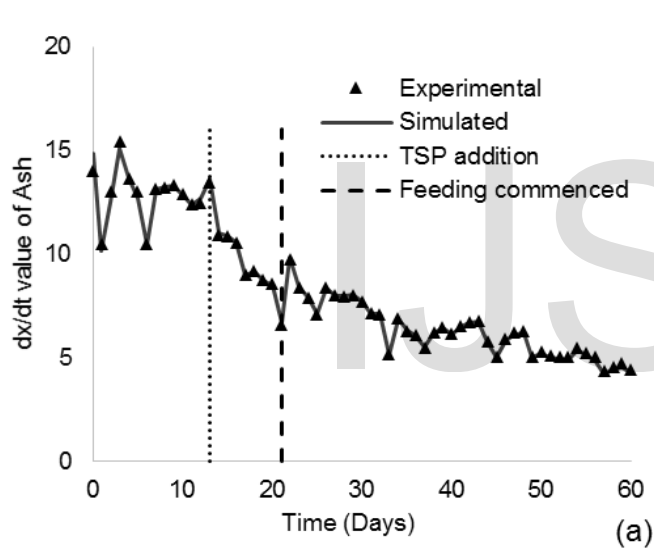Fig. 4 Cumulative TFS (ash) content variations with time

Fig. 5. Differential of cumulative ash variations with time (a)Whole mental period (b)Differential of cumulative TFS (ash) of experimental values showing simulated and predicted variation for fixed α and β values with time for third phase.

Logistic growth parameters for each phase are given in Table 3. Logistic growth curve coefficients give better understanding of the reactions and it is clearly illustrated in rate of change in TFS (ash). The prediction seems unrealistic, because the tendency is towards much greater reduction in ash due to mineralization. Therefore, a mathematical analysis of the mass balance is required to predict accurately the mineralization rate in the future.

TABLE 3. LOGISTIC GROWTH PARAMETERS FOR EACH PHASE

Phases	Growth parameters				R^2	Y
	X_o	C	α	β		
Phase 1	15	130	0.52	0.004	0.9915	0.9983x
	27	215	0.263	0.00122	0.9989	1.0109x - 1.768
Phase 2	78.5	429.9	0.092	0.000214	0.9975	1.0147x- 2.5004
Phase 3	140	638.4	0.043	0.000214	0.9985	1.0027x

3.5 Mass balance analysis for the TFS (ash)

Liquid–solid reactions are very important in systems with high levels of cations. Especially those that readily form carbonate precipitates such as mg^{2+} and ca^{2+} [46]. Fig. 6(a) shows the sum of (-ve) value as (+ve) and simulated result with the time. Some points showed slight deviation from the simulated one. R^2 of experimental sum of (-ve) value as (+ve) vs simulated cumulative value was 0.9915 and y = 1.005x. Fig. 6(b) shows the sum of (+ve) value and predicted result with the time. Some points show slight deviation from the predicted one. R^2 of the experimental sum of (+ve) value vs simulated cumulative value was 0.9782 and y = 0.9883x. As shown in Fig. 6(c) initially both (-ve) and (+ve) rate of change of ash are increasing until certain point. But the peak values are different. In other words, α/β of both (-ve) as (+ve) are different. (-ve) rate of change in positive terms is higher than the positive rate of change. After reaching the maximum points, both are decreasing and eventually merging together. The difference between (-ve) and (+ve) rate of change vary with time as shown in the Fig. 6(c). When LTB conditions became stable, the difference between the rates of change tended to and in time was zero. Fig. 6(d) shows the resultant value of (-ve) – (+ve) variations throughout the study period. This is showing the amount of TFS (ash) removed by LTB during the study period. Stable conditions were reached at the latter part of the experimental period. Experimental TFS (ash) of dx/dt reduced from 14 g/L/day to 4.4 g/L/day in a fluctuating manner with time. At the latter part, it had reached stable conditions. The deviations of the experimental values from the simulation curve are very much less towards the end of the experimentation as shown in Fig. 6(e).
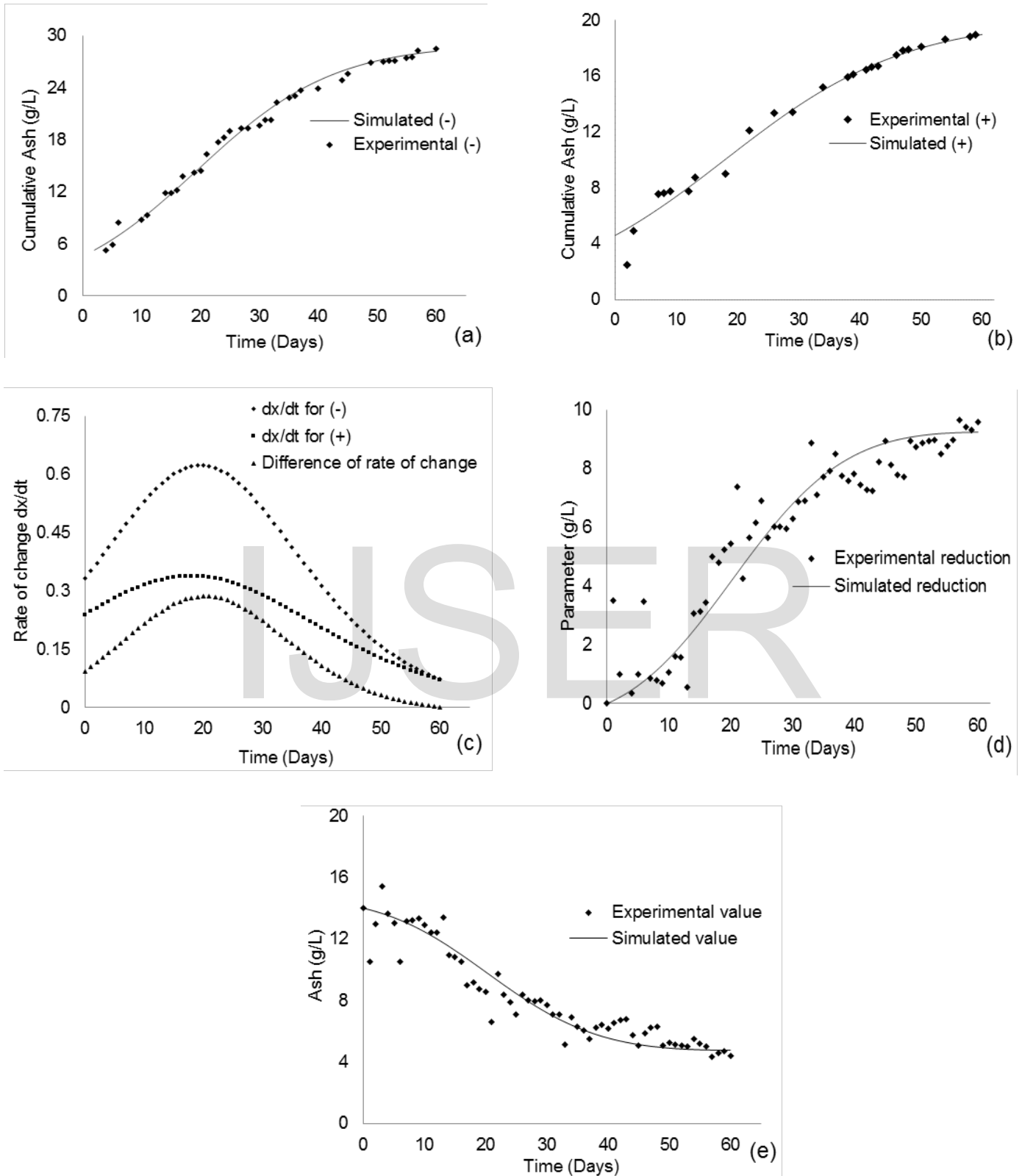
Fig. 6 Mass balance analysis for the TFS (ash) (a) Experimental sum of (-ve) value as (+ve) value with simulated result with time (b) Experiment sum of (+ve) value and simulated result with time (c) Rate of change of ash for fixed α and β values, (c) difference between the rates of change (d) Reduction value of Ash variation with time (e) Simulated values (dx/dt) of ash and experimental results (dx/dt) of ash variations with time

3.6 Design parameters for up-scaling laboratory unit

According to the results of the study, the most important design parameter can be deduced from the total TFS (ash) reduction in the mineralization process. The parameters and the values used in computing the up-scaling design criteria are height of the LTB, which was 0.55 m, cross sectional area of LTB was 0.0095 m^2, influent TFS (ash) content was 14 g/L, effluent TFS (ash) content 4.41 g/L, reduction amount was 9.59 g/L and hydraulic retention time (HRT) was 1day. It can be deduced that the TFS (ash) removal of LTB was 1.83×10^2 kg /m^3 of leachate/m height of LTB/day, which is a significant result.

3.7 Conclusion

Almost all of the measured parameters in the simulated laboratory scale LTB gradually reduced in a fluctuating manner, except pH and DO. DO initially did increase and then gradually reduced, thus indicating anaerobic conditions that was prevailing towards the end of experimentation. TS and VS contents reduced forming dissolved organic compounds and gases. The pH reached optimum conditions for anaerobic conditions, indicating suppression of excess ammonia productions while reducing the acidity of the leachate. It could have been due to conversion of TDS to end products of methane and carbon dioxide with the action of methanogens. Notably, there was no build-up of TFS, thus reduction in the ionic strength due to mineralization of inorganic compounds in the composite liner system. All of these phenomena can be explained with the logistic growth equation. It showed number of growth phases corresponding to the interventions. These operations were allowing adequate time for maturing the reactor, the addition of phosphate that was lacking in the leachate and daily feeding. The concept of separating growth and decay of microbes in expressing logistic growth equations did lead to accurate prediction of mineralization in the composite liner system, which is one of the important design parameters for up-scaling the reactor.

4 ACKNOWLEDGMENT

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