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COMBINED TREATMENT OF LANDFILL LEACHATE AND DOMESTIC SEWAGE IN A SEQUENCING BATCH REACTOR

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ABSTRACT

A study was undertaken to examine the feasibility of biologically treating a combined waste stream of landfill leachate and municipal sewage. The ratio of sewage to leachate was 9 to 1 by volume. The combined waste had an average BOD5 430 mg/l, COD 1090 mg/l, and TKN 133 mg/l (80% of which was in the form of ammonia). A laboratory-scale sequencing batch activated sludge reactor was used to carry comparative performance evaluations of biological treatment, including nitrification and denitrification. The SBR reactor was operating in daily time cycles employing the following sequential operation phases: filling phase, anoxic phase, aeration reaction phase, settling phase, and drain phase. In particular, the anoxic and aeration periods were tailored in order to develop conditions conducive to desired nitrification and denitrification. During the reaction period, the process was operated under an extended aeration mode with the MLSS concentration being around 3500 mg/l. The results indicated that successful biotreatment of combined leachate and sewage was possible, with the treated effluent being low in BOD_5 and COD. The system was capable of BOD5 removal efficiencies exceeding 95%. Furthermore, nitrate removal during the anoxic phase was approximately 99% due to denitrification. However, the overall nitrogen removal during a full cycle was about 50%. The inclusion of an anoxic period right after the aeration phase enhanced the nitrogen removal efficiency, yet this phase required the addition of an external carbon source to the reactor due to the low concentration of biodegradable carbon, and at the same time the process became less efficient in BOD removal. © 1997 IAWQ. Published by Elsevier Science Ltd

KEYWORDS

Denitrification; leachate; nitrification; sequencing batch reactor; sewage.

INTRODUCTION

Aerobic biological treatment of landfill leachate has emerged as a practical means of treatment (Chian and DeWalle, 1976; Ehrig, 1984; Forgie, 1988; Robinson and Grantham, 1988). Combined treatment of leachate and domestic wastewater (sewage) has received significant consideration (Raina and Mavinic, 1985; Schuk and James, 1986; Strachan *et al.*, 1994). Combined treatment may have certain advantages, including better control of the influent characteristics, since leachate pollutant loads and flowrates have, in general, significant variations in time (Hartmann and Hoffmann, 1990). The feasibility of combined treatment of leachates in most of the studies was examined primarily in terms of organic matter removal efficiency. However, leachates often present high ammonia concentrations (Manoharan *et al.*, 1992), and therefore a nitrification-denitrification process has to be considered for the complete leachate treatment.

Removal of nitrogen from wastewater can be accomplished through a variety of physicochemical and biological process. Biological nitrification-denitrification is considered to be one of the most promising and practical methods of treating high nitrogen leachates. In a study concerning the treatability of a landfill leachate with a TKN concentration of 180-300 mg/l in a conventional system, Carley and Mavinic (1991) achieved a 100% partial denitrification performance, yet the overall nitrogen removal was lower with the effluent having a nitrate-nitrogen concentration between 38-60 mg/l.

The Sequencing Batch Reactor (SBR) system is ideally suited to nitrification-denitrification studies since it provides an operation regime compatible with concurrent organic carbon oxidation and nitrification (Irvine and Busch, 1979). As a hybrid of the fill-and-draw configuration, a SBR operates on a cyclic basis: Fill, React, Settle, Draw and Idle phases. Interest in the application of SBR to wastewater treatment is the result of several process characteristics, such as combining the reactor and the settling tank in the same vessel, easily controlled performance with respect to reaction time and sludge solids maintenance, flexibility of operation for carrying out simultaneously different biochemical conversion reactions, such as nitrification and denitrification, reduction of oxygen transfer requirement, and inherent flow and organic equalization capacity. Systems with a wide range in flow and/or organic loading and systems requiring close control of effluent quality are particularly suited for batch operation of active sludge. As a result SBR processes have been extensively applied for the treatment of municipal (Irvine *et al.*, 1983) and hazardous wastes (Herzbrun *et al.*, 1985) including the nitrification-denitrification biological treatment of landfill leachates (Manoharan *et al.*, 1992). However the nitrification-denitrification performance of an SBR system for the combined treatment of leachate and domestic wastewater has received little attention.

The objectives of this work were to investigate the biological co-treatment and particularly the nitrification-denitrification performance of a high-strength ammonia leachate and domestic wastewater by means of a SBR system. In addition, the effect of different process schemes on the overall nitrogen removal capability of the treatment system was studied.

METHODS

The leachate used in this work was obtained from the landfill of the Thessaloniki Greater Area (population 1 million), which receives about 7,000 t of domestic solid wastes per week. Leachate samples were collected, characterized and stored in a refrigerator, unless used for immediate treatment by the SBR system. Raw domestic wastewater was taken from the influent of the Thessaloniki wastewater treatment plant. Raw wastewater was refrigerated at 4°C to retard biological decomposition. The influent to the SBR consisted of a mixture of leachate and sewage, containing 10% v/v leachate. The overall characteristics of the leachate, the sewage, and the mixture (influent to the SBR) are presented in Table 1.

Table 1. Characteristics of landfill leachate, sewage and influent to the reactor

PARAMETER (mg/l)	LEACHATE	SEWAGE	INFLUENT TO THE SBR	
			Mean	Range
BOD_5	2000-4700	60-270	430	336-600
COD	4700-12000	120-500	1090	790-1490
TKN	640-1020	19-78	133	106-155
$N\text{-}NH_3$	405-920	11-48	107	29-112
$N\text{-}NO_3^-$	4-25	2-5	3	1.3-6.5
$P\text{-}PO_4^{3-}$	0-12.5	1-10	4.9	1-9.4

All experiments were conducted in a bench-scale cylindrical Plexiglas reactor. Air was supplied to the system through two diffuser stones located at the bottom of the reactor. The reactor was operated in 24 hour batch cycles. At the beginning of the fill period, 2 l of the feed wastewater (containing 10% v/v leachate) were fed to the reactor. 2 ml of 1 percent phosphoric acid solution were added to the wastewater in order to provide the system with the appropriate nutrient concentration, since the phosphorus level was quite low. Feeding took place over a period of 3h by means of a peristaltic pump (Watson Marlow). The volume of the mixed liquor at the end of the fill stage was 4 l. During the fill and anoxic phases, mechanical mixing was provided by a magnetic stirring bar to maintain homogeneity of the mixed liquor. Following the anoxic phase, the mixture was aerated. At the end of the aeration (react) period, the air valve was closed and the sludge was allowed to settle. At the end of the settling period, the clear supernatant liquid was withdrawn from the reactor to a final volume of 2 l by means of the peristaltic pump.

Table 2. Experimental operating modes of SBR system

	Duration of Operation (hours)			
PHASE	Mode I	Mode II	Mode III	Mode IV
Fill	3	3	3	3
Anoxic	-	3	6	6
Aeration	20	17	14	11
Anoxic	-	-	-	3
Settle and Draw	1	1	1	1

The mixed activated sludge culture was taken from the aeration basin of Thessaloniki municipal wastewater treatment plant and was acclimatized for a period of one month prior to the experiments. The reactor was operated at an almost constant temperature of 20°C. Mixed Liquor Suspended Solids (MLSS) were maintained at around 3500 mg/l by properly wasting a portion of the mixed liquor.

Various operating modes were investigated. Variations on system operation were directed at possible denitrification improvement. As a result the time for the anoxic phase was varied between 0 and 6 hours with a corresponding variation in aeration time. In some cases an anoxic phase was included after the aeration stage in order to investigate increased efficiencies in nitrogen removal. In general, 1 h was sufficient time for both the Settle and Draw periods. Removal of the supernatant liquid began as soon as an appropriate quantity (2 l) was obtained over the settled sludge. The operating modes used in this study are summarized in Table 2.

Effluent samples were analyzed on a regular basis for COD, BOD_5, SS, pH, ammonia, organic, nitrite and nitrate nitrogen, while analysis was conducted on the reactor for temperature, DO, MLSS and pH. On occasion, the reactor's behavior was monitored over the course of one complete 24-hour cycle. Track studies were conducted in order to follow the change in concentration of various constituents during the various periods. The reactor was operated for at least 2 weeks in a certain mode to achieve stability before collecting samples for measurements.

Standard methods of chemical analysis were employed for the characterization of leachate and domestic wastewater (Standard Methods for the Examination of Water and Wastewater, 1981). Dissolved Oxygen was determined with an oxygenmeter, and an ion-selective electrode (Orion) was used for nitrate concentration measurements, in addition to the cadmium reduction method.

RESULTS AND DISCUSSION

The overall results of the study according to each of the operating modes are presented in Table 3. After the acclimatization period of micro-organisms, the SBR system was operated on Fill-React-Settle 24-hour cycles (mode I). No anoxic phase was included in the operating sequence, however since there was no aeration during the Fill phase, it was thought that denitrification could have been possible. The SBR system consistently attained a quality discharge over a 1-month period providing an effluent with BOD_5 less than

10 mg/l and COD values around 150-180 mg/l. Further reduction of nonbiodegradable organic matter could be accomplished by applying physicochemical techniques (Diamadopoulos, 1994). The organic matter removal efficiency was consistently above 98%. The sludge settleability was good, producing a clear effluent with suspended solids concentration lower than 30 mg/l. The MLSS concentration was maintained at about 3500 mg/l throughout this operation mode. The MLSS concentration remained almost constant without sludge wasting due to negligible sludge production as a result of the extended aeration regime established during the React period. The original color of the mixed wastewater was dark brown, while the effluent presented a light yellow color due to the presence of humic-like organic compounds.

The SBR system demonstrated high nitrification capacity with consistent TKN removal of 92%. However, the nitrate-nitrogen effluent concentration varied between 52-68 mg/l. Transition of the nitrogen species and progression of organic matter conversion through the course of a Fill and React sequence are shown in Figure 1. The mixing intensity during the anoxic Fill was sufficient to keep the MLSS in suspension, but insufficient to maintain a measurable concentration of dissolved oxygen. The dissolved oxygen concentration dropped below 0.1 mg/l at the onset the of anoxic phase.

Table 3. Mean values and standard deviation of removal efficiencies for the different operating modes

	Mode I		Mode II		Mode III		Mode IV	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
BOD_5	98.7	0.4	98.6	1.1	98.3	0.3	70.8	4.4
COD	85.5	1.3	81.9	3.3	79.3	1.8	67.7	3.6
Total Nitrogen	48.8	2.5	47.7	2.1	35.0	4.5	63.2	5.7

Total Nitrogen is the sum of TKN plus nitrate and nitrite nitrogen

The BOD_5 concentration at the end of the Fill period, as calculated by considering the dilution of the wastewater mixture with the reactor mixed liquor and excluding any biological activity, would be approximately 205 mg/l. However, the actual BOD_5 value after Fill was approximately 80 mg/l corresponding to a 125 mg/l decrease in organic biodegradable carbon. In addition, the TKN was calculated as 65 mg/l, while the measured concentration value was 60 mg/l. Assuming a molecular formulation of $C_5H_7O_2N$ for bacteria, the 5 mg/l nitrogen consumed during Fill would have resulted in the utilization of 21 mg/l carbon during the same period, if cell growth was the mechanism of uptake. It is obvious that a considerable amount of BOD_5 was removed from water without biological activity and at negligible DO concentrations. The increased substrate removal during the anoxic Fill period could be attributed to a physical-chemical adsorption of organics on the surface of micro-organism particles (Silverstein and Schroeder, 1983) or to an intracellular bacteria storage mechanism (Alleman and Irvine, 1980b).

Subsequent oxidation of organic carbon during the aeration phase resulted in mean BOD_5 level of 7.5 mg/l and mean COD level of 164 mg/l. Although the concentration of organic components was measured only at the beginning and end of the aeration period, it is likely that organic carbon concentration in the bulk liquid decreased very rapidly after aeration began as has been verified by other researchers (Alleman and Irvine, 1980a; Silverstein and Schroeder, 1983).

Transition of the nitrogen species towards the oxidized forms, nitrite and nitrate, took place during the aeration phase. As can be seen in Figure 1, ammonia nitrogen oxidation was complete. Its removal was attributed primarily to assimilation in the biomass and to nitrification. Ammonia-nitrogen loss through air stripping in the reactor was considered to be negligible as the pH during aeration was about 8.5. TKN effluent concentration was measured at 10 mg/l. The end product of the nitrification process was nitrate with a mean effluent concentration of 62 mg/l, while the nitrite-nitrogen concentration was less than 1 mg/l. Almost complete denitrification occurred during the anoxic fill phase and the nitrate-nitrogen concentration at the end of this period was 2.5 mg/l. During this phase, the inlet wastewater mixture provided the necessary carbon source for denitrification, resulting in the additional removal of organic load. The overall nitrogen removal was calculated by dividing the total nitrogen (organic, nitrate and nitrite) removed in the SBR by the total nitrogen entering the system. Overall nitrogen removal achieved during this operation mode was on average 48.8%.

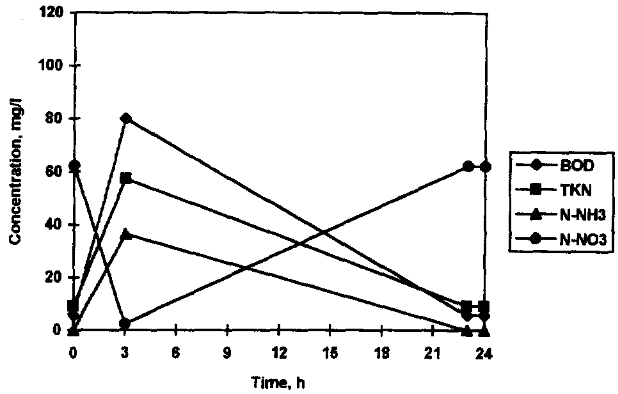

Figure 1. Track data for a full cycle for operating Mode I.

The operation of the SBR system could be arranged to provide an extended anoxic period before the React phase (operating mode II). The organic carbon required for denitrification could be provided by the inlet wastewater. High effluent quality with respect to organic substrate removal was also maintained during this operating mode. Effluent BOD_5 and COD values were around 6 mg/l and 170 mg/l respectively, resulting in 98.6% and 81.9% mean removal efficiencies.

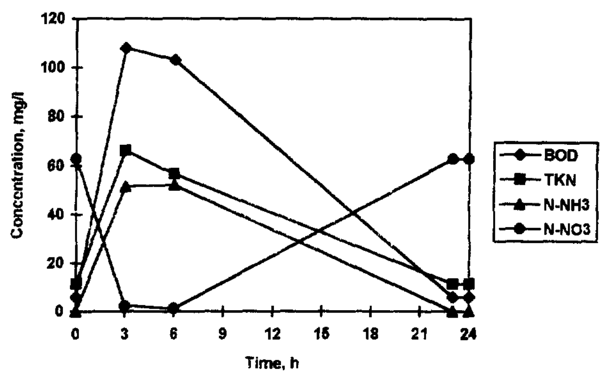

Figure 2. Track data for a full cycle for operating Mode II.

Track analysis data corresponding to nitrogen and biodegradable organic carbon profile during the different phases are shown in Figure 2. Both TKN and organic carbon profile depicted an almost similar rise-and-decline profile. During the 3 hours Fill period, the BOD_5 value increased from 6 mg/l to 108 mg/l (compared to the calculated value of about 264 mg/l due to dilution only), while the respective TKN concentration increased from 11 mg/l to 66 mg/l. At the same period nitrate-nitrogen decreased from a concentration of 63 mg/l to 2.4 mg/l resulting in a denitrification efficiency of 96% for this phase. During the subsequent anoxic phase, a small decrease in the concentration of nitrate-nitrogen to 1.2 mg/l was observed. However, effluent nitrate-nitrogen were maintained at 63 mg/l similar to the previous operation mode. The high nitrate-nitrogen concentration was due to nitrification of TKN during the aeration period. Overall nitrogen removal achieved was 47.7% which was statistically the same as in the previous operating mode.

Similar results for the reactor performance were observed when the anoxic phase was extended to 6 hours with a reduction in the aeration period to 14 hours (Mode III). The BOD5 removal efficiency achieved was 98%, while the mean nitrogen removal was only 35%. The mean effluent nitrate-nitrogen concentration was 67 mg/l, while the effluent TKN concentration was around 20 mg/l, indicating that nitrification during the aeration phase was not complete. For comparison reasons it should be mentioned that during the previous two operating modes, when the aeration phase was 20 and 17 hours, respectively, the TKN in the effluent never exceeded 10 mg/l.

These results indicate that the Fill phase could also be an effective anoxic phase providing extremely high denitrification efficiencies. The inclusion of an additional anoxic phase was not necessary for the system under investigation. On the contrary, a long anoxic period resulted in the reduction of the subsequent aeration phase with a detrimental effect on the nitrification efficiency.

In order to increase the denitrification capacity of the SBR, the system performance was examined with the addition of an anoxic phase after the aeration period (Mode IV). Preliminary experimental results showed small differences in nitrate-nitrogen effluent concentration, as compared to the previous modes, due to low availability of organic carbon. The results indicated the necessity of an external carbon source.

Methanol was chosen as an external carbon source as it was found to be effective for denitrification treatment of a high-ammonia landfill leachate (Carley and Mavinic, 1991). These researchers found that the minimum carbon to nitrogen ratio required for complete denitrification was approximately 6.2 : 1 and this minimum value was used for the estimation of the appropriate methanol dosage in this work.

Although total nitrogen removal increased to a mean value of 63.2%, both the BOD_5 and COD removal efficiencies dropped to 70.8% and 67.7%, respectively. The system became unstable and the variability in the organic load of both the leachate and sewage did not allow precise calculations of the required external carbon. This resulted in frequent overloading of methanol during the second anoxic phase. The excess methanol contributed to BOD, and at the same time it promoted the production of large quantities of MLSS during the next aeration cycle.

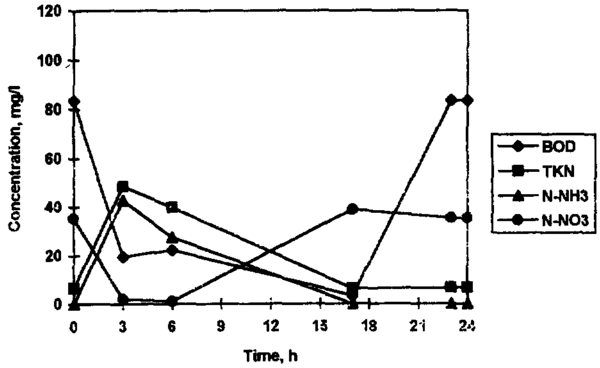

Figure 3. Track data for a full cycle for operating mode IV.

Track analysis data obtained during the various phases are presented in Figure 3. As mentioned above, the high effluent BOD5 value of 83 mg/l was attributed to the added methanol. A high degree of nitrification was achieved during the aeration period, yet during the subsequent anoxic phase, denitrification was higher than the previous modes, but less than expected (the mean nitrate-nitrogen effluent concentration was 44 mg/l). However, practically complete denitrification was observed during the first anoxic phase (prior to aeration phase). This difference could be attributed to the fact that the nitrifying bacteria were acclimated to a leachate-wastewater environment. It should be mentioned that the high nitrogen content of the leachate and the low BOD level of the domestic sewage rendered them inappropriate as an additional carbon source during the second anoxic phase.

CONCLUSIONS

Based on the results of this study, the following conclusion are drawn :

- A combined wastewater of a high-ammonia landfill leachate and domestic sewage was successfully treated in a sequencing batch reactor system.

- The SBR system provided excellent BOD_5 removal, over 98%. A significant fraction of organic matter was removed during the Fill period without mechanical aeration. This was attributed to the adsorption of the colloidal carbon on the biological flocs.

- In general, the nitrification of organic and ammonia nitrogen proceeded almost to completion during the aeration React period.

- Almost complete denitrification was achieved during the Fill period. An additional anoxic period was not necessary for this system. However, the overall nitrogen removal efficiency ranged from 35 to 50%.

- The inclusion of a second anoxic period following aeration required the addition of a supplementary carbon source (methanol). The total nitrogen removal increased to 63.2%, yet the system became difficult to control, and the respective removal efficiencies for BOD_5 and COD dropped significantly.

- Excellent settling of the flocs was observed for all operating modes studied.

Overall, the SBR system demonstrated an excellent capacity for the combined oxidation of organic carbon and nitrogen of a mixed wastewater consisting of landfill leachate and domestic sewage. In addition, this system provided the opportunity to arrange the operation phases in order to optimize performance. Such flexibility of operation is indicative of a sludge biomass containing an heterogeneous population capable of carrying out various biochemical conversions without being impaired by unfavorable conditions.

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