WIT CONFERENCES
This paper is part of the Proceedings of the 8th International Conference on Waste Management and The Environment (WM 2016)
www.witconferences.com

Short-term and long-term studies of the co-treatment of landfill leachate and municipal wastewater

Q. Yuan, H. Jia & M. Poveda,
Department of Civil Engineering, University of Manitoba, Canada

Abstract

The impact of the pre-treatment of landfill leachate on the co-treatment of landfill leachate and municipal wastewater was investigated through a short-term and a long-term study. The short-term study aimed to mimic the shock load of leachate on the wastewater treatment process. The leachate pre-treatment was achieved by coagulation and air stripping to remove partial chemical oxygen demand (COD) and ammonia. The long-term study aimed to investigate the effectiveness of leachate pre-treatment on nutrient removal of the wastewater treatment process in a long-term operational condition when air stripping was used as a means of pre-treatment. From the short-term study, it was found that at low mixing ratios (0.5% and 1%), pre-treatment did not produce any significant difference from the one without pre-treatment. When the untreated leachate mixing rate was increased (5% and 10%), the system was not able to achieve full nitrification during one cycle. However, the pre-treatment of leachate lowered the ammonia in the influent, therefore allowing for full nitrification. The long-term study demonstrated that even at a 10% mixing ratio, the high ammonia concentration in the leachate did not have a negative impact on the nitrification process. Due to the high non-readily biodegradable portion of COD in the leachate, the majority of the COD from the leachate ended up in the effluent thereby decreasing the effluent quality. It was found that at a 2.5% mixing ratio of leachate with wastewater, the overall biological nutrient removal process of the system was improved without compromising the COD removal efficiency.

Keywords: landfill leachate pre-treatment, biological nutrient removal, air stripping, landfill leachate to wastewater mixing ratio.

WIT Transactions on Ecology and The Environment, Vol 202, © 2016 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/WM160321

1 Introduction

Landfill leachate is produced by the seeping of liquids through landfilled waste. Rain water, melted snow percolating into the waste, the original water content or humidity of the waste itself, the degradation and compaction of the organic fraction, all contribute to the generation of leachate [1, 2]. Landfill leachate contains dissolved organic matter, inorganic macro components, heavy metals, and xenobiotic organic compounds such as halogenated organics. These contaminants play an important role in groundwater and soil pollution. Due to the complexity of the pollutants in the leachate, the treatment of landfill leachate is complicated, usually requiring various processes to reduce COD, nitrogen, and phosphorus all of which make the treatment of landfill leachate expensive.

The conventional landfill leachate treatment includes physico-chemical treatments and biological treatments. Physico-chemical treatments are usually used to reduce suspended solids, colloidal particles, colour, and certain toxic compounds. However the cost associated with this type of treatment is usually high. Current leachate treatment options include recycling and re-injection into the landfill cells, on-site treatment, discharge to a municipal water treatment facility, or a combination [3]. Co-treating the leachate together with municipal sewage is preferred for its easy maintenance and low operating costs. In addition, the degradation of organic pollutants is favoured because of the dilution and adaptation ability of the activated sludge [4]. However, considering that high concentrations of certain compounds (e.g. ammonia and toxic compounds) may inhibit the activated sludge treatment process, many wastewater treatment plants require the leachate to be pre-treated before it can be mixed and enters the municipal wastewater treatment process. It is believed that pre-treating the leachate is beneficial for the subsequent biological treatment at the plant.

Coagulation is widely used as a pre-treatment prior to biological treatment in order to remove non-biodegradable organic matter. Aluminium sulfate, ferrous sulfate, and ferric chloride are commonly used as coagulants [5]. Several studies have been conducted on the examination of coagulation for the treatment of landfill leachates. Those studies are aimed at performance optimization, i.e. selection of the coagulant, determination of operational conditions, evaluation of the effect of pH, and investigation of the addition of flocculants [6]. Depending on the landfill age and type of coagulant, the COD removal rate is in the range of 20 to 90%.

Air stripping is the most commonly used method for eliminating a high concentration of NH_4^+-N in the wastewater. In many applications, air stripping has been used successfully in the removal of ammonium nitrogen present in the leachate [7]. However, there are a few drawbacks to this technology. One drawback is the exhausted air which is mixed with NH_3 needs to be treated with either H_2SO_4 or HCl before it is released into the atmosphere. Other drawbacks are the calcium carbonate scaling of the stripping tower when lime is used for pH adjustment, and foaming when a large stripping tower is used [8].

As of this date, very few studies provide actual evaluations of the effect of the pre-treated leachate on additional biological treatment [9–11], a step that is considered necessary when dealing with leachate's complex characteristics. Most of the research evaluates the biodegradability of the leachate based only on a relationship between the BOD to COD ratio of the effluent as an indicator of the treatability of the leachate by biological means. There is a lack of information on if and how the leachate affects the biological nutrient removal process in wastewater treatment. This especially applies to the nitrification process, as nitrifiers are very sensitive to the environment. In addition, the benefit of pre-treating leachate to the wastewater treatment process has not been well studied. Therefore, the goal of this research is to investigate the short-term and long-term impact of leachate on the nutrient removal from municipal wastewater by comparing: 1) the leachate with and without pre-treatment; 2) different mixing ratios of leachate with wastewater.

2 Material and methods

2.1 Wastewater and leachate characterizations

The wastewater used for this research was from the SouthEnd Wastewater Treatment Plant (WWTP) in Winnipeg, Canada. It was delivered to the lab twice a week. Leachate was obtained from the Brady Road Landfill weekly. Both wastewater and leachate were stored in a cold chamber. The characteristics of wastewater and leachate are shown in Table 1.

Table 1: Characteristics of wastewater and leachate.

Parameter	Wastewater	Leachate
pH	7.5 ± 0.1	7.2 ± 0.1
COD (mg/L)	400 ± 210	1939 ± 108
TSS (mg/L)	196 ± 15	336 ± 203
BOD_5 (mg/L)	198 ± 35	248 ± 20
TN (mg/L)	45 ± 5	759 ± 56
$N\text{-}NH_4^+$ (mg/L)	36 ± 4	646 ± 84
TP (mg/L)	6.6 ± 1.5	6.7 ± 1.1

2.2 Leachate pre-treatment

2.2.1 Short-term test

The pre-treatment of leachate was achieved by chemical coagulation followed by air stripping. Chemical coagulation was carried out using ferric chloride solution. Jar test was carried out to determine the effective pH and ferric chloride dosage. The pH of leachate was first adjusted to 5.0 using an 18% w/w hydrochloric acid (HCl) solution. Then 500 mg/L of ferric chloride solution were added to the leachate. Rapid mixing was then applied for 3 minutes followed by slow mixing for 15 minutes. Finally, the leachate was allowed to settle for 30 minutes and the supernatant was drawn for the next treatment. For air stripping, the pH of leachate was first adjusted to 11 using a 25% w/w solution of sodium hydroxide (NaOH).

This was followed by 48 hours of aeration. Then the pH was neutralized to 7.5 using an 18% w/w HCl solution.

2.2.2 Long-term test

Due to the consideration of operational costs in real practice, pre-treatment leachate using chemical coagulation was eliminated in this study. Air stripping was used as only pre-treatment method for leachate. The air stripping method was same as described above.

2.3 Reactor setup

2.3.1 Short-term test

One sequencing batch (SBR) reactor was used to simulate the conditions of a biological nutrient removal (BNR) system. Waste activated sludge (WAS) was taken from the WestEnd WWTP, a BNR wastewater treatment plant, in Winnipeg to seed the reactors. The SBR reactor had a 4 L working volume with an HRT of 12 hours. The SBR was operated with 4 cycles per day and SRT of 10 days. Each cycle included feeding (5 minutes), anaerobic (1.5 hours), aerobic (4 hours), settling (20 minutes), and decant (5 minutes) periods. The SBR was fed with wastewater. The temperature was maintained at room temperature (20 ± 1°C), and the Dissolved Oxygen (DO) concentration over 4 mg O_2/L during aerobic phase. This reactor was operated and monitored for over 30 days (3 times the SRT) before starting the kinetic testing to ensure stable conditions.

For the kinetic test, the biomass from the SBR reactor was divided into three 1 L beakers, one served as control while the other two served as testing reactors. The Control reactor was fed only wastewater, while each one of the two testing reactors was fed with a specific mixture percentage of wastewater and leachate (either untreated or pre-treated with the combination of air stripping and chemical coagulation). The leachate to wastewater mixing ratios (by volume) were: 0.5%, 1%, 5% and 10%. Two sets of controls are reported in the discussion for untreated and for pre-treated tests. Since there were four mixing ratios to evaluate, one day the tests were done for 0.5%, 1% and a control. On a different day, the tests were carried out for 5%, 10% and a second control.

There were at least 7 days between each test to allow the recovery of the biomass. During the testing period, samples were taken from each of the reactors at 15 min intervals.

2.3.2 Long-term test

Three sequencing batch reactors (SBR) with working volumes of 3 L were setup. All three SBRs were seeded with the sludge from the WestEnd WWTP and were operated under the same condition as the SBR operated in the short-term test. Three SBRs were fed with wastewater and operated for over a month to reach a stable stage before the experiment. SBR1 served as a control reactor which was fed with wastewater only. SBR2 was fed with the mixture of wastewater and raw leachate. SBR3 was fed with the mixture of wastewater and pre-treated leachate. Three mixing ratios of leachate (with and without pre-treatment) with wastewater of 2.5, 5 and 10% were tested. The test with a mixing ratio of 2.5% lasted for 22 days. This was followed by the test with a mixing ratio of 5% for 38 day and then one with a mixing ratio of 10 % for 57 days.

In order to understand the performance of each reactor, kinetic tests of treatment cycles were carried out. Samples were taken from each reactor at 30 min intervals. The parameters monitored included pH, soluble COD, ammonia nitrogen ($N\text{-}NH_4^+$), NO_x (nitrite + nitrate) and ortho-phosphate ($P\text{-}PO_4^+$).

2.4 Analytical methods

COD, total nitrogen (TN), and total phosphorus (TP) were measured using HACH® digestion vials. BOD_5 and total suspended solids (TSS) measurements were carried out following laboratory procedures according to the Standard Methods [12]. $N\text{-}NH_4^+$, $P\text{-}PO_4^+$, $N\text{-}NO_3^-$, $N\text{-}NO_2^-$ was measured using an automatic flow injection analyser Quick Chem 8500, LACHAT Instruments.

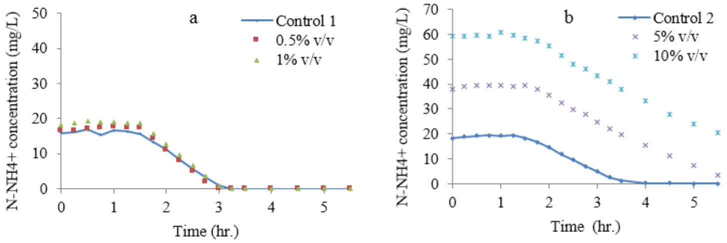
3 Results and discussion

3.1 Short-term study

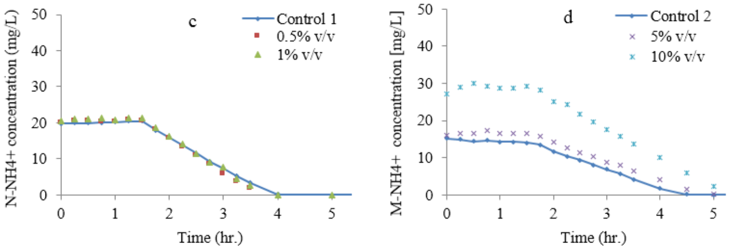
Figure 1 presents the results when untreated and pre-treated leachate was mixed with wastewater at different percentages. Control represents the reactor with only wastewater as influent. Mixing leachate (either pre-treated or untreated) with wastewater at 0.5% and 1% ratios did not produce any significant difference in the ammonia influent concentrations or the system response (Figures 1a and 1c). However, when the mixing ratio was increased to 5% and 10% with untreated leachate (Figure 1b), it can be seen that the ammonia influent concentration increased 2 to 3 times the value of the control. Additionally, the system was not able to achieve full nitrification in one cycle (ammonia concentrations in the effluent were 3.6 mg/L and 20.4 mg/L, respectively). This could be due to the higher concentration of ammonia in the influent. The nitrification rate was calculated based on the slope of the curves. Since the nitrification rates of 5% and 10% treatments were comparable to the rate of the control, the nitrification inhibition probably did not occur. A longer aeration period would be needed for the full conversion of ammonia at these higher concentrations.

As shown in Figure 1d, the pre-treatment of leachate lowered the ammonia in the influent, thus allowing full nitrification under the same operational condition. It was concluded that in the case of shock load (i.e. one time addition), pre-treatment of leachate is necessary when the mixing ratio of leachate with wastewater is higher (5% to 10%), to assure the performance of nitrification at the wastewater treatment plant.

In terms of soluble COD (sCOD) removal, systems fed with the pre-treated leachate also provide a better removal than the ones with untreated leachate. The effluent sCOD concentration after the 5.5 hour operation with the pre-treated leachate in all cases was lower than 50 mg/L, which is very close to the control values (Figures 2c and 2d). However, for the ones with untreated leachate, the sCOD in the effluent was in the range of 50 to 92 mg/L (Figures 2a and 2b).

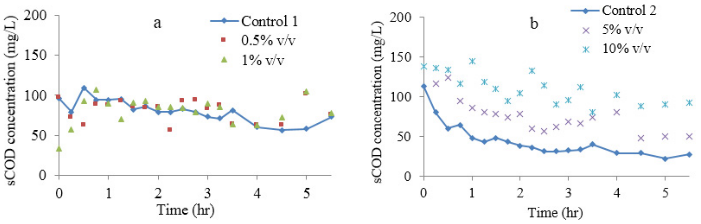


Untreated leachate

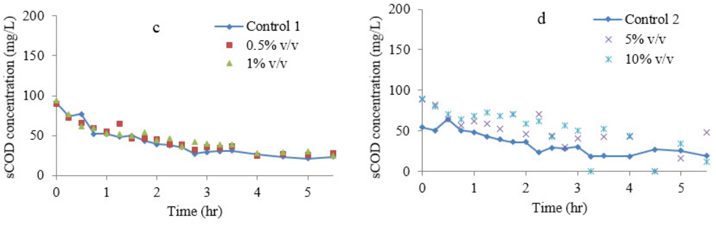


Pre-treated leachate

Figure 1: Ammonia degradation at different mixing ratio of leachate with wastewater.



Untreated leachate



Pre-treated leachate

Figure 2: Soluble COD degradation at different mixing ratio of leachate with wastewater.

The pre-treatment, by both air striping and chemical coagulation, was effectively reduced the soluble COD and ammonia concentrations of the leachate. Without the pre-treatment, mixing the leachate with the municipal wastewater increased the influent values of sCOD and ammonia to a point where removal by biological means was not achievable in the normal operation time of the BNR system.

3.2 Long-term test

3.2.1 COD removal

The COD removal rate of the control reactor SBR1 was fairly constant, within the range of 81–87% (Figure 3). Air stripping was used to pre-treat the leachate, which had no significant impact on the COD content of leachate. Therefore, SBR2 and SBR3 had fairly similar COD concentrations in the influent and both reactors also showed similar COD removal rates at each mixing ratio. In comparison to SBR1, the COD concentrations in the influent of the SBR2 and SBR3 increased approximately from 100 mg/L to 200 mg/L with mixing ratios from 2.5% to 10%. At a mixing ratio of 2.5%, both reactors achieved similar COD removal rates of SBR1 of 87%. However, when the mixing ratios were increased to 5% and 10%, the COD removal rate of both reactors decreased to around 80% and 63% respectively. This was probably due to the fact that a major part of COD in the leachate was non-readily biodegradable (rbCOD) (Table 1). Increasing leachate mixing ratios increased the non-readily biodegradable COD content in the influent which resulted in the decreased COD removal rates in SBR 2 and SBR3.

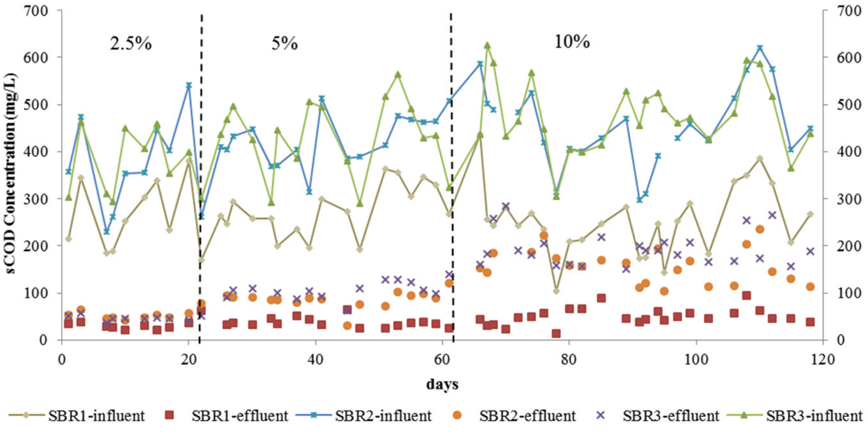


Figure 3: COD profile at different mixing ratio.

3.2.2 Nitrogen removal

Only wastewater was used as a substrate for the control reactor SBR1 throughout the experiment. Therefore, the influent ammonia concentration of SBR1 was fairly constant (Figure 4). Pre-treatment of leachate with air stripping significantly decreased (about 80%) the ammonia concentration of leachate. Therefore, the ammonia concentration in SBR3 was only slightly higher than the control reactor SBR1 (Figure 4). Whereas SBR2 which received the mixture of raw leachate and wastewater, had a much higher ammonia concentration in the influent. At a 10% mixing ratio, the average N-NH_4^+ concentrations of the SBR2 were 111 mg/L. Regardless of the different N-NH_4^+ concentrations in the influent, all three reactors showed excellent N-NH_4^+ removal performance throughout the experimental period. The kinetic study at 5% and 10% mixing ratio showed that all three reactors were able to fully remove ammonia in three hours (data not shown). The nitrification rates of three reactors are presented in Table 2. It was observed that with similar influent N-NH_4^+ concentration, the nitrification rates of SBR1 and SBR3 were very close, and they were in the range of 3.3-4.3 mg/g VSS hr, whereas the nitrification rate of SBR2 was approximately 8.3 mg/g VSS hr which was significantly higher than that of SBR1 and SBR3. The increased nitrification rate of SBR2 indicated that the system was able to adapt to the increased ammonia load.

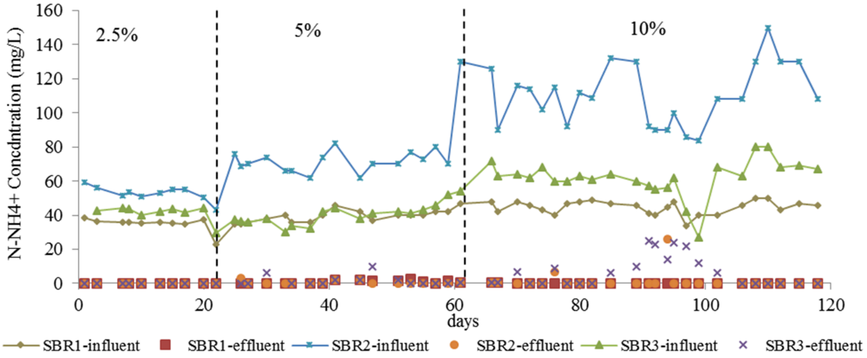


Figure 4: Ammonia (N-NH_4^+) profile at different mixing ratios.

Table 2: Reactors nitrification rate (mg/gVSS hr) at different mixing ratios.

	Mixing ratio	
	5%	10%
SBR1 (control without leachate)	3.4	3.3
SBR2	8.0	8.3
SBR3	3.5	4.3

At the completion of this part of the experiment, testing on SBR 3 was continued for another 12 days. The goal of this test was to examine the effect of no pH adjustment after pre-treatment of leachate on the nitrification of the system. This test was conducted in order to reduce the amount, and thereby the cost, of the chemical used for pH adjustment in the industrial setting. After pre-treating the leachate by air-stripping for 48 hours, the pH of the leachate was approximately 10.5. The pH of the influent, after the leachate was mixed with wastewater at a 10% ratio, was close to 9.0. The pH of the reactor was in the range of 8.5–9.5. It was observed that in 2 days, the SBR 3 started losing nitrification. On day 5, the SBR3 lost about half of its nitrification capacity, i.e. only half of the influent ammonia was converted to nitrate. No further deterioration of nitrification was observed until day 12. In terms of the COD removal, no significant difference was observed compared to the previous test. This test demonstrated that the pH adjustment of the leachate after pre-treatment was crucial for the subsequent treatments with wastewater, as nitrifiers are very sensitive to pH.

Certain degrees of denitrification were observed in all three of the reactors and only nitrate was detected (i.e. nitrite was not detected) in the effluent of all the three reactors. Although the influent ammonia concentration of both SBR1 and SBR3 were comparable, it was observed that SBR 3 had better denitrification performance than SBR1 as shown in Table 3. This could be due to the fact that the additional COD from the leachate in SBR3 facilitated the denitrification, even though the majority of the COD in the leachate was non-biodegradable. This was also reflected in the denitrification performance of SBR2. SBR2 was mixed with untreated leachate which increased the influent ammonia concentration, whereas SBR1 and SBR3 were not. Therefore, the overall nitrogen removal rate of SBR2 was lower than SBR1 and SBR3. However, SBR2 had the best denitrification performance among the three reactors. It had the highest nitrogen removal with an average 54.6 mg/L at mixing ratio of 10%. It was concluded that the observation of better denitrification performance in SBR2 and SBR3 than SBR1 was due to the additional COD in the leachate which promoted the denitrification.

Table 3: Average nitrogen removal during the experiment.

Mixing ratio	SBR1 (mg/L)	SBR2 (mg/L)	SBR3 (mg/L)
2.5%	20.6 (±0.9)	32.1 (±5.3)	24.0 (±4.4)
5%	24.1 (±3.8)	41.1 (±6.3)	26.2 (±4.2)
10%	23.9 (±4.6)	54.6 (±16.3)	35.5 (±8.4)

3.2.3 Phosphorus removal

The phosphorus concentration in the leachate was very low with an average of 6.7 mg/L, which was in the same level as that of wastewater. Therefore, the phosphorus concentrations in the influent to all three reactors were in the same range.

Control reactor SBR1 showed poor phosphorus removal throughout the experiment with an average removal rate of 35%. This suggested that the wastewater did not have sufficient rbCOD for the biological phosphorus removal. On the other hand, at mixing ratio of 2.5%, both reactor sSBR2 and SBR3 showed excellent phosphorus removal (close to 100% removal rate). The kinetic study showed (Figure 6a) that the anaerobic phosphorus release of SBR2 and

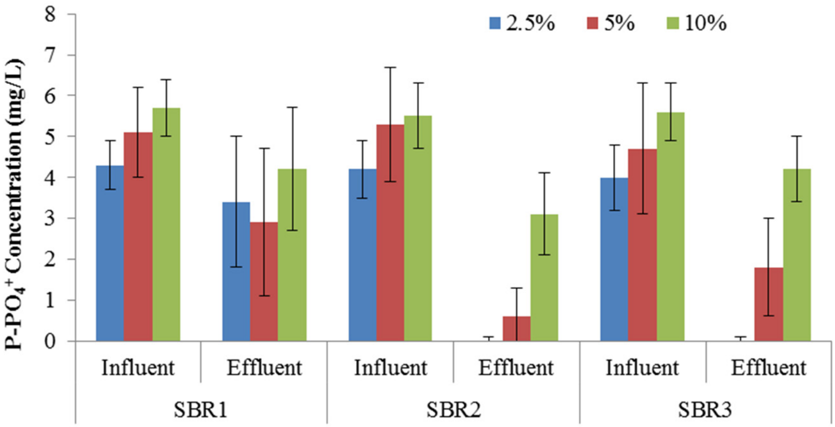


Figure 5: Phosphorus (P-PO$_4^+$) profile at different mixing ratios.

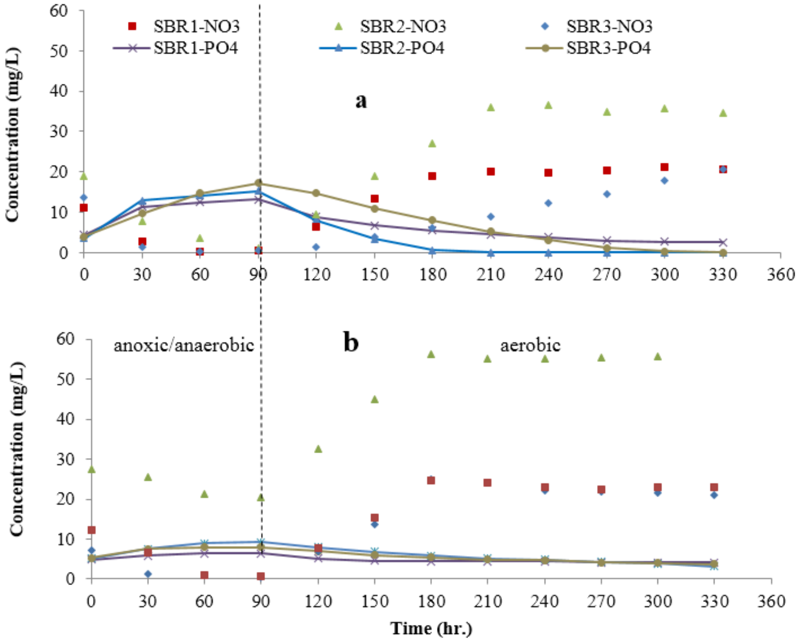


Figure 6: N-NO$_3^-$ and P-PO$_4^+$ cyclic profile of the reactor at 2.5% (a) and 10% (b) mixing ratio.

SBR3 were up to 17.2 and 15.2 mg/L respectively. This indicated the existence of phosphorus accumulating organisms (PAOs) in the systems. The small portion of the biodegradable COD from the leachate might have helped the phosphorus removal process in SBR2 and SBR3. The leachate used for this stage (2.5% mixing ratio) was collected from the cells that were used for biosolids disposal. Therefore, the rbCOD in the leachate was fairly high compared to the leachate used during the rest period which was taken from different wells (cells). The further kinetic study at 10% (Figure 6b) showed that very little anaerobic/anoxic phosphorus release occurred in all the reactors. This indicated that the population of PAOs was significantly decreased. This was likely due to the low availability of the rbCOD in both wastewater and leachate. In addition there was a competition of the rbCOD between the denitrification microorganisms with PAOs since both groups of microorganisms existed in the reactors. The full removal of nitrate during the initial 1.5 hr anoxic /anaerobic period in both SBR1 and SBR3, as well as the particle denitrification in SBR3, indicated that denitrifiers out-competed the phosphorus removal microorganisms (Figure 6).

4 Conclusion

The shock load (short-term) study showed that at low mixing ratios (0.5 % and 1% of leachate to wastewater), regardless of pre-treatment, there was no impact of leachate on the overall wastewater treatment process performance due to the high dilution of the wastewater. When the mixing ratio increased to 5% and 10%, the system supplied with the untreated leachate was not able to achieve full nitrification during one treatment cycle. On the other hand, full nitrification was achieved in the system fed with pre-treated leachate as the pre-treatment lowered the ammonia concentration in the influent. The long-term study demonstrated that the system was able to gradually adapt to the increased ammonia concentration in the influent. Therefore, even at a 10% mixing ratio, the high ammonia concentration in the leachate did not have a negative impact on the nitrification process. Full nitrification was achieved in both reactors that co-treated wastewater mixed with leachate with/without pre-treatment. In terms of COD removal, the increased mixing ratio of leachate to wastewater resulted in decreased effluent quality. This was due to the high fraction of the non-readily biodegradable COD in the leachate. It was found that at a 2.5% mixing ratio of leachate with wastewater, the overall biological nutrient removal process of the system was improved without compromising the COD removal efficiency.

References

[1] Kjeldsen P, Barlaz MA, Rooker AP, Baun A, Ledin A, Christensen TH. Present and Long-Term Composition of MSW Landfill Leachate: A Review. Critical Reviews in Environmental Science and Technology. pp. 297–336, 2002.

[2] Kurniawan TA, Lo WH, Chan GYS. Physico-chemical treatments for removal of recalcitrant contaminants from landfill leachate. Journal of Hazardous Materials. pp. 80–100, 2006.

[3] Neczaj E, Kacprzak M, Kamizela T, Lach J, Okoniewska E. Sequencing batch reactor system for the co-treatment of landfill leachate and dairy wastewater. Desalination. **222(1-3)**, pp. 404–409, 2008.

[4] Welander, U, Henrysson, T, Welander, T. Biological nitrogen removal from municipal landfill leachate in a pilot scale suspended carrier biofilm process. Water Res. **32(5)**, pp. 1564–1570, 1998.

[5] Amokrane A, Comel C, Veron J. Landfill leachates pretreatment by coagulation-flocculation. Water Res. **(31)**, pp. 2775–2782, 1997.

[6] Tatsi AA, Zouboulis AI, Matis KA, Samaras P. Coagulation-flocculation pretreatment of sanitary landfill leachates. Chemosphere. pp. 53:737–44, 2003.

[7] Marttinen SK, Kettunen RH, Sormunen KM, Soimasuo RM, Rintala JA. Screening of physical-chemical methods for removal of organic material, nitrogen and toxicity from low strength landfill leachates. Chemosphere. **(46)**, pp. 851–858, 2002.

[8] Li XZ, Zhao QL, Hao XD. Ammonium removal from landfill leachate by chemical precipitation. Waste Management. pp. 409–415, 1999.

[9] Wang X, Chen S, Gu S, Wang K. Pilot study on the advanced treatment of landfill leachate using a combined coagulation, fenton oxidation and biological aerated filter process. Waste Manage. **29(4)**, pp. 1354–1358, 2009.

[10] Guo J.-S, Abbas A, Chen Y-P, Liu Z-P, Fang F, Chen P. Treatment of landfill leachate using a combined stripping, Fenton, SBR, and coagulation process. J. Hazard. Mater. (178), pp. 699–705, 2010.

[11] Silva T, Fonseca A, Saraiva I, Vilar V, Boaventura R. Biodegradability enhancement of a leachate after biological lagooning using a solar driven photo-Fenton reaction, and further combination with an activated sludge biological process, at pre-industrial scale. Water Research. **47(10)**, pp. 3543–3557, 2013.

[12] APHA, 2005. Standard Methods for Examination of Water and Wastewater, 21st ed. American Public Health Association, Washington, DC, USA.