Comparison of the performance of MBBR and SBR systems for the treatment of anaerobic reactor biowaste effluent

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Abstract Anaerobic reactor biowaste effluent was treated with biofilm and activated sludge sequencing batch reactors to compare the performance of both systems. The treatment targets were organic carbon removal and nitrification. The pilot plant was operated in two phases. During the first phase, it was operated like a Moving Bed Biofilm Reactor (MBBR) with the Natrix media, with a specific surface area of 210 m^2/m^3. The MBBR was operated under Sequencing Batch Reactor (SBR) modality with three 8-hour cycles per day over 70 days. During the second phase of the experiment, the pilot plant was operated over 79 days as a SBR. In both phases the influent was fed to the reactor at a flow rate corresponding to a Hydraulic Retention Time (HRT) of 4 days. Both systems presented a good carbon removal for this specific wastewater. The Chemical Oxygen Demand (COD) total removal was 53% for MBBR and 55% for SBR. MBBR offered a higher dissolved COD removal (40%) than SBR (30%). The limited COD removal achieved is in agreement with the high COD to BOD_5 ratio (1/3) of the influent wastewater. In both systems a complete nitrification was obtained. The different efficiencies in both systems are related to the different biomass concentrations.
Keywords Carbon removal; moving bed biofilm reactor (MBBR); nitrification; sequencing batch reactor (SBR); solid waste fermentation

Introduction

Biological treatment based upon suspended biomass has proved to be effective for organic carbon and nutrient removal in small and large wastewater treatment plants. However there are problems associated with the sludge settleability and the need for large reactors; the settling tanks and the biomass recycling. Poor settleability can give rise to serious operating problems like increased effluent suspended solids and washout of biomass from the system.

The application of the Sequencing Batch Reactor (SBR) concept gives flexibility to the process because it presents the possibility of operating the plant according to a time-oriented sequence of events taking place in the same reactor. This is in comparison with the space-oriented sequence of continuous-flow stirred-tank reactors, which is where the different biological processes take place simultaneously.

SBR systems are operated in cycles divided into the following successive phases: filling, mixing, aeration, settling and drawing. There is no need for a return activated sludge system, because both aeration and settling occur in the same tank. No sludge is lost in the reaction step and none has to be returned from the clarifier to maintain the sludge constant in the aeration chamber. However, bacteria use up the nutrients in growth, which results in an excess of sludge which has to be removed from the reactor.

Biofilm reactors are also becoming more important in the wastewater treatment field. The advantages of biofilm reactor systems in comparison to activated sludge systems include: higher volumetric load, increased process stability and compactness of the reactors due to a higher biomass concentration and higher specific removal rates. Slow growing organisms can be more easily accumulated in biofilm reactors because the sludge age is independent of the mean residence time of the fluid.

The basic idea behind the Moving Bed Biofilm Reactor (MBBR) is to have a continuously operating, non-cloggable biofilm reactor with low head-loss and with a high specific biofilm surface. This is achieved by having the biofilm or biomass growing on small carrier elements that move along with the water in the reactor. This medium consists of freely floating carriers that can be made of different materials, shapes and sizes. Some of the advantages of moving bed reactors compared to most types of attached growth systems are:

1. Very good mixing of reactor contents, resulting in an efficient mass transfer and elimination of the risks of liquid short-circuiting and clogging of media with biomass or other solids.
2. No need for backwashing, no filter bed channeling and low head-loss.
3. High specific biofilm surface area.

The suspended carrier (moving bed) process has already been successfully used in the treatment of dairy wastewater (Rusten *et al*., 1992), paper mill wastewater (Broch-Due *et al*., 1994), and municipal wastewater (Odegaard *et al*., 1993). However, very few studies have been focused on the treatment of the wastewater generated by dewatering of anaerobically treated biowastes. This specific wastewater must be treated to remove nitrogen and organic compounds before being discharged. The major treatment difficulty is caused by the poor biodegradability of the organic content in the wastewater. It was assumed that the metabolic capacity to degrade these substances is found in slow growing bacteria rather than in fast growers. Subsequently, a biofilm reactor should be advantageous. To study the relevance of this assumption comparison studies were concluded with biofilm and activated sludge sequencing batch reactors.

Therefore the aim of the present investigation was the comparison of a biofilm and activated sludge sequencing batch reactors to observe the organic carbon removal and the nitrification of the wastewater generated by dewatering anaerobically treated biowastes.

Materials and methods

Wastewater characteristics

The wastewater used during this study was an effluent from a full scale biowaste fermentation plant treating biowaste with the wet-fermentation process, located in Munich. The wastewater consists of the centrifuged effluent from a one step mesophilic digestion process. The average composition, based on analyses performed on samples that were regularly collected is given in Table 1.

Low TSS and 50% of COD in dissolved form indicates a low amount of suspended solids. The significantly high COD/BOD_5 ratio is typical for process waters from biowaste fermentation, as well as the high NH_4-N values. Particulate COD biodegrades slowly because it has first to be hydrolyzed before it can be taken up by the bacteria.

Pilot plant

The pilot plant was built according to the scheme in Figure 1. For the first phase of the experiment, the pilot plant was operated over 70 days like a biofilm process with the Natrix media as carrier. For the second part of the experiment, the same pilot plant was operated over 79 days like an activated sludge process. The operating conditions of both phases were identical except for the settling time. The MBBR was operated with two different settling times (15 min and 1 hr), while the SBR was operated only with a 1 hour settling time. The two phases of the reactor operation compare the performance of a biofilm process (Phase 1) and an activated sludge process (Phase 2).

The reactor of the pilot plant consisted of a 36 litre plastic tank, aerated in both phases by

Table 1 Wastewater characteristics

Parameter	Unit	Average	Range
pH	–	8	7–8.6
TSS	mg/l	338	90–1,344
COD total	mg/l	3,162	1,470–4,269
COD dissolved	mg/l	1,875	1,130–3,450
BOD_5	mg/l	900	590–1,212
COD/BOD_5	mg/l	3.5	2.5–3.5
NH_4-N	mg/l	232	11–625
NO_3-N	mg/l	23	5–200
NO_2-N	mg/l	8	0.15–122

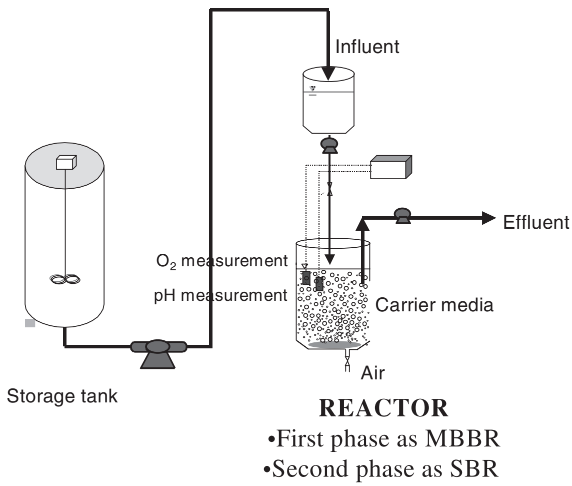

Figure 1 Pilot plant scheme

means of a membrane diffuser at the bottom of the tank. The influent was collected on a weekly basis from the biowaste fermentation plant and it was fed to the reactor at a flow rate corresponding to a hydraulic retention time (HRT) of 4 days. The treatment objectives were carbon removal and nitrification. To this end, in both phases of the experiment, the reactor was operated under the SBR modality with three 8-hour cycles per day. The time employed for each stage of the cycle is shown in Table 2.

Carrier media

For the first phase of the experimentation Natrix model 6/6C was used, which is a plastic carrier made of high density polyethylene. Natrix media produced by ANOX (Lund, Sweden) is built up of 12 walls arranged radially to form a cylindrical body with a length and diameter of 32 and 30 mm respectively. The carrier element has an inner surface area of 210 m^2/m^3. Only the inner surface is available for biofilm growth as the

Table 2 Organization of the SBR cycle

Fill:	5 min
Aeration and mix:	405 min = 6.75 hrs
Settle:	1 hr (MBBR and SBR)
	15 min (MBBR)
Draw:	10 min
Total:	480 min = 8 hrs
Exchange volume:	3 l

outer surface is continuously cleaned of biofilm by the frequent collisions between the carrier elements.

The most important advantages of the media are as follow.

1. The enhanced transfer of substrate and oxygen. The carrier media is open for the passage of water and gas from all directions.
2. Natrix media carriers facilitate the interactions with several air bubbles at a time and do not simply follow the water movement in the aeration tank. In addition to that, it is relatively easy to stop them from flowing out of the aeration tanks.

Analysis

The continuously monitored parameters were: N-NH_4, N-NO_3, N-NO_2, total COD, dissolved COD, TSS, VSS, pH, dissolved oxygen and temperature. N-NH_4, N-NO_3, N-NO_2 and COD levels were determined using test tubes from Dr. Lange Company. All other analyses were performed according to the procedures described in the *Standard Methods* (APHA, 1995).

Results

COD removal with the biofilm process

The MBBR system was operated over 70 days. Following the process stabilization, the reactor was operated using the cycles shown in Table 2. During the experiment, the influent to the pilot plant and the effluent wastewater were monitored. Total COD and dissolved COD concentrations in the influent and the effluent are shown respectively in Figures 2 and 3.

In the MBBR process the average efficiency for total COD removal was 40% (Figure 2). This value is related to an average inflow concentration of 3,162 mgCOD/l and average outflow concentration of 1,950 mgCOD/l. The efficiency for total COD removal improved after 49 days, up to 53%. This could be due to the longer settling time (1 hour instead of 15 minutes).

The average efficiency for dissolved COD removal was 30%. This value is related to an average inflow concentration of 1,875 mgCOD/l and average outflow concentration of 1,360 mgCOD/l. The efficiency for dissolved COD removal improved after the 49th day to 40%.

Nitrification with the biofilm process

The performance of the biofilm process with respect to nitrification is shown in Figure 4. As Figure 4 shows, a stable ammonium removal was maintained throughout the experimental period with an average efficiency of 99%. The average concentrations resulted in 242 mgNH_4-N/l in the influent and 2.2 mgNH_4-N/l in the effluent.

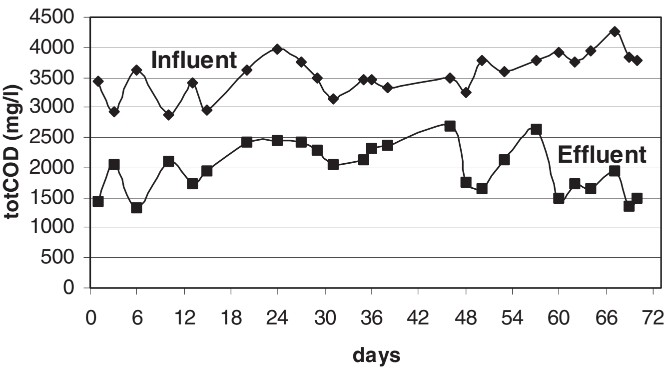

Figure 2 Total COD removal in the MBBR

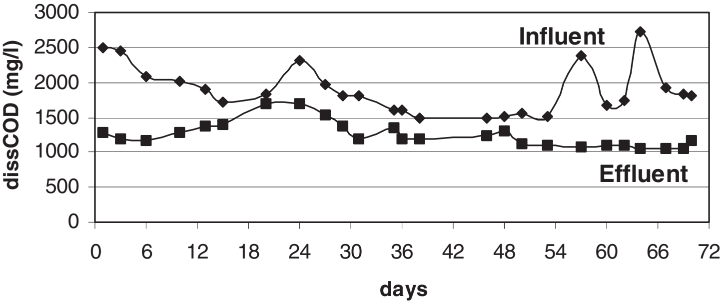

Figure 3 Dissolved COD removal in the MBBR

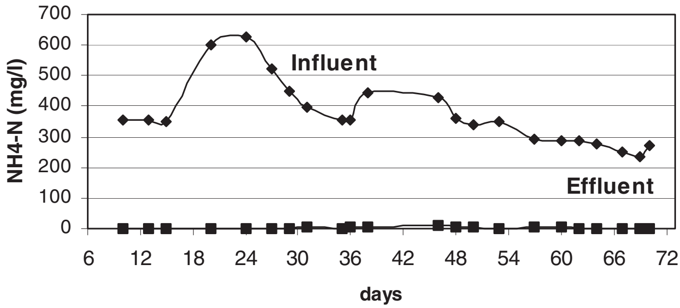

Figure 4 Influent and effluent ammonium concentrations in the MBBR

COD removal with the suspended biomass process

In the second part of the experiment, the pilot plant was operated under the activated sludge Sequencing Batch Reactor (SBR) modality. The operating conditions of the SBR were the same as the first part of the experiment (Table 2) with a 1 hour settling time and the purpose was to compare a biofilm process with an activated sludge process.

Figure 5 shows the total COD removal over 79 days. The average total COD removal percent is 55%. This value is related to an average inflow concentration of 2,340 mgCODtot/l and average outflow concentration of 1,012 mgCODtot/l. The efficiency for dissolved COD removal is 30% and this value is related to an inflow concentration of 879 mgCODdiss/l and average outflow concentration of 626 mgCODdiss/l (Figure 6).

Nitrification with the suspended biomass process

The behavior of the nitrification process is presented in Figures 7 and 8. The ammonium removal is 99% over the total experimental period, independent of the influent concentration.

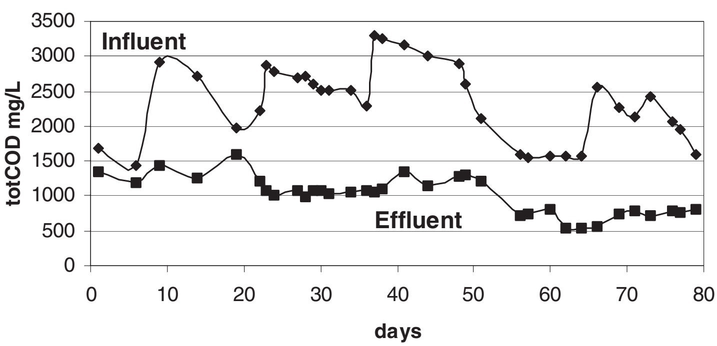

Figure 5 Total COD removal in the SBR

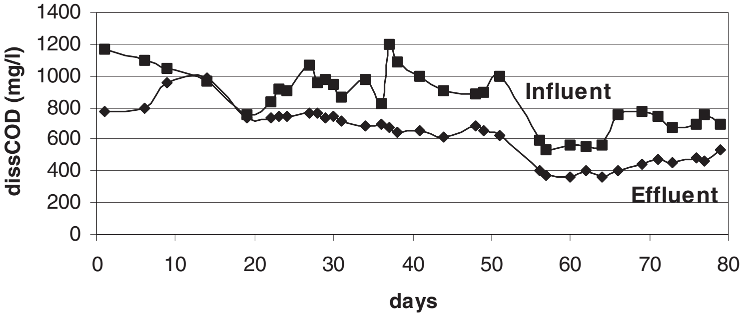

Figure 6 Dissolved COD removal in the SBR

Nitrification to nitrate was complete and the nitrite concentration dropped dramatically to values near zero. The effluent NO_3-N values are not significantly different from the influent NH_4-N concentrations (Figure 8). It can be concluded that the high ammonia concentrations in the influent do not negatively affect the ability of the system to nitrify.

Comparison of the MBBR and the SBR

The MBBR was operated with two different settling times (15 min and 1 hr). In terms of COD removal the MBBR performance increased with the increasing of the settling time. As Table 3 shows, with a 1 hour settling time, the average COD removal in both phases is similar.

Effluents from an anaerobic reactor biowaste show a high DQO/DBO ratio, which means a low biodegradability of the treatment process. To improve the removal in the specific wastewater it is necessary to develop a specialized biocenosis with a system better adapted to the wastewater composition. This is likely to be achieved with a biofilm process,

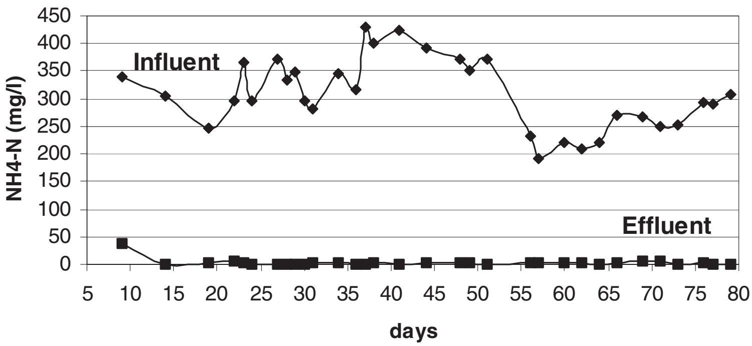

Figure 7 Ammonium removal with the SBR

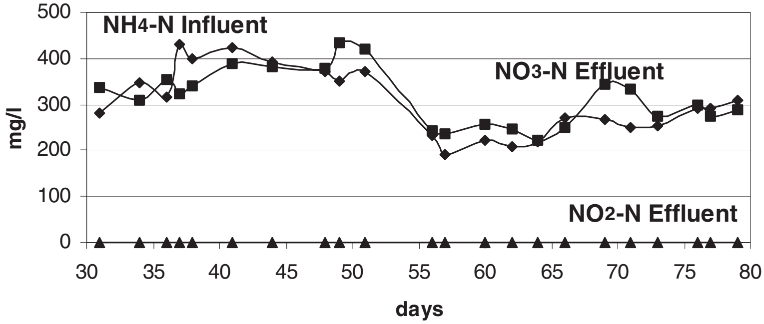

Figure 8 Nitrification performance in the SBR

Table 3 Comparison of the MBBR and SBR

Parameter	Average removal (percent)		
	MBBR		SBR
	St = 15 min	St = 1 hr	St = 1 hr
COD total	40	53	55
COD dissolved	30	40	30
NH_4-N	99	99	99

St – Settling time

which increases the total biomass concentration in the reactor and particularly the solids residence time of the attached biomass. Elements with a high specific surface area allow an increase of the volumetric load removed.

The limited COD removal achieved in the tests is in agreement with the high COD to BOD ratio (3/1) of the influent wastewater. Table 3 shows that although both systems presented a good carbon removal for this specific wastewater, MBBR presented a higher dissolved COD removal. Furthermore, in both systems a complete nitrification was obtained. The differences in the efficiency in the two systems is related to the different biomass concentration. In the SBR the biomass concentration ranged from 1.07 to 4.4 kgTSS/m^3 (average value: 2.1 kgTSS/m^3) and from 0.8 to 2.4 kgTSS/m^3 (average value: 1.7 kgTSS/m^3) in the MBBR system. The particulate COD removal increases with the enzymatic hydrolysis and bioflocculation due to the higher biomass concentration and the combined settling of totCOD with the reactor microorganisms. Therefore, the SBR system showed higher total COD removal efficiencies when compared to the MBBR. The apparent reason is the low specific surface of the employed carriers which did not present a better performance than the SBR system. It could be concluded that elements with higher specific surface will allow an increased volumetric load removal.

Conclusions

1. Moving bed biofilm reactors were showed to be an equivalent alternative to activated sludge systems for the treatment of biowaste effluents. During the experimentation total COD removal of 53%, dissolved COD removal of 40% and ammonium concentration removal of 99% were obtained.
2. The comparison of the performance of MBBR and SBR systems for the treatment of anaerobic reactor biowaste effluents showed that the different efficiencies in the two systems are related to the different biomass concentrations.

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