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The use of a submerged membrane batch reactor (S.M.B.R) for co-treatment of landfill leachates and domestic wastewater

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ABSTRACT

The aims of this work were the examination of the treatment potential of landfill leachates-domestic wastewater mixtures by a pilot scale membrane bioreactor system using a submerged plate and frame microfiltration (MF) membrane module and the investigation of the optimum operation conditions for the achievement of maximum COD and total nitrogen removal rates. The bioreactor was inoculated by 60 l of activated sludge and operated at an MLSS content reaching up to 25,000 mg/l; increased COD removal efficiencies were observed reaching up to 98%. High ammonium nitrogen removal efficiencies were achieved reaching up to 99% at extended operation times associated to long SRTs, resulting in effluent concentrations of about 1 mg/l; however, total nitrogen content of effluents was high, about 160 ± 50 mg/l, due to reduced denitrification capacity of the system.

Keywords: Wastewater; Co-treatment; Landfill leachate; Submerged membrane batch reactor; Plate membrane bioreactor; COD removal; Nitrogen removal

1. Introduction

Sanitary landfilling is often used as a primary method for solid waste disposal, especially in developing countries. The principal environmental impact of landfills is attributed to the production of liquid wastewaters, that is, the leachates. Leachate production rate is quite high, even after the landfill closure [1]. The chemical composition of leachate depends upon the age and maturity of the landfill site. "Fresh" leachates from young landfills (acid-phase landfills), are characterized by high concentration of organic compounds (BOD_5 and COD), whereas "mature" leachates from old landfills (methanogenic-phase landfills) contain much lower levels of organic matter [2]. The appropriate site management may substantially reduce the amount and strength of the produced leachate. The major environmental problem usually associated with landfill leachate production is the contamination of underground and surface waters. Therefore, leachates have to be collected and efficiently treated before discharged to a water receiver.

The appropriate leachate treatment strategy is not easily defined, due to the high variability in the leachates composition and characteristics that depend upon a large number of parameters. Several researchers have studied the most effective processes for leachate treatment depending on its characteristics. Consistent to leachate characteristics, biological treatment has shown to be very effective for young leachates, while for old or partially stabilized leachates, physicochemical processes are more appropriate [3,4].

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The biologic technologies that had been investigated and used for leachate treatment are: UASB, stabilization ponds, activated sludge, trickling filters, biodiscs and SBR [5–7]; on the other hand, the physicochemical technologies include coagulation–flocculation–sedimentation, membrane processes (reverse osmosis, micro and ultrafiltration), ammonia stripping and advanced oxidation processes [8–12]. Besides these methods, the techniques for the leachate treatment include also methods as recirculation through the wastes and dispersion over the land [13].

In general, treatment of landfill leachates may be achieved by biological and physicochemical processes. The latter are generally far more costly, with lower effectiveness and reliability than the biological ones. Nevertheless, biological treatment based on the suspended-growth biomass process, has been proved to exhibit satisfactory and consistent performance for organic carbon and nutrients removal [14,15]. Furthermore, several efforts have been taken for the study of the co-treatment of landfill leachates with domestic wastewater, so that existing sewage treatment plants can be utilized for leachate treatment [16].

A variation of the conventional activated sludge process commonly used for leachate treatment is the sequential batch reactor (SBR). The main feature of the SBR technology is that both biological oxidation and sludge separation are carried out in the same tank. Furthermore, its operation cycle can be easily modified to offset possible changes in process conditions, influent characteristics or effluent objectives. However, the SBR may have some negative aspects, such as inadequate sludge settling, resulting in poor clarification and a turbid effluent [17,18].

The use of a membrane-coupled sequencing batch reactor (SMBR) might be an alternative treatment option, to overcome potential drawbacks of SBR. Membrane bioreactors are paid more attention in landfill leachate treatment owing to their several advantages which include small footprint (elimination of clarifier), high biomass content and low-rate biomass production, ability to handle a wide range of solids residence times (SRTs) and relatively short hydraulic retention times (HRTs), excellent microbial separation abilities and removal of solids and organic matter [19,20]. Sludge separation through membrane filtration leads to complete biomass retention and the maintenance of high suspended solids concentrations in the mixed liquor. Typical MLSS concentrations in SMBR are in the range of 15,000–25,000 mg/l, although some authors suggest that MLSS should not exceed the value of 12,000 mg/l [21,22]. Another key feature of these systems is the complete decoupling of sludge age (SRT) and hydraulic residence time (HRT), resulting to additional intensification of the biological process. This intensification is directly related to the reduction of reactor volume and to high effluent quality [23,24].

The aim of the present work was the investigation of the performance of a pilot – scale flat – sheet membrane bioreactor for the treatment of a 1:1 mixture of "mature" landfill leachate and high – strength domestic wastewater and the determination of optimum operation conditions for the removal of organic and nutrients loading.

2. Materials and methods

2.1 Experimental setup

A pilot-scale submerged membrane batch reactor (SMBR) was designed and constructed, by using a microfiltration (MF) plate and frame membrane module (A3 Maxflow "330"), in order to investigate the co-treatment of landfill leachate and domestic wastewater. The reactor unit, is shown in Fig. 1, and consisted in three sections: (a) the influent section; (b) the reaction section (Membrane Bioreactor); and (c) the effluent section. The influent section included an 180 l cylindrical plastic vessel and a peristaltic pump of variable flow (Watson – Marlow 302S) for the introduction of the influent to the reactor. The bioreactor was constructed by a 300 l cylindrical plastic vessel; a microfiltration (MF) plate and frame membrane module (A3 Maxflow "330") was immersed into the reactor. A variable peristaltic pump (SEKO PR1) was used for the addition of methanol solution in the reactor during the denitrification period. The treated leachate/permeate was removed by a peristaltic pump (Watson – Marlow 503U) connected to the effluent outlet of the membrane module. The transmembrane pressure (TMP) values were monitored by an analogue manometer (Kindmen) located on the permeate line. A drum air diffuser was placed under the membrane unit. The air flowrate was adjusted for scouring the accumulated

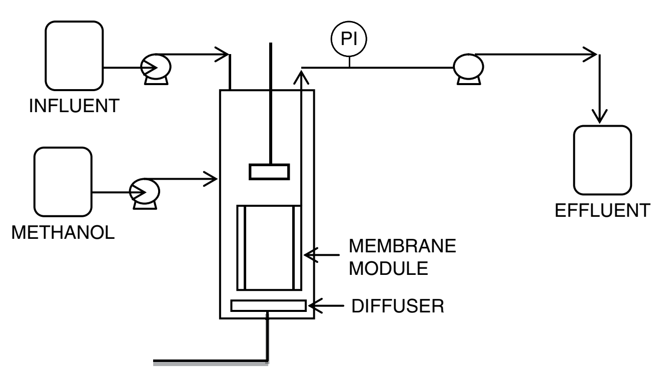

Fig. 1. Conceptual diagram of the experimental Submerged Membrane Batch Reactor unit.

biomass away from the membrane surface, providing the biomass with the required oxygen concentration and for complementary mixing of the mixed liquor. Mixing of the SMBR content during the aerobic and anoxic periods carried out by a flat-blade impeller. The effluent was collected in a 180 l cylindrical plastic vessel.

During the initial first three months of the operation, influent was added to the system with COD concentration ranging from 1,000 to 4,600 mg/l, aiming to increase the MLSS content into the SMBR system. Synthetic wastewater was used in concentrations corresponding to the desired COD content. The following substances were used for the preparation of the synthetic wastewater stock sample, with a COD of 1,000 mg/l: peptone water, 0.60 g/l, meat extract, 0.42 g/l, urea, 0.020 g/l, $CaCl_2 \cdot 2H_2O$, 0.008 g/l, $MgSO_4 \cdot 7H_2O$, 0.004 g/l, K_2HPO_4, 0.022 g/l, NaCl, 0.014 g/l. During the first operation period, 40 ml of pure methanol were added during the anoxic stage, in order to enhance the denitrification process, while lower amounts of methanol, 25 ml, were added during the second period. The main physicochemical characteristics of the landfill leachate used in this study are shown in Table 1. The high pH values and the low COD concentrations measured in the sample were representative of a "mature" landfill leachate.

2.2. Operation conditions

Leachate samples were collected from the municipal landfill site of Thessaloniki in North Greece where leachate is collected in an artificial lagoon, located at the lowest point of the site. For the evaluation of the SMBR performance, samples were taken from the mixed liquor, the raw leachate and the treated effluent/permeate. Mixed liquor samples were analyzed for suspended solids (MLSS, MLVSS and MLNVSS), dissolved oxygen (DO) and pH according to standard methods of analysis [25]. Influent and effluent samples were measured for the determination of COD, TN, NH_4–N, NO_3–N and PO_4–P content, alkalinity and pH, according to standard methods of analysis, under the provisions described in details in previous work [26].

3. Results and discussion

3.1. System start-up and operational patterns

The bioreactor was initially inoculated by 60 l of activated sludge received from the recirculation of a full scale municipal wastewater treatment plant, mixed with 85 l of synthetic wastewater with COD = 1,000 mg/l. The performance of the activated sludge reactor was examined during two operation periods, for the treatment of 50 and 20 l/day influent respectively, containing 1:1 v/v landfill leachate and municipal wastewater. The 24 h operation modes during the two periods are given in Table 2. The hydraulic retention time was nine days while no sludge wastage took place during the overall experimentation period, resulting in high SRTs; the organic loading rate (OLR) values during the two periods was estimated to range between 0.03 and 0.25 g COD/g MLSS/day.

3.2. Suspended solids

The concentration of mixed liquor suspended solids (MLSS), non-volatile suspended solids (MLNVSS) and volatile suspended solids (MLVSS) are presented in Fig. 2 during the subsequent operation periods of the reactor, including the initial acclimatization period. During the first period, the MLSS content varied between 2,000 and 6,000 mg/l while the fraction of volatile solids was between 80% and 84%. During the second operation period, the MLSS concentration varied between 5,900 and 25,000 mg/l, due to the addition of a higher COD synthetic wastewater. The MLVSS/MLSS was fluctuated a little around a mean value of 70%. It indicated that low discernible inert and inorganic compounds were accumulated in the bioreactor during the whole experiment. It might be because the inorganic substance in the influent was low, and can be degraded by some bacteria which propagate slowly [27]. Nevertheless, transmembrane pressure slightly increased by the time and was attributed to the increase of MLSS content. Although the general trend found in the literature is membrane fouling to increase with increasing MLSS concentration,

Table 1
Physicochemical characteristics of Thessaloniki landfill leachate

	pH	Alkalinity, $CaCO_3$ (mg/l)	COD (mg/l)	NH_4^+–N (mg/l)	NO_3–N (mg/l)	TN (mg/l)	PO_4–P (mg/l)
Maximum	9.50	2600	3898	347	25.4	530	11.2
Minimum	8.26	1530	1459	194	8.3	346	1.8
Average	8.7	2023	2544	269	15.3	388	6.8
St. Dev.	0.52	360	802	57	5.9	72	2.7

Table 2
The operation periods of the SMBR system for the treatment of leachate:sewage mixture

Stage	Mixing	Aeration	Time, h	% of cycle time
First operation mode				
Fill	Yes	No	1.30	5.40
React-aerobic	Yes	Yes	18.95	78.90
React-anoxic	Yes	No	2.00	8.40
Draw	Yes	Yes	1.75	7.30
Total cycle time			24	100
Second operation mode				
Fill	Yes	No	0.1 + 0.1 (During the anoxic stages)	0.08
React-aerobic	Yes	Yes	18.00 (10.00 + 6.00 + 2.00)	75.00
React-anoxic	Yes	No	6.00 (three stages each one about 2.00 h)	23.75
Draw	Yes	Yes	0.30 (During the last aerobic stage)	1.25
Total cycle time			12 h	100

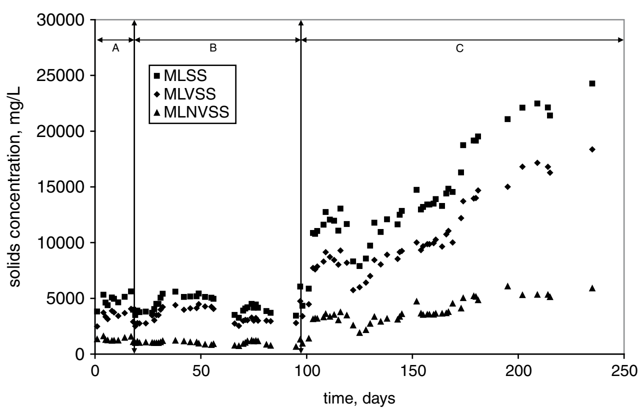

Fig. 2. Suspended solids variation during the SMBR operation. (a) acclimatization, (b): first operational period, (c) second operational period.

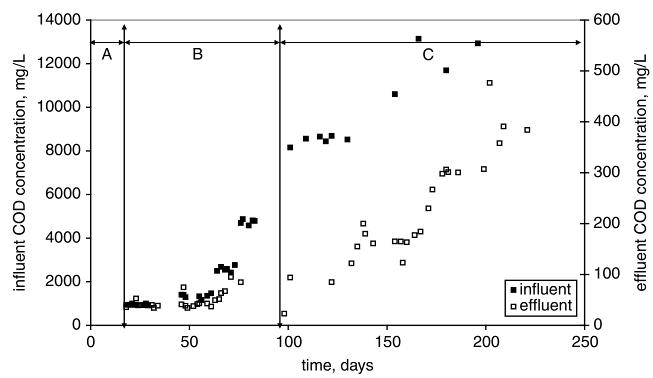

Fig. 3. Influent and effluent COD concentration during the treatment of leachate and sewage mixtures in the SMBR system. (a) acclimatization, (b) first operational period, (c) second operational period.

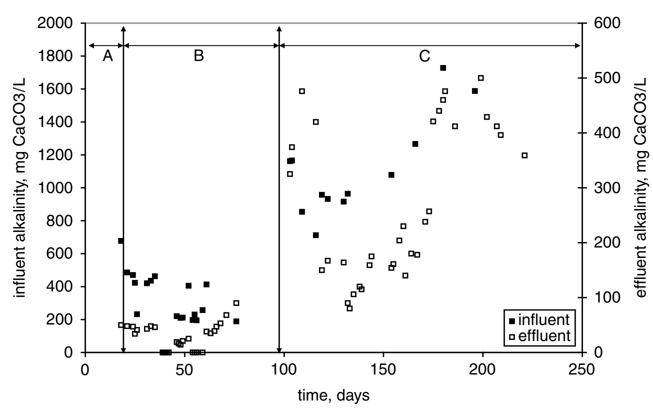

Fig. 4. Influent and effluent alkalinity during the treatment of leachate and sewage mixtures in the SMBR system. (a) acclimatization, (b) first operational period, (c) second operational period.

some other studies have revealed no effect of MLSS on fouling up to a threshold concentration, from 3.6–8.4 up to 30–40 g/l [28].

3.3. *Organic substances and nutrients removal*

The chemical properties of influents and effluents are presented in the following figures: influent and effluent COD values are shown in Fig. 3, while alkalinity is given in Fig. 4.

As shown in Fig. 3, COD removal rate varied between 95% and 97% during the first operation period and between 97% and 99% during the second operation period. COD removal was not affected by the increase of the biomass concentration; furthermore, a high COD removal rate was maintained during both periods, although methanol was daily added for the enhancement of denitrification process, indicating that methanol was completely degraded or consumed. In addition, low effluent alkalinity values were observed in the first operation period; however, optimization of system performance in the second period resulted to high alkalinity values.

The influent and effluent concentrations of ammonia–nitrogen, nitrate-nitrogen and total nitrogen are presented in Figs. 5–7 respectively. During the first operation period an increased effluent ammonia–nitrogen concentration was observed, reaching to values up to 25 mg/l, attributed to the low alkalinity content of influent. However, almost complete ammonia–nitrogen removal was observed during the second operation period. This higher efficiency of nitrification in the second period resulted from a longer SRT and a higher sludge concentration compared with the first period. An increase of the nitrate content was observed during the first period attributed to the operation mode including one short anoxic stage and to the lack of an e-donator for the optimization of denitrification process. In order to enhance the denitrification process, the addition of 40 ml of pure methanol during the anoxic stages was applied, together with a redesign of the daily cycle aiming to increase the anoxic stages. As a result, nitrate nitrogen content decreased to values lower than 150 mg/l while total nitrogen content removal rate varied between 76% and 95%.

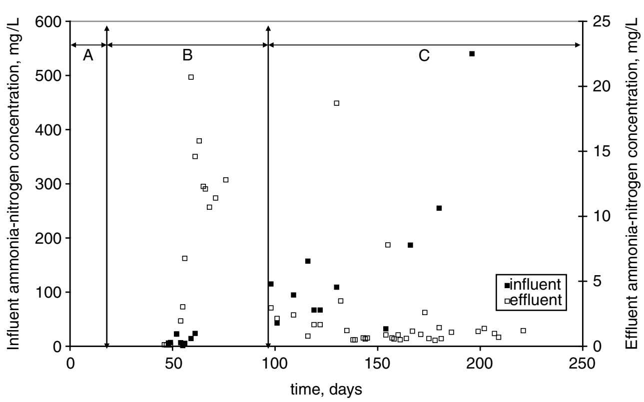

Fig. 5. Influent and effluent ammonia–nitrogen concentration during the treatment of leachate and sewage mixtures in the SMBR system. (a) acclimatization, (b) first operational period, (c) second operational period.

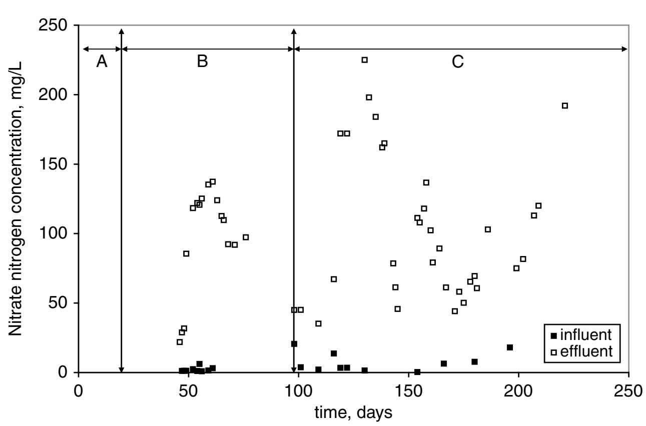

Fig. 6. Influent and effluent nitrate nitrogen concentration during the treatment of leachate and sewage mixtures in the SMBR system. (a) acclimatization, (b) first operational period, (c) second operational period.

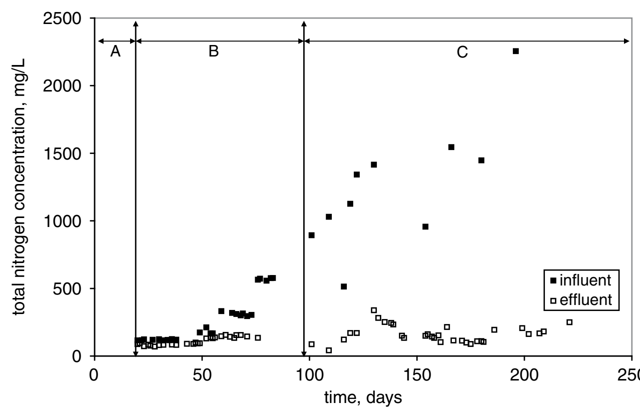

Fig. 7. Influent and effluent total nitrogen concentration during the treatment of leachate and sewage mixtures in the SMBR system. (a) acclimatization, (b) first operational period, (c) second operational period.

The removal of TN in the membrane bioreactor was mainly attributed to nitrification and denitrification in the reactor. When the aeration stage finished, the DO in the reactor decreased to 0 mg/l in a few minutes, and a sufficient carbon source was available due to the supplemented influent, which was good for denitrification. So for operation period 2, a higher removal rate for TN was observed in general than that for operation period 1, especially at extended operation times. However, the removal rate for TN was not satisfactory, and the concentration of NO_3^- in the effluent was still high, which probably indicated that the denitrification in the SMBR was not complete.

The influent and effluent concentrations of phosphates are presented in Fig. 8. During the first operation period, low phosphorous removal rates were observed, and phosphate concentration was almost similar in influent and effluent. However, redesign of the system operation mode and performance optimization resulted to phosphorous removal rates reaching up to 60%.

The average properties of SMBR effluents during both operational periods are given in Table 3, where the required limits have been included. As shown in this table, the treatment of the mixture of leachate and synthetic domestic wastewater by the SMBR resulted

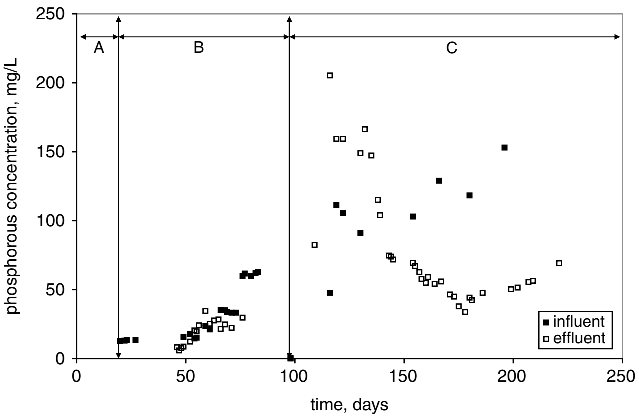

Fig. 8. Influent and effluent phosphorous concentration during the treatment of leachate and sewage mixtures in the SMBR system. (a) acclimatization, (b) first operational period, (c) second operational period.

Table 3
Discharge conditions and SMBR effluent properties during the treatment of leachate and sewage mixtures

Parameter	Discharge conditions	Effluent data	
		First operational period[a]	Second operational period[a]
pH	6–9	6.2	7.7
COD (mg/l)	180	50	220
NO^-_3–N (mg/l)	50	100	100
NH^+_4–N (mg/l)	35	4.8	1.9
PO^-_4–P (mg/l)	30	20.2	75.3

[a]The presented data are average values during the overall period.

in an effluent with such a quality that it should not be discharged in a water body, but further treatment is required, possibly by a combination of physical–chemical processes [26,29].

4. Conclusions

A pilot-scale microfiltration (MF) plate and frame (flat sheet) membrane unit was used for the study of co-treatment of landfill leachate and domestic wastewater aiming to the examination of the co-treatment potential and the investigation of the optimum operation conditions. Two operational patterns were examined in order to obtain maximum COD and total nitrogen removal rates, including various combinations of aerobic and anoxic stages; 40 ml of methanol were added during the anoxic stage, aiming to the enhancement of the denitrification capacity. A high MLSS concentration was maintained during both periods. High removal rates of organic substances were measured during both experimental periods; COD removal rate exceeded 95%, resulting in the production of a high quality effluent. Similar to organic loading, high removal rates of ammonia nitrogen were observed, reaching up to 99%. However, low total nitrogen removal rate was measured, although additional anoxic stage and methanol addition as an external carbon source were applied during the second period. Effluent total nitrogen concentrations of about 150 mg/l were measured; the combination of extended anoxic stages and methanol addition resulted in the lowest total nitrogen effluent content and almost 60% phosphorous removal. In general, the configuration of the submerged membrane batch reactor proved to be an effective technique for the treatment of high strength wastewaters and the production of an effluent of high quality; however, the appropriate operation conditions have to be determined between a number of alternative operation modes in each case, in order to maximise the removal of pollutants, especially of nutrients, and to achieve long term operation efficiency.

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