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Landfill leachate treatment with sequencing batch reactor and membrane bioreactor

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Abstract

Landfill leachate from a composting field of a Finnish municipal waste landfill was treated with sequencing batch reactor (SBR) and a submerged membrane bioreactor (MBR) fed batchwise. The average quality of the leachate was 475 mg/l suspended solids, 1240 mg/l BOD_7, 10 mg/l phosphorus, and 210 mg/l ammonium nitrogen. Hydraulic retention times in SBR varied from four to nine days and in MBR from two to five days. Solids retention times in SBR were from 10 to 40 days and in MBR from 35 to over 60 days. The sludge concentration in SBR varied from 6.6 to 10 g/l and in MBR from 7.3 to 9.3 g/l in normal conditions. In SBR, suspended solids concentration in effluent was up to 89% smaller than influent suspended solids concentration. However, sometimes bulking reduced the efficiency. The preliminary results with MBR start-up showed that it is free from bulking problems and compared to feed concentration the retention was over 99% of suspended solids. It also increased the retentions of both BOD_7 and ammonium nitrogen to >97% and reduced variations. Phosphorus retention was >88%.

Keywords: Landfill leachate; Membrane bioreactor; Sequencing batch reactor; Nitrification

1. Introduction

In modern waste treatment, the qualities of wastewaters, spill waters, and leachates, produced in different parts of waste treatment process vary considerably with waste qualities. The possible treatment methods to be considered are: treatment with municipal wastewater and separate treatment of all or some of the wastewater fractions [1]. So far, most Finnish landfills do not treat their wastewaters separately but conduct them into a municipal wastewater treatment plant. If the treatment plant is small, e.g. the high nitrogen content of

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the landfill wastewaters may cause some operational problems. Moreover, the national biowaste strategy asks for decreasing the amount of organic waste to landfills so that the amount of biodegradable material to landfills will be in 2006 75% or less of the amount in 1994, in 2009 50% or less and in 2016 35% or less [2]. Thus increasing amounts of organic waste are treated separately in digesters or in composting plants. According to Kettunen et al. [3] the wastewaters originating from the organic waste treatment has highest organic matter and nitrogen concentrations. The intensified treatment in composting plants with internal water recycling lead to wastewaters much stronger than those originating from open composting fields and thus the separate treatment of these wastewaters for organic matter and nitrogen removal is reasonable.

In this study sequencing batch reactor (SBR) and a dual-tank membrane bioreactor (MBR) processes were studied for the treatment of landfill leachate from a composting field. The SBR technology is an activated sludge process designed to operate under non-steady state flow conditions and there is a degree of flexibility associated with working in a time rather than in a space sequence [4]. According to literature [5], membrane bioreactor offers a treatment method for achievement of high quality treated water with reduced sludge production. The SBR system seems suitable for treating the leachate from biological waste treatment in which the volumes and concentrations of the produced water can vary considerably with time. Previously, the SBR has been successfully applied for the treatment of concentrated wastewaters from milk farms [6]. Moreover, the process can be modified so that both nitrification and denitrification can be achieved in the same unit. However, in SBR process the sludge must settle and in case of disturbances sludge bulking can reduce the quality of produced water. With membrane, bulking is no problem and the quality of produced water is much more stable. The treatment of landfill leachates with MBR has been mentioned to be especially promising field for MBRs in Europe with existing reference plants in Germany, France, and Holland [7]. Witgens et al. [8,9] have studied the use of membrane bioreactors for the removal of endocrine disrupters from landfill leachate. Ahn et al. [10] have presented a case study of an advanced landfill leachate treatment process using membrane bioreactor and reverse osmosis for aged landfill, in which leachate the carbon to nitrogen ratio was unbalanced for proper biological operation. Setiadi and Fairus [11] used an activated sludge-membrane system, in which the membrane unit placed outside the activated sludge tank, for the treatment of hazardous waste landfill leachate.

2. Experimental

The municipal waste landfill leachate (Table 1) from an open ditch next to composting field was treated in a sequencing batch reactor (SBR) and in a dual-tank membrane bioreactor (MBR) fed batchwise. A simplified flow sheet of the equipment used is presented in Fig. 1. The SBR was operated in nitrification/denitrification tank, the total operational volume of which was approximately 165 l. When operated as SBR the following steps were done in a 24-h cycle: feeding, reaction,

Table 1
Average quality of composting field leachate used as feed

Parameter	Leachate
pH	7.2 ± 0.2
Conductivity, mS/m	450 ± 130
Suspended solids, mg/l	480 ± 260
BOD_7, mg/l	1300 ± 300
COD_{Cr}, mg/l	2200 ± 230
Total P, mg/l	10.8 ± 2.6
Soluble P, mg/l	3.5 ± 2.1
Total N, mg/l	240 ± 80
NH_3+NH_4 –N, mg/l	210 ± 90
NO_3+NO_2 –N, mg/l	0.130 ± 0.115
Alkalinity, mmol/l	34.4 ± 13.0
Turbidity, FNU	530 ± 140

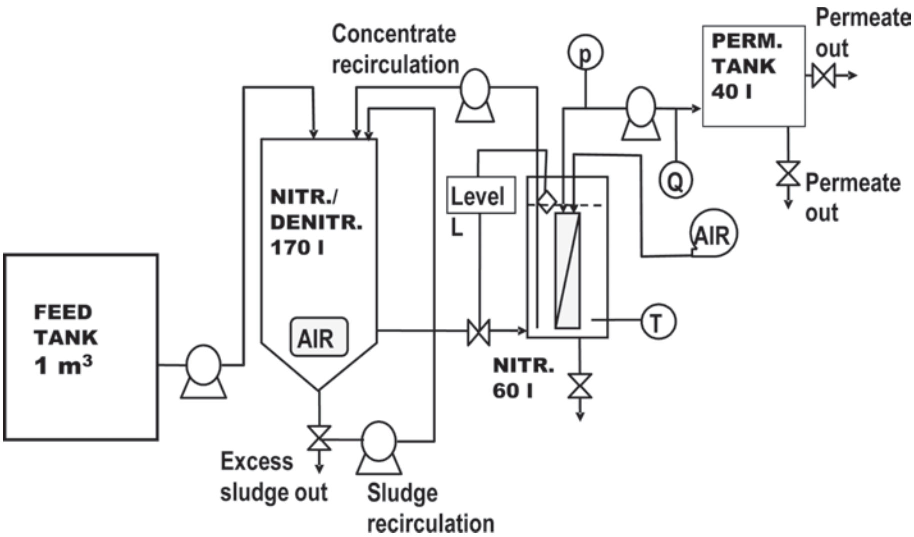

Fig. 1. A simplified flow sheet of used SBR and MBR equipment. For SBR operation only nitrification/denitrification tank was used and for MBR operation the whole equipment was in use. Abbreviations: Nitr. = nitrification, Denitr. = denitrification, p = pressure, T = temperature, and Q = flow.

settling and decanting. For the period of 24 h, 21.5 h the unit was aerated, 2 h was settling, and 30 min was needed for decanting and feeding. At the beginning of August an air control valve was installed to nitrification/denitrification tank enabling better control of the aeration and at the end of August, after 61 days of operation, the aerated time was decreased to 17.5 h, and time for settling was increased to 3 h.

When MBR was operated the nitrification/ denitrification tank had a volume of 120 l and MBR tank 60 l. The cycles for aeration in the SBR unit were the same as in SBR operation. The MBR unit was ZeeWeed® 10 (ZW10) unit from Zenon. ZeeWeed ZW10 is fully automized membrane bioreactor unit in which the membranes are submerged to an aerated tank. Membrane fouling is prevented by air scouring (air flow 2 Nm^3/h) and with periodical backwashing of the membranes. In these experiments, the backwashing was done for 10 s every 60 s. Membrane area in the unit was 0.93 m^2. A new ZeeWeed® 500 membrane (nominal pore size of 0.04 µm) was used in the experiments. The membrane was cleaned prior to use with 200 ppm sodium hypochlorite solution and rinsed thoroughly with water.

The leachate was analyzed for pH, conductivity, suspended solids, volatile suspended solids, biological oxygen demand (BOD_7), chemical oxygen demand (COD_{Cr}), total organic carbon (TOC), total and soluble phosphorus, total nitrogen, total ammonia (NH_3+NH_4 –N), and nitrate-nitrite nitrogen (NO_3+NO_2 –N), alkalinity, and turbidity. List of analyses is presented in Table 2. From the supernatant or permeate almost the same set of analyses were made. The mixed liquor was analyzed for pH, suspended solids and volatile suspended solids.

From analyses it must be mentioned that BOD_7 was analyzed without allyl thiourea and in case of effluents, the values include some oxygen consumption from nitrification. It was also observed that the total nitrogen analysis of the supernatant and permeate gave values smaller than expected from the total ammonia and total nitrite/ nitrate nitrogen concentrations. The oxidizer used

Table 2
Analysis methods

Analysis	Method	Standard
pH	MeterLab PHM 220 Lab pH meter	SFS 3021
Conductivity	MeterLab CDM 210 conductometer	SFS-EN 27888
Suspended solids (TSS)	Filtration with Whatman GF/A, drying at 105ºC	SFS-EN 872[1)]
Fixed suspended solids (FSS)	Incineration at 550ºC	SFS-EN 872[1]
Volatile suspended solids (VSS)	Calculated from the difference between TSS and FSS	SFS-EN 872[1]
Biological oxygen demand (BOD_7)	Dilution method	SFS-EN 1899-1
Chemical oxygen demand (COD_{Cr})	Closed tube method. Oxidation with dichromate. Hach COD reactor	SFS 5504
Total organic carbon (TOC)		SFS-EN 1484
Total phosphorus	Decomposition with peroxide sulfate	SFS 3026
Dissolved phosphorus	Filtration with Whatman GF/A, digestion with peroxide sulphite	SFS 3026
Total nitrogen	Modified Kjeldahl method	SFS 5505
Total ammonia nitrogen (NH_3+NH_4 –N)		SFS 5505
Total nitrite/nitrate nitrogen (NO_3+NO_2 –N)	Flow injection analysis	SFS 3030
Alkalinity	Potentiometric titration	SFS 3005
Turbidity	Hach ratio turbidimeter	SFS-EN 27027

[1)]Not accredited method.

for total nitrogen analysis was found to be ineffective for the kind of effluent produced in this study.

The experiments were started in SBR, with 77% of activated sludge from municipal wastewater treatment plant and with 23% of leachate. For a start-up period of one month the process was operated as a sole SBR process and after that the MBR tank was connected to SBR tank and process was started to operate as dual-tank MBR.

3. Results and discussion

In general, the SBR process was operated with hydraulic retention times (HRT) from 4 to 8 days and MBR with HRT around 3 days (Fig. 2). During process changes from SBR to MBR and vice versa, both longer and shorted HRTs were experienced.

The quality of effluent from SBR and that from MBR are given in Table 3. The high concentrations of suspended solids, turbidity, and BOD_7 as well as high deviations in values show that the

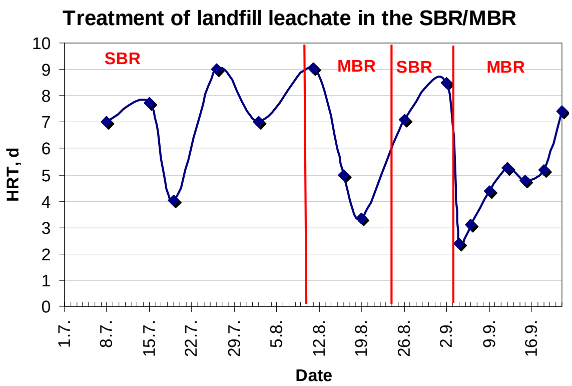

Fig. 2. Hydraulic retention times (HRT) observed during operation of SBR and MBR.

SBR process was having every now and then bulking problems and sludge was escaping.

The MBR unit was operated with stable flux of 2.1 ± 0.4 l/(m²h) since the bioprocess was decisive parameter for the organic loading. In MBR effluent, the concentrations were much lower than in SBR. In some cases, the effluent values were

Table 3
Effluent quality from SBR and MBR

Parameter	SBR effluent	MBR effluent
pH	8.2 ± 0.3	8.4 ± 0.2
Conductivity, mS/m	320 ± 90	350 ± 40
Suspended solids, mg/l	290 ± 210	1.2 ± 0.9
BOD_7, mg/l	190 ± 140	8.3 ± 9.6
COD_{Cr}, mg/l	500 ± 110	340 ± 30
Total P, mg/l	6.9 ± 4.2	0.77 ± 0.37
Soluble P, mg/l	0.89 ± 0.35	0.75 ± 0.37
NH_3+NH_4 –N, mg/l	1.84 ± 0.39	2.4 ± 2.2
NO_3+NO_2 –N, mg/l	150 ± 60	140 ± 40
Alkalinity, mmol/l	8.5 ± 3.5	12.0 ± 4.3
Turbidity, FNU	250 ± 210	0.9 ± 0.31

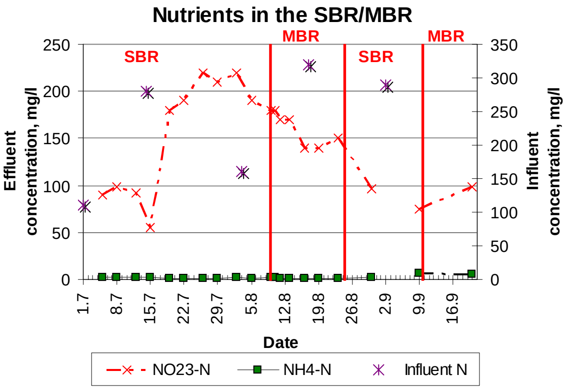

Fig. 3. Nitrogen concentrations in influent and effluent of SBR and MBR during the operation period. Influent N is total nitrogen in influent, NO23–N is nitrite/nitrate nitrogen in effluent and NH4–N is total ammonia nitrogen in effluent.

close to detection limit of the analyzing method and thus high deviations were observed, e.g. BOD_7.

Total nitrogen concentrations in influent as well as total ammonia concentrations and nitrite/nitrate nitrogen concentrations in the effluent are presented in Fig. 3. Since the total ammonium nitrogen concentrations in feed were almost same as total nitrogen concentrations (difference 10–30 mg/l), it can be seen that nitrification worked well in both units and ammonia nitrogen reductions over 97% were achieved. After mid August it seems that some denitrification also occurred and nitrogen reductions compared to total nitrogen concentrations in influent were from 52 to 71%. The changes in influent concentrations can be seen in effluent usually after approximately two weeks. Thus the doubling of influent concentration in the middle of August gives first the false idea of denitrification, but since the nitrate concentrations continue to decrease it is obvious that some denitrification occurred. The reasons for this are probably the better control of aeration in the nitrification/denitrification tank after installation of an air control valve, increase of non-aerated time at the end of August as well as less effective mixing of nitrification/denitrification tank from the beginning of September due to some problems in the recirculation pump. The less effective mixing in the nitrification/denitrification tank means that the oxygen conditions in the tank get poorer towards the bottom and it is possible to have some anoxic zone at the very bottom of the tank under the aerator.

In SBR, suspended solids reduction up to 89%, BOD_7 up to 94%, ammonia nitrogen up to 99.5%, and phosphorus up to 82% compared to feed concentrations were achieved. However, the variations were high and when sludge was escaping the effluent had sometimes higher concentrations of solids and total phosphorus than those in the original leachate. The MBR improved the effluent quality and reduced the variations (Fig. 4). In MBR, the reduction of suspended solids was over 99%, that of both BOD_7 and ammonium nitrogen over 97%, and that of phosphorus over 88%. The total phosphorus in the MBR permeate was actually the same as the amount of soluble phosphorus. Total nitrogen removal was at its best around 50–60%.

4. Conclusions

As a conclusion, both the SBR and MBR remove total ammonia nitrogen effectively. However, the sludge was escaping from the SBR unit

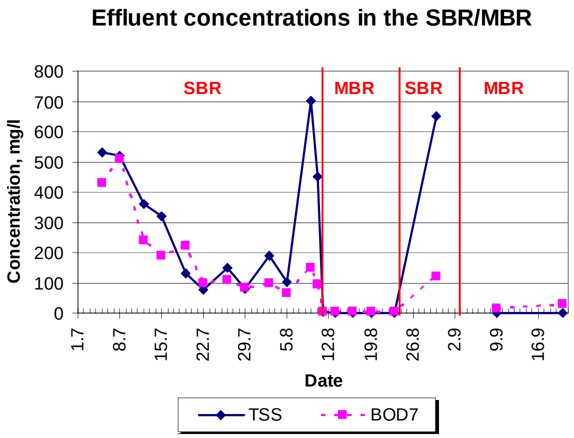

Fig. 4. Concentrations of total suspended solids (TSS) and biological oxygen demand (BOD_7) in effluent during SBR and MBR treatment of composting field leachate.

whenever the process was disturbed and thus quite high suspended solids, BOD_7, and phosphorus concentrations were observed. MBR effluent was significantly better in quality and had lower variations. However, the results from MBR treatment are preliminary and fully developed membrane bioreactor activated sludge with stable operation is yet to be reached. The optimization of operational variables needs to be done, including the requirements for denitrification.

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References

[1] S. Marttinen, J. Jokela, J. Rintala and R. Kettunen, KAATO 2001-HANKE: Jätteiden hajoaminen kaatopaikalla sekä kaatopaikkavesien muodostuminen, ominaisuudet ja käsittely, Kirjallisuuskatsaus 20.6.2000, http://www.jatelaitosyhdistys.fi/katsaus2.pdf, 21.1.2004.

[2] Finnish Ministry of Environment, 2.12.2004, National strategy for decreasing the amount of biodegradable waste to landfills (in Finnish).

[3] R. Kettunen, J. Rintala, S. Marttinen, J. Jokela and K. Sormunen, Kaatopaikkavesien vaikutus yhdyskuntajätevedenpuhdistamon toimintaan ja mitoitukseen sekä kaatopaikkavesien esikäsittelytarpeen ja menetelmien arviointi, KAATO 2001–hanke, Loppuraportti 20.6.2000, http://www.jatelaitosyhdistys.fi/julkaisut.htm, 16.2.2004.

[4] Anon, ILE (Industrial liquid effluents), Cluster Paper, Report: Pulp and Paper Industry: Characterization of the Wastewater Treatment Processes, 2004.

[5] T. Stephenson, S. Judd, B. Jefferson and K. Brindle, Membrane Bioreactors for Wastewater Treatment. IWA Publishing, London, 2000.

[6] T. Valkeapää, J. Vilen and A. Luonsi, Sequencing batch reactor for a dairy farm's wastewater — low-load application suitable to meet future requirements, Proc. 6th Specialist Conference on Small Water & Wastewater Systems, Fremantle, Australia, February 11–13, 2004.

[7] Anon, Market report: MBR technology, Filtration Industry Analyst, July 2003, p. 14.

[8] T. Wintgens, M. Gallenkemper and T. Melin, Endocrine disrupter removal from wastewater using membrane bioreactor and nanofiltration technology, Desalination, 146 (2002) 387–391.

[9] T. Wintgens, M. Gallenkemper and T. Melin, Occurrence and removal of endocrine disrupters in landfill leachate treatment plants, Wat. Sci. Tech., 48 (2003) 127–134.

[10] W.-Y. Ahn, M.-S. Kang, S.-K. Yim and K.-H. Choi, Advanced landfill leachate treatment using an integrated membrane process, Desalination, 149 (2002) 109–114.

[11] T. Setiadi and S. Fairus, Hazardous waste landfill leachate treatment using an activated sludge-membrane system, Wat. Sci. Tech., 48 (2003) 111–117.