Desalination and Water Treatment
www.deswater.com

doi: 10.1080/19443994.2015.1106347

57 (2016) 19596–19608
September

Taylor & Francis
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Hydrodynamic evaluation of an anaerobic baffled reactor for landfill leachate treatment

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Received 5 April 2015; Accepted 2 October 2015

ABSTRACT

Performance of an anaerobic baffled reactor (ABR) used for landfill waste leachate treatment was evaluated in this study. For this purpose, the effects of different values of hydraulic retention time (HRT) and various concentrations of landfill leachate on the reactor performance during 52 d were evaluated. In this research, the system exhibited, during entire start-up period, a good performance in terms of removing chemical oxygen demand (COD), nitrate, and total Kjeldahl nitrogen (TKN). The obtained results indicated reductions in COD, TKN, nitrate, and total dissolved salts contents from 55 to 86%, from 42 to 92.4%, from 41 to 96.6%, and from 20 to 64%, respectively. During the entire start-up period, the value of oxidation–reduction potential was continuously monitored to ensure the remaining under anaerobic conditions. Also, the value of pH ranged from 6.1 to 8.2 in the course of reactor performance. Achieved at the COD concentration of 2,700 mg/l within a HRT of 48 h, maximum COD and nitrate removal performances were 86 and 96.6%, respectively. Furthermore, realized at the COD concentration of 1,800 mg/l within a HRT of 48 h, the maximum TKN removal performance was 92.4%.

Keywords: Anaerobic baffled reactor; Landfill leachate; Anaerobic digestion; Hydraulic retention time; Alkalinity

1. Introduction

Over the past few decades, the growth of prosperity and urbanization, technological advancements, evolution of lifestyle, the increasing ubiquitous tendency toward prodigality in the societies, and changes in the productivity and consumption behaviors have caused an increase in the amount of municipal and industrial solid wastes [1], such that the municipal solid production rate has been increased from 1.3 billion tons per day in 1994 to 1.7 billion tons per day in 2008 [2].

Today, landfilling, rather than other methods such as incineration and composting, is the most popular approach toward disposing municipal and industrial wastes [3]. Preparing a basis for the waste to be decomposed under controlled conditions, landfills are associated with some economic advantages along with lower environmental problems [4]. However, it has

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been identified as a potential source of ground and surface waters' contamination due to the generation of leachate. Further, landfill leachate may percolate through the soil causing the streams, creeks, and water wells to be largely polluted. As penetrating into the soil and passing through soil particles, landfill leachate not only causes groundwater pollution, but it can also lead to considerable soil contamination. [5]. Landfill leachate is some highly contaminated wastewater resulting from the percolation of rainwater and moisture through the wastes disposed in a landfill [6]. Generated in a landfill, leachate may contain large amounts of organic matter as well as metal ions, heavy metals, ammonia, ammonium nitrogen, chlorinated, and some other inorganic materials [7]. Landfill leachates are characterized with their composition, volumetric flow rates, and penetration of groundwater through the landfill. The generated volume of landfill leachate is much dependent on the climate. Other factors influencing landfill leachate generation and quality are the differences in waste disposal technology, the landfill age (which reflects the level of stabilization of the waste), and location. The leachate flow rate is dependent on the rate of evaporation and precipitation in landfill; the evaporation and precipitation rates depend, in turn, on climate and geographic location of the landfill [8,9]. Composition of landfill leachate varies from site to site and depends on several factors such as nature of waste, landfill age, particle size, level of compaction, hydrology of the landfill, composition of the solid waste, and various biological, chemical, and physical reactions occurring in a landfill [10–12]. Young landfill leachates usually contain large amount of volatile fatty acids (VFA) which are easily decomposed. The biodegradation rate of young leachates is high due to their ratio of biological oxygen demand (BOD) to chemical oxygen demand (COD). Older landfill leachates, however, contain lower VFA but more biorefractory contaminants are formed in the course of acetogenic and methanogenic phases' degradation; as a result, the rate of biological degradation of landfill leachate is reduced [13,14].

Over the past few decades, increased pollution from landfill leachate has motivated different countries to go for the treatment of landfill leachate [15]. Different physical, chemical, and biological methods are used to treat landfill leachates. Today, due to their simplicity, high cost-effectiveness, easier management, and lower costs, biological treatment methods are commonly used for the treatment of landfill leachates containing a high ratio of BOD to COD.

There are two types of biological treatment methods, namely aerobic and anaerobic. In general, aerobic treatment is suitable for low-strength wastewaters (with biodegradable COD concentrations lower than 1,000 mg/L). Anaerobic treatment is, however, suitable when high-strength wastewaters (with biodegradable COD concentrations higher than 4,000 mg/L) are to be treated [16]. Anaerobic biological treatment methods have some advantages such as higher loading rates, lower sludge production, lower required energy, and lower methane production [17]. When landfill leachate treatment is concerned, anaerobic methods are more desired due to the lower working costs they offer coupled with the generation of usable biogas product, removal of most pathogens, and lower sludge production in these methods [18].

Today, the main objective of using anaerobic approach is to ensure the degradation and decomposition of organic substances. Anaerobic processes are performed by different types of bacteria. These bacteria may increase the rate of chemical reactions under anaerobic conditions. Anaerobic digestion follows four important steps: acidogenesis, hydrolysis, acetogenesis, and methanogenesis. Hydrolysis is the rate-limiting step in the process of degradation [19]. As reported in the literature, the rate-limiting step in the course of complex organic material degradation is the hydrolysis step, where toxic substances or inappropriate VFA are formed [20]. Micro-organisms' growth rate in an anaerobic process is very slow. Therefore, one of the main objectives in terms of this process is to fabricate the reactors for long-term preservation of micro-organisms of suitable mix to obtain a high rate of contact between the cells and their substrate [21]. As a result, choosing a suitable reactor is an important factor in anaerobic conditions. Due to slow growth of anaerobic bacteria, anaerobic reactors should provide a long retention time for biomass. Anaerobic reactors achieve a high reaction rate per unit reactor volume. Also, the reactor provides longer biomass retention times, solids retention time (SRT), in the reactor, independent of the incoming wastewater's hydraulic residence time (HRT) [22]. Compared to other high-rate reactors already developed, such as anaerobic continuous stirred tank reactor (CSTR), up-flow anaerobic sludge blanket (UASB) reactor, anaerobic filter, and hybrid bed filter, the anaerobic baffled reactor (ABR) has many advantages such as simple design, lower sludge production, high SRT, less HRT, and stability against hydraulic shock loads [23]. Previous studies have shown that the ABR has been suitable, at laboratory scale, for the anaerobic treatment [24]. ABR could be operated as a two-phase digester due to its superior design, in terms of separating anaerobic bacteria types in their growth conditions [25]. This protects more sensitive bacteria from being exposed to toxic materials, hence increasing their resistance to changes in environmental parameters such as pH and levels of VFA and heavy metals. For this reason, ABRs have been used for the treatment of different wastewaters [26,27]. The successful application of the anaerobic process for the treatment of landfill leachate is dependent on the type of high-rate anaerobic reactors used. This study is focused on the performance evaluation of a laboratory-scale ABR at different COD concentrations and hydraulic retention times (HRT) to improve the COD removal efficiency. Also evaluated was the ability of the reactor to perform denitrification and nitrate removal from landfill leachate in the course of treatment process.

2. Methods

2.1. Bioreactor dosing

Constructed from Perspex, the used ABR was 10-cm wide, 60-cm long, and 10-cm deep with an effective volume of 6 L. Fig. 1 shows the schematic structure of the used ABR. This reactor was divided, by vertical baffles, into seven chambers of same size, shape, and volume. The anaerobic baffled reactor produced effective mixing and contact between the landfill leachates and anaerobic sludge. Flowing from the down-comer to the up-comer, the landfill leachate was passed through the sludge bed at the bottom of the chambers. This provided a suitable mixing and contact between the landfill leachate and biomass within each chamber. The width of the down-comer and up-comer was 2.5 and 5.5 cm, respectively. Each chamber was equipped with sampling ports in the top of the reactor, where samples were collected from each chamber for the analysis. The landfill leachate was pumped into the ABR by a peristaltic pump. Then, the reactor was operated at 35°C in a temperature-controlled room.

2.2. Sludge seeding

The ABR was fed with anaerobically digested sewage sludge taken from an anaerobic digester at a wastewater treatment plant in the Qaemshahr city, Iran. Half of each chamber was filled with the anaerobic sludge with a total suspended solids (TSS) content of 25,000 and 12,000 mg/l VSS. In the study, SRT was 52 d.

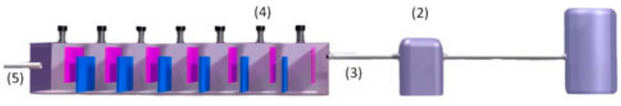

Fig. 1. The ABR.
Notes: (1) feed tank, (2) peristaltic pump, (3) influent, (4) sampling ports, and (5) effluent.

2.3. Landfill leachate characteristics

Landfill leachate used in this study was collected from a municipal waste landfill located in Kiasar, Sari. Average composition of landfill leachate used in this study is shown in Table 1.

2.4. Reactor start-up and operation

The reactor was started with a HRT of 48 h at 35°C. In this period, organic loading rate was set at 1.2 kg COD/m^3 d [28]. Also, influent pH value was between 7.6 and 7.8. Fig. 2 shows COD removal efficiency at start up. The landfill leachate flow rate was adjusted with a peristaltic pump. Constant effluent COD concentration was considered as the indicator for the steady-state conditions [29]. The ABR required 24 d to achieve a constant effluent COD. Once the ABR reached its capacity, the continuous phase started to flow. Then, the ABR performance evaluation was carried out at different HRTs and different influent COD concentrations after four steps. In each step, the ABR was filled with a constant concentration of landfill leachate at various HRTs. The initial loading rate was increased by increasing the leachate concentration in four steps with HRT being varied at each step. COD concentrations were 1,300, 1,800, 2,200, and 2,700 mg/l in steps 1, 2, 3, and 4, respectively.

2.5. Analytical methods

The experiments used in this study include COD, total Kjeldahl nitrogen (TKN), suspended solids (SS),

Table 1
Physicochemical characteristics of landfill leachate

Parameter	Concentration
pH	8–8.3
Alkalinity (mg/L as CaCO3)	7,300–7,500
SS	2,500–2,700
BOD (mg/L)	910
COD (mg/L)	2,700
Total Kjeldahl nitrogen (mg/L)	3,300
Total phosphorus (mg/L)	2,300
NH_3-N (mg/l)	450
NO_3-N (mg/l)	640
TDS (ppm)	7,800
Conductivity (ms/m)	15.5
NH_4-N (mg/l)	1,450

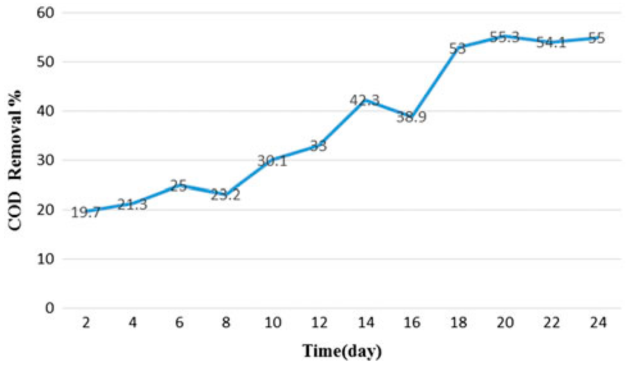

Fig. 2. COD removal efficiency in start-up.

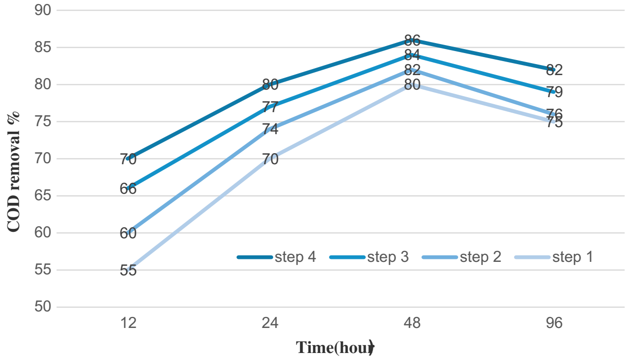

Fig. 3. COD removal efficiency at different feed concentrations at each HRT.

pH, oxidation–reduction potential (ORP), alkalinity, nitrate, conductivity, and volatile suspended solids (VSS) tests. Once centrifuged at 9,000 rpm for 10 min at 4˚C, extracted supernatants from the waste were collected for COD analysis. In order to measure COD, the sample was added to an aqualytic COD vario tube test. Then, it was heated at 150˚C in the ET 108 COD reactor for 2 h, after which they were analyzed in an AL 250 COD Photometer. For each chamber, SS in the effluent were measured by the standard method. Samples were filtered by glass fiber filters (Whatman filter paper with a pore size of 0.45 lm) and dried at 105˚C for 24 h. For each chamber, the values of pH in the effluent were measured using a pH meter (model 744) at room temperature. Sample conductivity, total dissolved salts (TDS), and ORP were measured at room temperature using a HI 8733 conductivity meter. Furthermore, sample alkalinity, nitrate content, and total phosphorus (TP) content were analyzed according to the standard methods (American public health association standards, APHA) [30]. TKN was measured by subjecting the samples to acid digestion and alkali distillation. The samples were collected and placed in boric acid solution and titrated against 0.2 N sulfuric acid until titration endpoint was determined by the change in the indicator color.

3. Results and discussion

3.1. *Effect of HRT and COD concentrations on COD removal and nitrogen removal*

The COD concentrations in influent and effluent were evaluated in different operations. Fig. 3 shows COD removal efficiency at different COD concentrations at each HRT. According to Fig. 3, COD removal was dependent on the organic loading rates and HRT. According to the results, at each HRT, COD removal increased as COD concentration increased from 1,300 to 1,800 mg/l, 1,800 to 2,200 mg/l, and 2,200 to 2,700 mg/l, indicating positive contribution of COD concentration into COD removal efficiencies. Significantly higher reaction rate was observed for

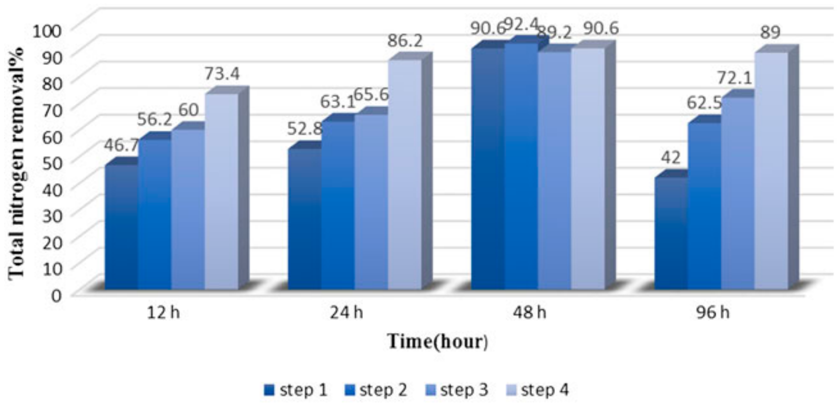

Fig. 4. Total nitrogen removal efficiency for different feed concentrations at each HRT.

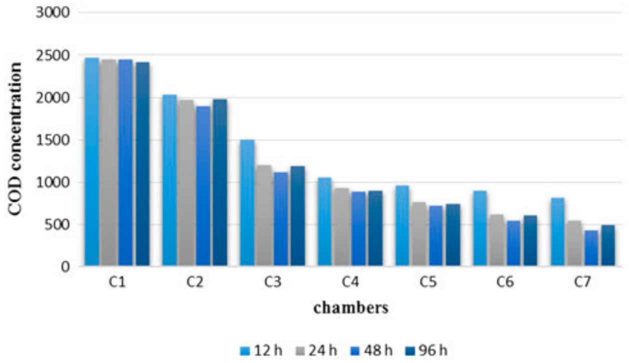

Fig. 5. COD concentration in each chamber reactor for step 4.

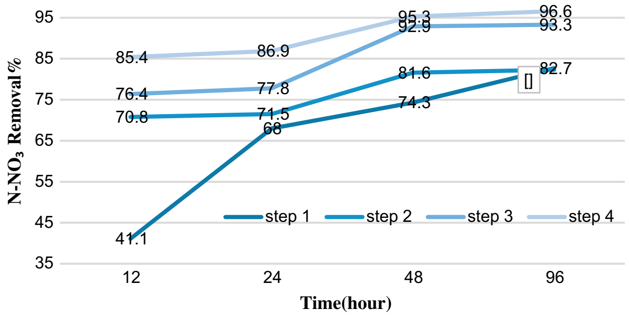

Fig. 6. Nitrate concentration for four steps at different HRTs.

higher COD concentrations. This is because of high mass transfer driving forces according to Monod kinetics [31]. Therefore, the substrate removal rate is improved. The results showed an increase in the COD removal as HRT decreased from 96 to 48 h. An explanation for this trend is that a decrease in the HRT is associated with an increase in the amount of substrate fed into the reactor [32]. On the other hand, COD removal was seen to decrease when HRT decreased from 48 to 24 h and from 24 to 12 h due to the occurrence of the shocked OLR [32].

The TKN and phosphorus content of the landfill leachate were 3,300 and 2,300 mg/l, respectively. The TKN and TP removal efficiencies were found to be 90/6 and 9%, respectively, for the COD concentration of 2,700 mg/l at HRT of 48 h. The removal efficiency of TKN was very high and phosphorous was very low because bacteria need two groups of elements to grow, namely microelements and macroelements, and metabolic processes. Microelements are the elements which are needed in small amounts for the bacterial growth and metabolism, such as phosphorus, while the macroelements are those that bacteria need in large amounts, including nitrogen and carbon. For this reason, the removal and consumption of phosphorus are frequently less compared with nitrogen [33]. Fig. 4 shows TKN removal efficiency at different COD concentrations at various HRTs. In all steps, TKN removal efficiency increased when HRT decreased from 96 to 48 h, as it would increase the amount of substrate fed into the reactor. However, TKN removal efficiency was seen to decrease when HRT was decreased from 48 to 24 h and 24 to 12 h. An explanation for this trend is the occurrence of the shocked OLR.

Table 2
COD removal efficiencies of each chamber at each HRT for step 4

Influent COD concentration (mg/l)	HRT	C1 (%)	C2 (%)	C3 (%)	C4 (%)	C5 (%)	C6 (%)	C7 (%)
2,700	12	8.5	17.8	26.1	30	8.6	6.2	10
2,700	24	9.2	19.6	39	22.5	18.3	18.4	12.9
2,700	48	9.2	22.4	41	20	19.1	25	20
2,700	96	10.3	18.1	39.9	24.3	17.7	17.6	19.6

Table 3
Operating conditions of the four steps applied in the study

	HRT (h)	COD (mg/L)	Temperature (°C)	pH	Alkalinity (mg/L as)
Step 1	12, 24, 48, 96	1,300	35	7.28–7.44	6,990–7,130
Step 2	12, 24, 48, 96	1,800	35	7.54–7.65	6,660–6,830
Step 3	12, 24, 48, 96	2,200	35	7.87–8.03	7,250–7,590
Step 4	12, 24, 48, 96	2,700	35	8.05–8.23	6,210–6,420

3.2. Effect of reactor chambers on COD removal

The concentrations of COD at each chamber and the COD removal efficiencies during different operations were evaluated. Fig. 5 shows the changes in the percent of COD removal at each chamber for the COD concentration of 2,700 mg/l at HRT of 48 h, where the chambers are denoted by C1, C2, C3, C4, C5, C6, and C7 (Table 2). In step 4, chamber 3 performed the high-

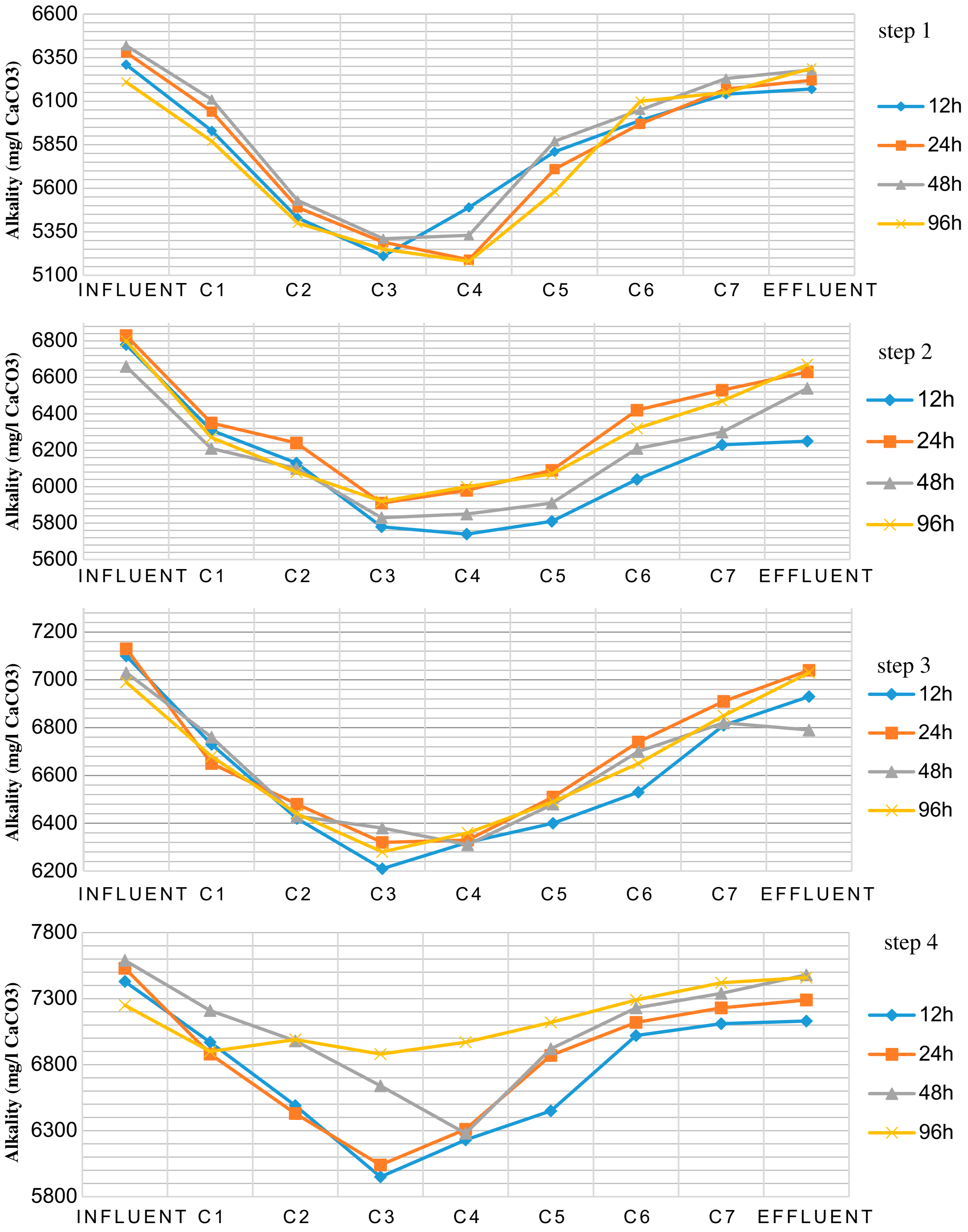

Fig. 7. The changes in alkalinity at any step in the chambers of reactor.

est proportion of COD removal. At step 4, as HRT decreases from 96 to 48 h, an increase is observed in the COD removal by C3. However, as HRT decreased from 48 to 24 h and 24 to 12 h, COD removal decreased. Summarized in Table 3 are the COD removal efficiencies of each chamber at each HRT for step 4. Based on the results, C3 had the largest contribution into COD removal. The landfill leachate is a low-strength wastewater, so this result indicates that less compartment number might be suitable for the

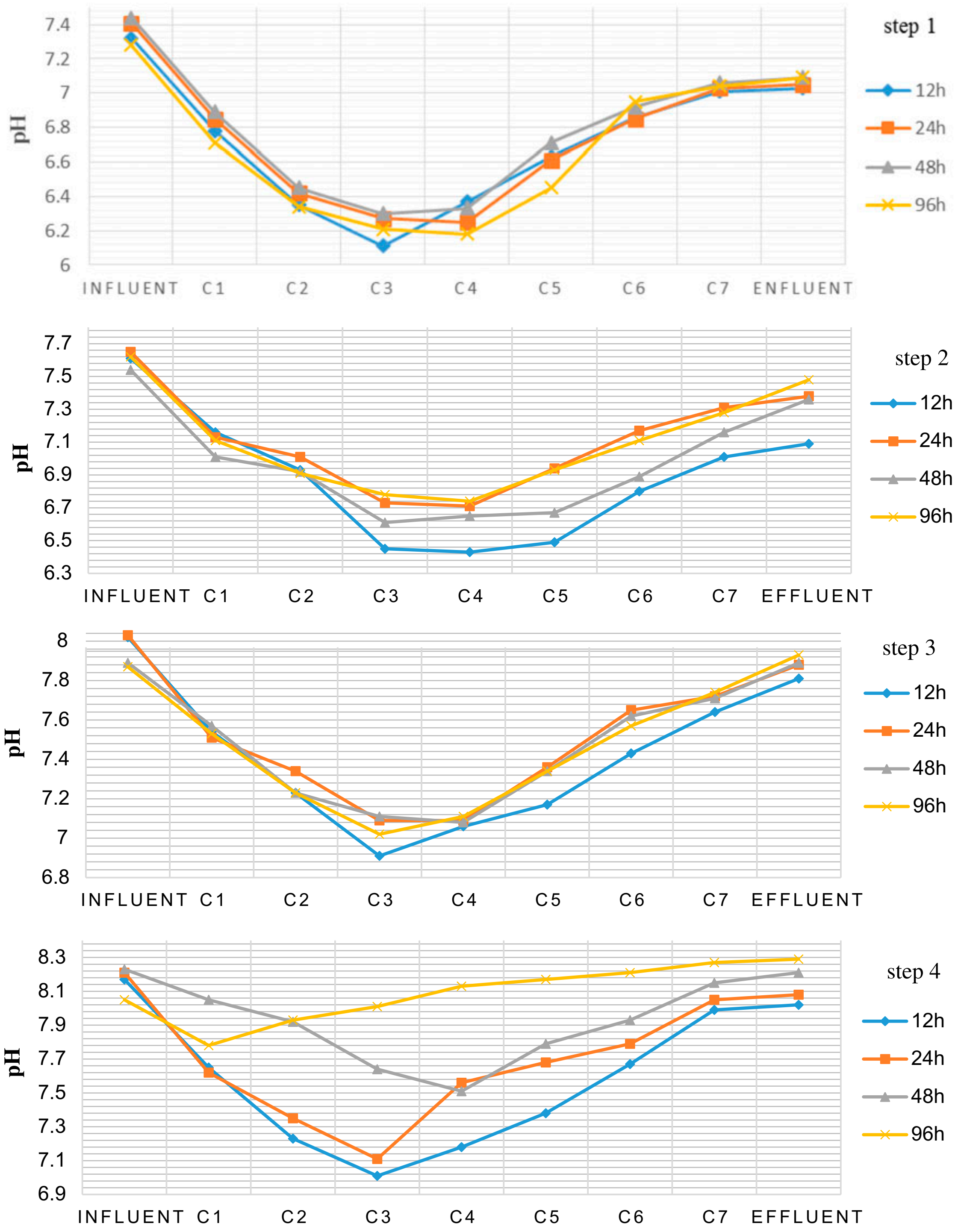

Fig. 8. The changes of pH in each chamber at any step.

ABR treating low-strength wastewater [34]. On the other hand, phase separation occurs in the ABR reactor, leading to the growth of hydrolyser and acid-forming bacteria in the frontal rooms and other bacteria in other rooms. Among the characteristics of hydrolyser and acidogenic bacteria is their rapid growth which led to a significant reduction in COD. It seems that these bacteria are accumulated in the first room and especially in the third room.

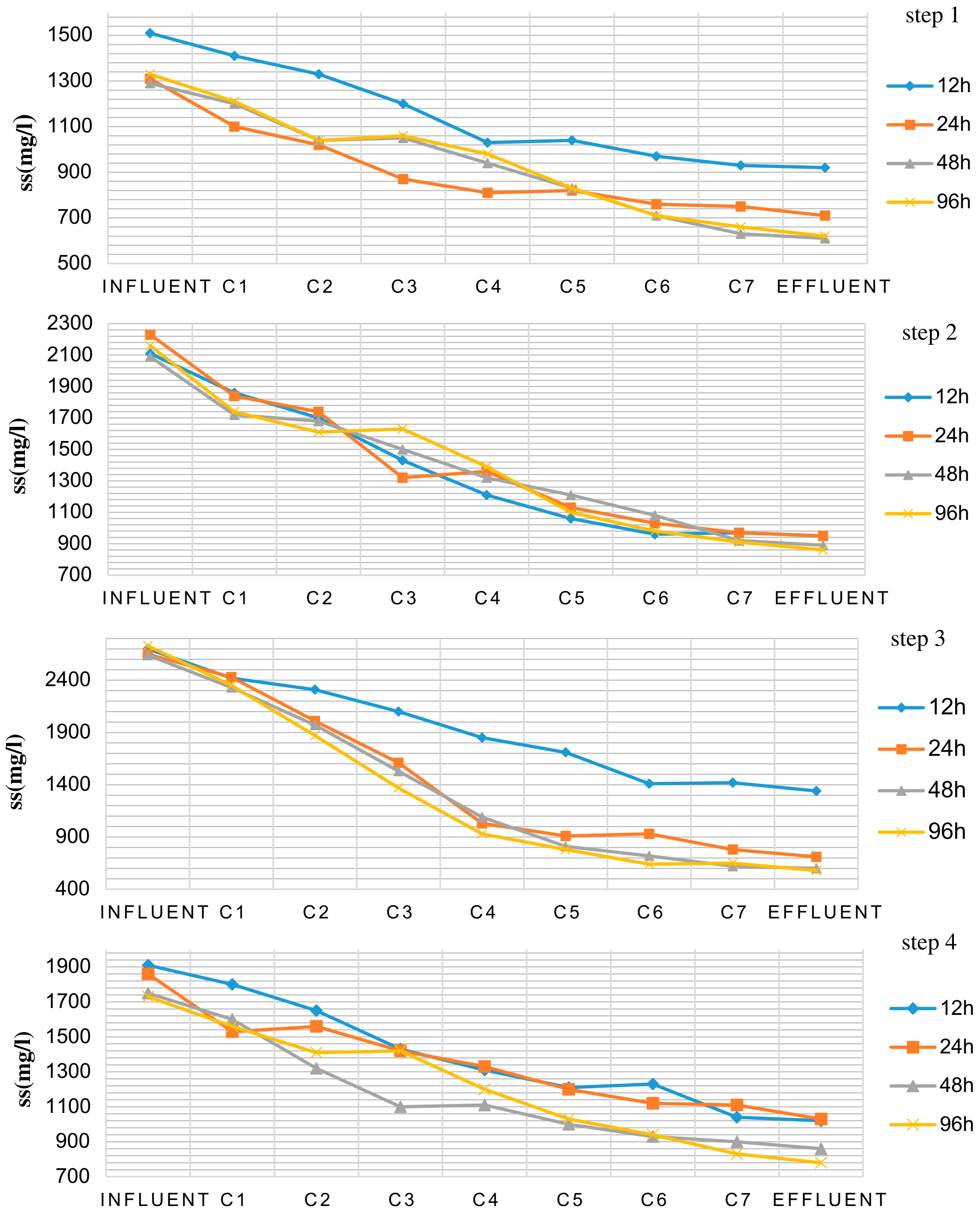

Fig. 9. The variation in SS for each chamber at any step.

3.3. Nitrate removal

In this study, nitrate concentration in the landfill leachate was measured at about 450 mg/l. As shown in Fig. 6, the nitrate removal efficiency was over 40% for all steps and HRTs. In theory, the nitrite/nitrate ration was to be reduced in the ABR via denitrification process. Denitrification had some positive contributions into the reactor performance because of several factors including: use of an oxidizable electron donor in the form of the feed COD, increased system pH at the reactor which improves the environmental conditions, and a high hydrogen demand during nitrate reduction to ammonium (improving conditions for syntrophic bacteria) [35]. By reducing HRT from 96 to 48, 48 to 24 h, and 24 to 12 h, nitrate removal was seen to decrease. An explanation for this trend can be the slow progress of biological nitrogen removal. Therefore, nitrate removal increased at high HRTs. It seems that, by reducing the HRT, the bacteria responsible to remove the nitrate will be reduced. According to the reaction related to denitrification, bacteria required COD to nitrate reduction. According to stoichiometry denitrification, 1 kg of nitrate requires 0.645 kg of a carbon source for denitrification to occur [36]. By decreasing the COD consumption with a reduction in the retention time, the required nitrate removal amount reduced too. On the other hand, the reduction of the nitrate removal can be due to the shock of ORL increase due to the reduction in HRT.

3.4. Total alkalinity

Alkalinity level shows the performance of an anaerobic process. Lower values of alkalinity in the effluent indicate inappropriate performance of the reactor. During the study, alkalinity levels were observed to be decreased because of the shift of HRT to the next lower HRT. Low effluent alkalinity was associated with lower COD reduction efficiencies [37]. Fig. 7 shows the changes in alkalinity at any step within the reactor chambers. Results showed an initial reduction in the alkalinity level in reactor chambers because of increased amounts of VFA. After a while, however, the alkalinity increased as VFA were consumed, producing carbonates and bicarbonates in other chambers [32].

3.5. pH

Value of pH is an important parameter to evaluate the performance of ABR. As pH value is related to the amount of VFA and alkalinity, it can indicate whether the ABR is performing well. Generally, at higher pH values, the amount of VFA collected in the first chamber of the ABR decreased. Fig. 8 shows pH changes in each chamber at each step. In this study, the pH was seen to decrease in chambers 1, 2, and 3 because of the production of VFA. In the front chambers, pH decreased due to the accumulation of VFA. An increase in the pH was observed in the next chambers as the concentration of VFA decreased with increase in alkalinity. It was observed that, in the constant COD concentration, as HRT decreased, the pH in the first three chambers rapidly reduced; other chambers were, however, less affected. Actually, the hydrolysis, acidogenesis, and acetogenesis were seen to occur in the first three chambers. Effluent pH was decreased by decreasing the HRT from 96 to 48 h, 48 to 24 h, and 24 to 12 h. That was because the micro-organisms were hungry at 96 h HRT and the resulting pH in the effluent decreased when they acquired a greater amount of substrate by shortening the HRT from 96 to 48 h, 48 to 24 h, and 24 to 12 h. Results related to the progress of acidogenesis step indicated an accumulation of VFA concentrations as a result of a decline in pH and alkalinity values.

3.6. Suspended solids removal

Fig. 9 shows the variation in SS for each chamber at various feed concentrations and HRTs. The results showed that increasing the COD concentration reduced the effluent SS because of higher COD removal as well as lower sludge production. The influent SS concentration ranged from 2,500 to 2,700 mg/l in step 4. In the COD concentration of 2,730 mg/l, SS

Table 4
Changes of ORP (mv) in the reactor for all steps

Step	C1	C2	C3	C4	C5	C6	C7	HRT
1	−150	−178	−196	−201	−232	−253	−254	12
2	−154	−176	−198	−209	−253	−267	−269	12
3	−159	−188	−200	−223	−246	−278	−285	12
4	−174	−197	−234	−265	−288	−303	−306	12
1	−220	−264	−274	−297	−310	−321	−327	24
2	−231	−252	−268	−287	−297	−320	−327	24
3	−251	−287	−299	−334	−356	−377	−382	24
4	−250	−289	−294	−330	−347	−386	−390	24
1	−310	−328	−352	−367	−369	−389	−393	48
2	−330	−336	−354	−367	−387	−401	−403	48
3	−326	−336	−344	−364	−378	−396	−399	48
4	−331	−345	−363	−378	−389	−400	−402	48
1	−351	−366	−378	−389	−401	−409	−416	96
2	−366	−376	−380	−400	−405	−413	−419	96
3	−365	−377	−387	−395	−406	−400	−403	96
4	−389	−399	−406	−411	−422	−426	−433	96

were reduced by about 79% at 96 h HRT, 77% at 48 h HRT, 73% at 24 h HRT, and 50% at 12 h HRT. Further, the SS concentrations in the landfill leachate effluent were observed to be unaffected by the changes in SS concentrations in the influent landfill leachate in a particular HRT.

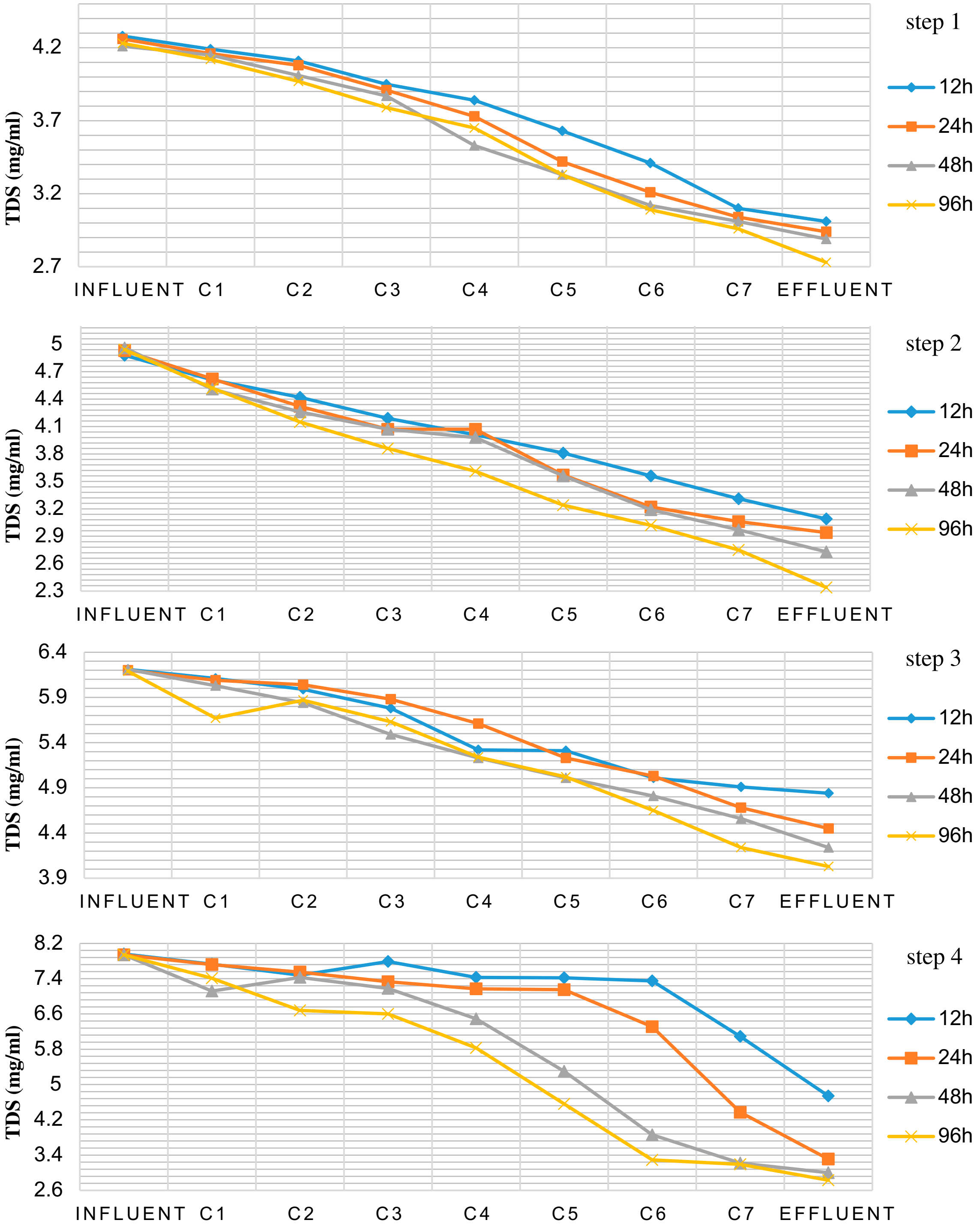

Fig. 10. The variation in TDS for various feed concentrations in each chamber at different HRTs.

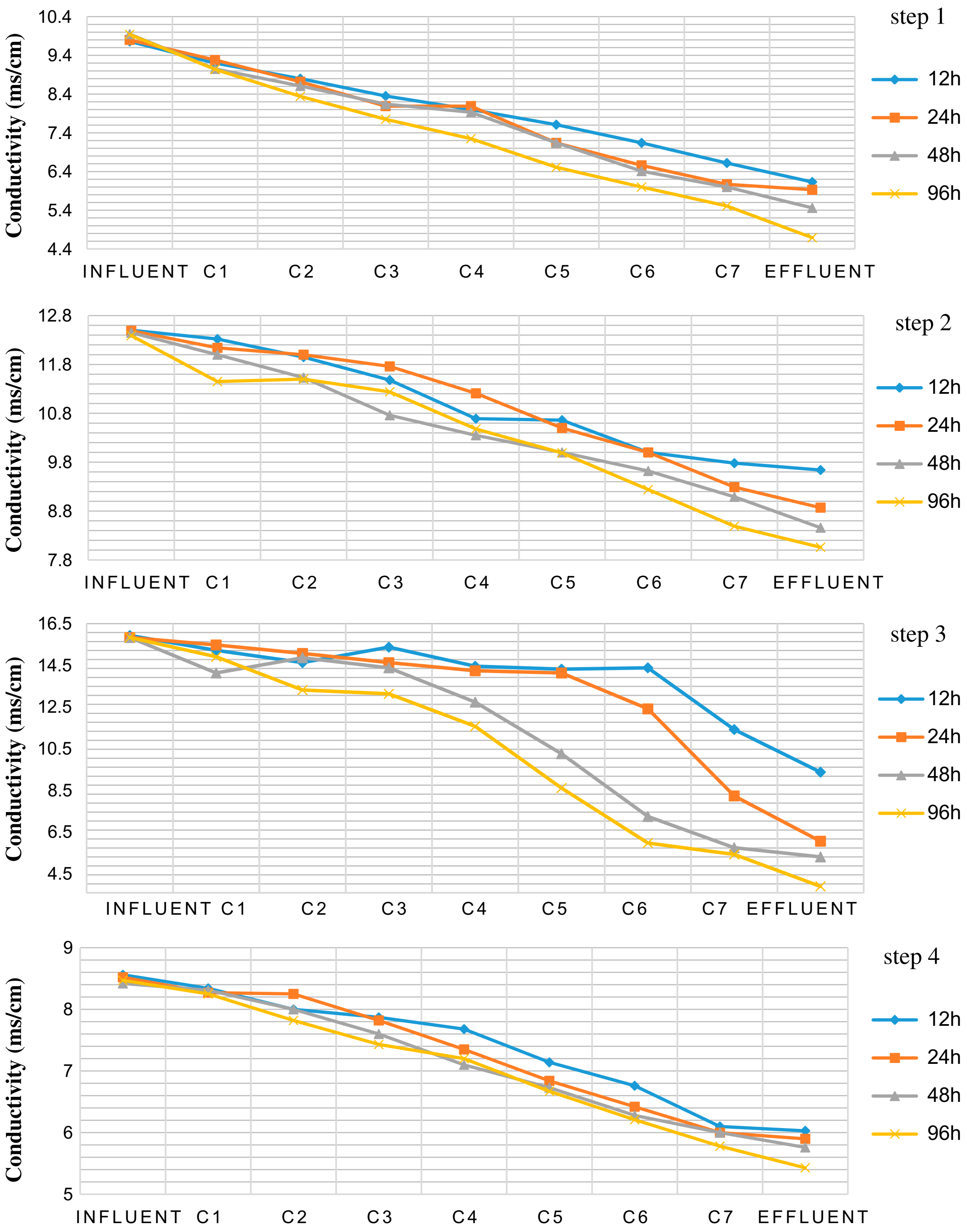

Fig. 11. The variation in conductivity in each chamber at any step.

3.7. Oxidation–reduction potential

ORP is an effective parameter on the performance of anaerobic digesters and microbial populations. It is a useful indicator for checking a biological treatment process and sees whether the system works in aerobic or anaerobic conditions. Denitrification predominated with the ORP in the range of −50 to −150 mV, while the sulfate-reducing bacteria and bacteria responsible for denitrification are active with ORP less than −150 mV. In this research, ORP was controlled in order to ensure from the presence of anaerobic conditions. So, the ORP values of the two rooms were close to the denitrification amount and were in the range in which both of the sulfate-reducing bacteria and bacteria responsible for denitrification are active [38,39]. The results showed that changing this parameter during this study affected the COD removal in each chamber of the reactor. According to the results earned in four steps, ORP reduced during the reaction. The average range of ORP was found to be 150–433 (−mv), further confirming the anaerobic condition in ABR. Table 4 shows the changes of ORP in the reactor for all steps.

3.8. TDS and conductivity

TDS indicates total dissolved solids including all inorganic and organic substances. Generally, the amount of TDS for landfill leachate is high. In this study, TDS removal capacity of the system was measured to be between 20 and 64%. TDS indicate the total dissolved solids such as mineral elements and ions which will be consumed by the bacteria, during the reaction when the wastewater is being passed through the reactor. The result indicates that TDS removal capacity of the system improved with increase in the concentration of COD. It seems that TDS decreased because of high mass transfer driving forces according to Monod kinetics. On the other hand, TDS removal was seen to decrease when HRT decreased from 96 to 48 h, from 48 to 24 h, and from 24 to 12 due to the occurrence of the shocked OLR. The performance of ABR was better than the performance of MABR′S Zwain et al. in which the TDS removal capacity of their system was 50% [34]. Fig. 10 shows the variation in TDS for any step at different HRTs in each chamber. Effluent TDS increased when HRT decreased from 96 to 48 h, 48 to 24 h, and 24 to 12 h. Effluent TDS decreased when COD concentration increased. Fig. 11 shows the variation in the conductivity for any step at different HRTs in each chamber. The results showed a decrease in the conductivity as TDS decreased.

4. Conclusions

The purpose of this study was to evaluate the performance of an ABR for landfill leachate treatment. The following conclusions can be drawn according to the obtained results from the experiments:

1. Considering a HRT of 48 h, ABR could achieve a great COD removal efficiency for landfill leachate at 35°C.
2. The results showed that ABR was highly capable of reducing total nitrogen and nitrate contents, so that the reactor could remove over 40% of the total nitrogen and nitrate contents in all experiments.
3. The reactor had a high capacity to withstand high organic shock loads.

Microbial population in the reactor could tolerate high levels of ammonia.

References

[1] A. Bachmann, V.L. Beard, P.L. McCarty, Performance characteristics of the anaerobic baffled reactor, Water Res. 19 (1985) 99–106.

[2] S. Uyanik, P.J. Sallis, G.K. Anderson, The effect of polymer addition on granulation in an anaerobic baffled reactor (ABR). Part I: Process performance, Water Res. 36 (2002) 933–943.

[3] J. Zhang, Y. Wei, W. Xiao, Z. Zhou, X. Yan, Performance and spatial community succession of an anaerobic baffled reactor treating acetone–butanol–ethanol fermentation wastewater, Bioresour. Technol. 102 (2011) 7407–7414.

[4] A. Bayrakdar, E. Sahinkaya, M. Gungor, S. Uyanik, Performance of sulfidogenic anaerobic baffled reactor (ABR) treating acidic and zinc-containing wastewater, Bioresour. Technol. 100 (2009) 4354–4360.

[5] M. Henze, P. Harremoës, Anaerobic treatment of wastewater in fixed film reactors a literature review, Water Sci. Technol. 15 (1983) 1–101.

[6] G.F. Zhu, J.Z. Li, P. Wu, H.Z. Jin, Z. Wang, The performance and phase separated characteristics of an anaerobic baffled reactor treating soybean protein processing wastewater, Bioresour. Technol. 99 (2008) 8027–8033.

[7] Federation, Water Environmental, and American Public Health Association, Standard methods for the Examination of Water and Wastewater, American Public Health Association (APHA), Washington, DC, USA, 2005.

[8] H. Feng, L. Hu, Q. Mahmood, C. Fang, C. Qiu, D. Shen, Effects of temperature and feed strength on a carrier anaerobic baffled reactor treating dilute wastewater, Desalination 239 (2009) 111–121.

[9] P. Thanwised, W. Wirojanagud, A. Reungsang, Effect of hydraulic retention time on hydrogen production and chemical oxygen demand removal from tapioca wastewater using anaerobic mixed cultures in anaerobic baffled reactor (ABR), Int. J. Hydrogen Energy 37 (2012) 15503–15510.

[10] W.P. Barber, D.C. Stuckey, Nitrogen removal in a modified anaerobic baffled reactor (ABR): 1, denitrification, Water Res. 34 (2000) 2413–2422.

[11] S.Y. Bodkhe, A modified anaerobic baffled reactor for municipal wastewater treatment, J. Environ. Manage. 90 (2009) 2488–2493.

[12] F.N. Ahmed, C.Q. Lan, Treatment of landfill leachate using membrane bioreactors: A review, Desalination 287 (2012) 41–54.

[13] K.Y. Foo, B.H. Hameed, An overview of landfill leachate treatment via activated carbon adsorption process, J. Hazard. Mater. 171 (2009) 54–60.

[14] M. Ince, F. Yildiz, G.O. Engin, S.N. Engin, B. Keskinler, Respirometric kinetic parameter calculations of a batch jet loop bioreactor treating leachate and oxygen uptake rate estimation by DTM, J. Hazard. Mater. 153 (2008) 991–998.

[15] S. Renou, J.G. Givaudan, S. Poulain, F. Dirassouyan, Landfill leachate treatment: Review and opportunity, J. Hazard. Mater. 150 (2008) 468–493.

[16] A.A. Tatsi, A.I. Zouboulis, K.A. Matis, P. Samaras, Coagulation–flocculation pretreatment of sanitary landfill leachates, Chemosphere 53 (2003) 737–744.

[17] J. Bohdziewicz, A. Kwarciak, The application of hybrid system UASB reactor-RO in landfill leachate treatment, Desalination 222 (2008) 128–134.

[18] D. Kulikowska, T. Jóźwiak, P. Kowal, S. Ciesielski, Municipal landfill leachate nitrification in RBC biofilm —Process efficiency and molecular analysis of microbial structure, Bioresour. Technol. 101 (2010) 3400–3405.

[19] A. Montusiewicz, M. Lebiocka, Co-digestion of intermediate landfill leachate and sewage sludge as a method of leachate utilization, Bioresour. Technol. 102 (2011) 2563–2571.

[20] M. Ince, E. Senturk, G. Onkal Engin, B. Keskinler, Further treatment of landfill leachate by nanofiltration and microfiltration–PAC hybrid process, Desalination 255 (2010) 52–60.

[21] D. Fatta, A. Papadopoulos, M. Loizidou, A study on the landfill leachate and its impact on the groundwater quality of the greater area, Environ. Geochem. Health 21 (1999) 175–190.

[22] J.M. Lema, R. Mendez, R. Blazquez, Characteristics of landfill leachates and alternatives for their treatment: A review, Water Air Soil Pollut. 40 (1988) 223–250.

[23] M. El-Fadel, E. Bou-Zeid, W. Chahine, B. Alayli, Temporal variation of leachate quality from pre-sorted and baled municipal solid waste with high organic and moisture content, Waste Manage. 22 (2002) 269–282.

[24] E. Neczaj, M. Kacprzak, J. Lach, E. Okoniewska, Effect of sonication on combined treatment of landfill leachate and domestic sewage in SBR reactor, Desalination 204 (2007) 227–233.

[25] M.N. Adlan, P. Palaniandy, H.A. Aziz, Optimization of coagulation and dissolved air flotation (DAF) treatment of semi-aerobic landfill leachate using response surface methodology (RSM), Desalination 277 (2011) 74–82.

[26] A. Uygur, F. Kargı, Biological nutrient removal from pre-treated landfill leachate in a sequencing batch reactor, J. Environ. Manage. 71 (2004) 9–14.

[27] R.H. Kettunen, T.H. Hoilijoki, J.A. Rintala, Anaerobic and sequential anaerobic-aerobic treatments of municipal landfill leachate at low temperatures, Bioresour. Technol. 58 (1996) 31–40.

[28] Y.J. Chan, M.F. Chong, C.L. Law, D.G. Hassell, A review on anaerobic–aerobic treatment of industrial and municipal wastewater, Chem. Eng. J. 155 (2009) 1–18.

[29] K.J. Kennedy, E.M. Lentz, Treatment of landfill leachate using sequencing batch and continuous flow upflow anaerobic sludge blanket (UASB) reactors, Water Res. 34 (2000) 3640–3656.

[30] S. Imen, T. Ismail, S. Sami, A. Fathi, M. Khaled, G. Ahmed, Characterization and anaerobic batch reactor treatment of Jebel Chakir Landfill leachate, Desalination 246 (2009) 417–424.

[31] H. Feng, L. Hu, Q. Mahmood, C. Fang, C. Qiu, D. Shen, Effects of temperature and feed strength on a carrier anaerobic baffled reactor treating dilute wastewater, Desalination 239 (2009) 111–121.

[32] A. Grobicki, D.C. Stuckey, Performance of the anaerobic baffled reactor under steady-state and shock loading conditions, Biotechnol. Bioeng. 37 (1991) 344–355.

[33] P.F. Stanbury, A. Whitaker, SJ Hall, Principles of Fermentation Technology, Elsevier, Quezon City, 2013.

[34] H.M. Zwain, S.R. Hassan, N.Q. Zaman, H.A. Aziz, The start-up performance of modified anaerobic baffled reactor (MABR) for the treatment of recycled paper mill wastewater, J. Environ. Chem. Eng. 1 (2013) 61–64.

[35] W.P. Barber, D.C. Stuckey, The use of the anaerobic baffled reactor (ABR) for wastewater treatment: A review, Water Res. 33 (1999) 1559–1578.

[36] W.P. Barber, D.C. Stuckey, Nitrogen removal in a modified anaerobic baffled reactor (ABR): 1, denitrification, Water Res. 34 (2000) 2413–2422.

[37] Ö.S. Kuşçu, D.T. Sponza, Performance of anaerobic baffled reactor (ABR) treating synthetic wastewater containing p-nitrophenol, Enzyme Microb. Technol. 36 (2005) 888–895.

[38] G. Liu, Z. Zhang, Z. Chen, L. Wei, N. Ren, Continuous-flow experiment of denitrification inhibiting sulfate reduction, China Water and Wastewater 23(5) (2007) 39.

[39] Z. Zhang, G. Liu, Y. Feng, Z. Chen, P. Zhan, Inhibiting sulfate reducing bacteria activity by denitrification in an anaerobic baffled reactor: Influencing factors and mechanism analysis, Desalin. Water Treat. 52 (2014) 4144–4153.