0273-2289/96/5758—0837$6.75

Operation of a Novel Anaerobic Biofilter for Treating Food-Processing Wastewater

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ABSTRACT

An anaerobic biofilter was operated with 4500 mg COD/L food-processing waste water, fed at 10 d of hydraulic retention time (HRT). In 45 d after seeding, established biofilms were dominated by dense layers of *Methanococcus*-like and *Methanothrix*-like cells. The average COD and grease removal efficiencies were 85 and 53%, respectively, when the HRT was decreased stepwise to 1.5 d. Immobilized biofilms enabled the biofilter to be started up easily, to have stable treatment performance, and to recover rapidly from shock loadings and process failure.

Index Entries: Anaerobic biofilter; food-processing waste water; grease removal; shock loading; process recovery.

INTRODUCTION

Anaerobic processes have been used to convert a wide variety of organic wastes into energy-rich biogas. A high degree of organic stabilization and energy efficiency has rendered the anaerobic process an attractive option for in-house pretreatment of waste water at industrial and agricultural production sites *(1–3)*. However, owing to the slow growth rates of anaerobic microorganisms, anaerobic processes may require as long as 6 mo to initiate. Fluctuations in organic and hydraulic loadings often result in process instability and failure. Furthermore, difficulties are commonly encountered in the treatment of persistent industrial wastes. For instance, greasy waste waters from petrochemical, meat-packing, and food-processing industries often result in an impermeable film of grease over the biomass, which hampers material transfer between the waste water and the microorganisms *(4)*. Hydraulic retention time (HRT) as long as 20 d is common for a conventional anaerobic reactor to achieve a mere 40% organic removal from slaughter house waste water *(5)*.

In this study, an anaerobic column-type biofilter was initiated to treat high-strength food-processing waste water. Shock loadings were introduced to test the ability of the biofilter to recover from temporary inhibition.

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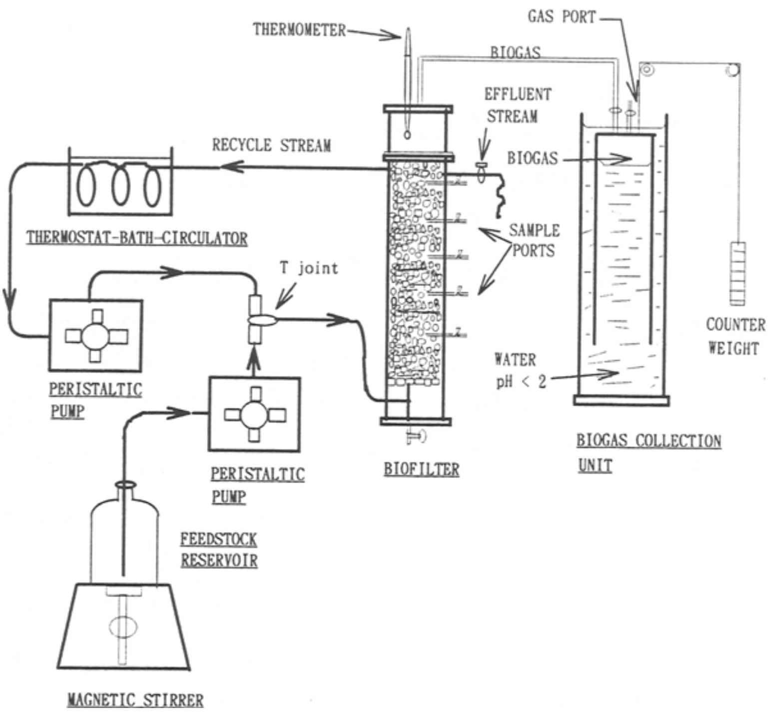

Fig. 1. Schematic of anaerobic biofilter system.

METHODS

Biofilter Assembly

The biofilter was a column with an internal diameter of 9 cm and a height of 1.2 m (Fig. 1). The column was packed with fire-expanded clay spheres (FECSs) with an average diameter of 1 cm. The biofilter was continuously fed in an upflow direction, and the effective volume was 3 L. Ten sampling ports, which extended into the axis of the biofilter column, were evenly spaced along the entire length of the column. Mixing in the packed bed was achieved by recirculating the biofilter liquor at 3 L/h in an upflow direction. This recirculation rate was equivalent to replacing the entire liquid content of the biofilter once in an hour. The recirculation stream passed through a coiled brass tube, which was submerged in a 40°C water bath. This maintained the biofilter liquor at 30–35°C throughout the entire operation.

The biogas was collected by water replacement in acidified water to minimize the dissolution of carbon dioxide. Daily biogas production was measured after equilibrating the collected biogas to atmospheric pressure.

Initiation Procedure

Anaerobic digested sludge from a municipal sewage treatment plant was used to seed the biofilter two times over a week. Each time, 3 L of sludge were sieved with a 2-mm screen and pumped into the biofilter. Immediately after the first seeding, the biofilter was fed with food-processing waste water at an HRT of 10 d. The waste water had concentrations of COD, BOD_5, grease, and total suspended solids (TSS)

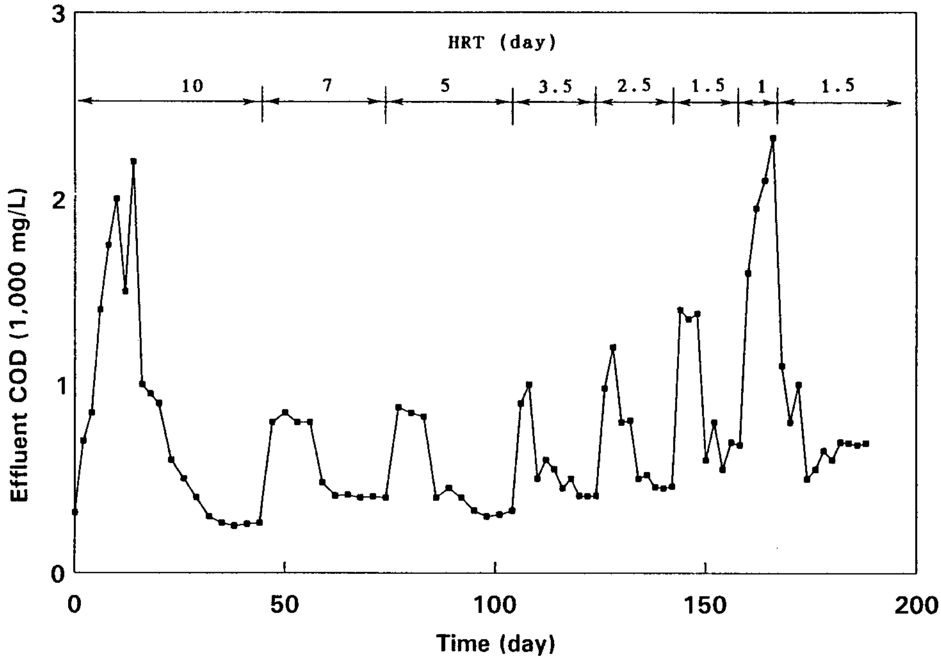

Fig. 2. COD level in treated effluent.

at 4500, 2750, 780, and 150 mg/L, respectively, and the pH was 7.03. When analysis of the treated effluent indicated that steady-state conditions were reached, the HRT was lowered stepwise, allowing the biofilter to attain stable performance at each HRT. The HRTs investigated were 1–10 d.

Shock Loading Experiments

When the operation of the biofilter was stable at 10 d of HRT, the HRT was reduced to 5 d for a period of 5 d, and then returned to 10 d of HRT. This change in HRT without adjusting the organic strength of the feed represented a shock loading equivalent to a 100% increment in hydraulic and organic loadings. Similarly, when the biofilter was stable at a short HRT of 3.5 d, the HRT was reduced to 1.5 d for a period of 1.5 d, and then returned to 3.5 d of HRT. This represented a 230% increment in hydraulic and organic loadings.

Analytical Methods

Analyses for COD, BOD_5, grease, TSS, and volatile suspended solids (VSS) in the effluent were determined according to standard methods *(6)*. The biogas was assayed for methane and carbon dioxide using a Varian Model 3300 Gas Chromatograph with a 2-m Porapak Q 80/100 mesh column.

RESULTS AND DISCUSSION

COD Removal

The variation of COD level in the treated effluent over the 200-d operation is shown in Fig. 2. The average COD level of the treated effluent, COD removal effi-

Table 1
Average* COD Removal at Different HRTs

HRT, d	COD in treated effluent, mg/L	COD Removal efficiency, %	COD Removal rate, mg/d
10.0	266	94	1269
7.0	405	91	1755
5.0	330	93	2511
3.5	408	91	3510
2.5	456	90	4860
1.5	695	85	7650
1.0	2332[b]	48	6552

[a]All average values were calculated with relevant data obtained after the biofilter had achieved stable performance at a particular HRT. Generally, the performance at each HRT was considered stable after the biofilter operated for a period equivalent to three times that of HRT.

[b]Biofilter could not attain stable performance at 1 d of HRT. This value was taken prior to adjustment of HRT to 1.5 d.

ciency, and COD removal rate under stable operation at each HRT are listed in Table 1. After 45 d of start-up operation at 10 d of HRT, dense layers of immobilized biofilms were established on the FECSs (Figs. 3 and 4). The biofilms examined were dominated by *Methanococcus*-like and *Methanothrix*-like cells. The biofilms were acclimatized to the food-processing waste water, as indicated by the low and stable COD level in the treated effluent, averaging 266 mg/L. The COD removal efficiency was 94%.

Excellent COD removal efficiency, which ranged between 85 and 94%, was achieved when the HRT was decreased stepwise from 10 to 1.5 d. The biofilter could attain stable performance at each HRT within a period equivalent to three times that of HRT. However, as the HRT was further reduced to 1 d, there was a drastic drop in COD removal efficiency to 48% in 8 d. The biofilter could not attain stable performance and was considered to have failed. The system was recovered by returning to a longer HRT. The cause for biofilter failure and process recovery is discussed below.

The best performance of the biofilter in terms of COD removal efficiency was achieved at 10 d of HRT, with the treated effluent at 266 mg COD/L and a COD removal efficiency of 94%. On the other hand, the best performance in terms of COD removal rate was achieved at 1.5 d of HRT, with a COD removal rate of 7650 mg COD/d and a specific treatment capacity of 2550 mg COD/L/d. This performance surpassed that reported by Sach et al. *(7)* for a similar biofilter treating ethanol at 1000 mg/L.

Grease Removal

The average grease concentration, grease removal efficiency, BOD_5 level, and COD/BOD_5 ratio of the treated effluent under stable operation at each HRT are listed in Table 2. The grease removal efficiency was 53–71% for HRTs between 10 and 1.5 d. Only a small fraction of very persistent grease, such as insoluble animal fats, remained undegraded. This resulted in an increase in COD/BOD_5 ratio

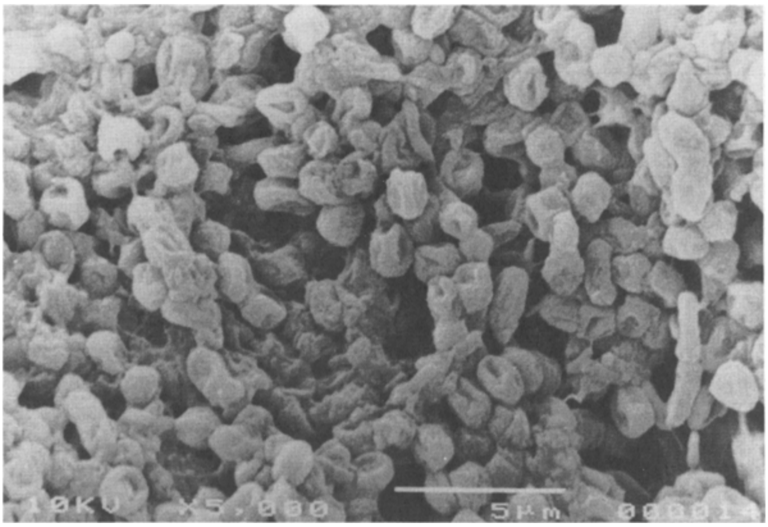

Fig. 3. Biofilm on FECS dominated by *Methanococcus*-like cells.

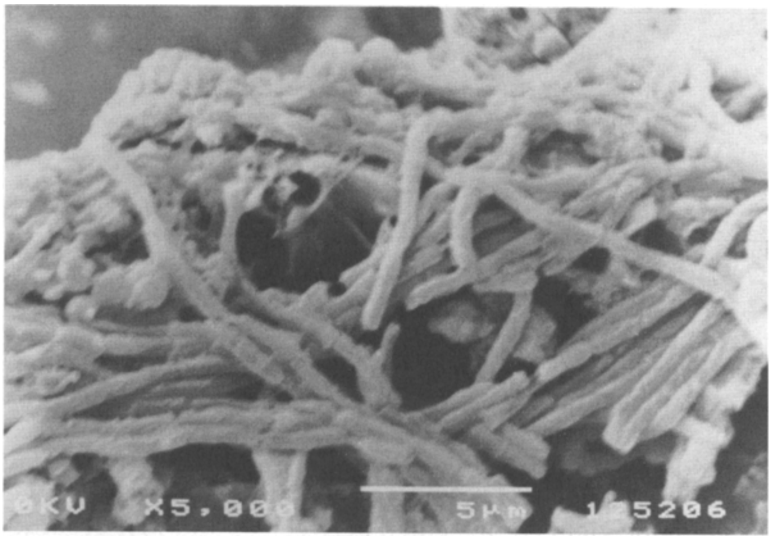

Fig. 4. Biofilm on FECS dominated by *Methanothrix*-like cells.

from 1.64 in the untreated food-processing waste water, to between 2.15 and 2.55 in the treated effluent.

Biogas Production and Biomass Wastage

The average biogas production, methane yield, and VSS in the treated effluent under stable operation at each HRT are listed in Table 3. The maximum biogas production rate of 3.06 L/d was obtained at 1.5 d of HRT. Methane concentration in the biogas remained between 68 and 75% throughout the entire operation before the biofilter failed. These values were slightly higher than the theoretical value of 68.75% *(8,9)*, which could be attributed to the dissolution of carbon dioxide in the biofilter

Table 2
Average Grease Removal at Different HRTs

HRT, d	Grease Concentration in treated effluent, mg/L	Grease Removal efficiency, %	BOD5 in treated effluent, mg/L	COD-BOD5 ratio
10.0	230	71	124	2.15
7.0	234	70	172	2.35
5.0	272	65	141	2.34
3.5	226	71	171	2.39
2.5	345	56	193	2.36
1.5	367	53	273	2.55

Table 3
Biogas Production and Biomass Wastage at Different HRTs

HRT, d	Grease production rate, mg/L	Methane concentration, %	Methane yield, mg/L	VSS in treated effluent, mg/L
10.0	0.54	68	0.29	697
7.0	0.68	72	0.28	696
5.0	1.00	73	0.29	411
3.5	1.51	72	0.31	577
2.5	2.14	75	0.33	804
1.5	3.06	75	0.30	871
1.0	1.81	65	0.18	501

liquor, since the pH of the liquor was between 6.6 and 7.4. These observations of high methane concentration are consistent with that reported in the literature *(1,10)*.

Methane yield was 0.28–0.33 L/g COD for different HRTs before the biofilter failed. These values are very close to the theoretical maximum of 0.35 L/g COD, which suggested that a high proportion of the degraded organic constituents in the waste water was converted to biogas, with much less being converted to biomass. These methane yields represented between 80 and 94% organic conversion to biogas. This is advantageous in the operation of a biofilter, since the problems of biomass accumulation and clogging are reduced. The consistency in methane yield was markedly different from the behavior of the mixed-flow biofilter described by Ng and Chin *(2)*, where methane yield increased from 0.17 to 0.53 L/g COD removed as the HRT was reduced from 6.3 to 2.1 d.

The VSS level in the treated effluent, between 501 and 874 mg/L, was higher than that expected from an immobilized biofilm process with high methane yield *(1,11,12)*. This could be attributed to the suspended sludge from the initial seeds remaining in the biofilter bed. This was also an indication that the recirculation rate of 3 L/h was insufficient for creating thorough mixing in the packed bed of the biofilter. This observation is consistent with a study on hydrodynamics in a similar biofilter system *(13)*, which showed that a recirculation rate equivalent to replacing the biofilter liquor 5 times/h was required to achieve thorough mixing.

Shock Loadings, Biofilter Failure, and Recovery

Changes in HRT from 10 to 5 d and from 3.5 to 1.5 d, without changing the organic strength of the feed, represented shock loadings equivalent to 100 and 230% increments in loadings, respectively. Response to these shock loadings was a temporary drop in COD removal efficiency, followed by a resumption of stable operation within 5 d. Anaerobic microbial ecosystems comprise several groups of interactive microorganisms that convert organic matter into methane and carbon dioxide *(8,14)*. When a shock loading was performed, it is believed that inhibition of one or more microbial groups caused a drop in COD removal efficiency. However, immobilization of the microorganisms as biofilms in the biofilter prevented a washout of the inhibited microorganisms. This allowed a new balance of microbial population to be re-established and resumption of operation, rendering the biofilter more tolerant to shock loadings.

The biofilter failed at 1 d of HRT. COD level in the treated effluent increased drastically and the biofilter could not attain stable performance (Fig. 2). Methane concentration and yield decreased, and the pH of the biofilter liquor dropped to 6.4, the lowest value observed. These observations indicated that the balance of the anaerobic bacterial population was temporarily upset, and intermediate volatile fatty acids accumulated, as indicated by the drop in pH, which resulted in "souring" of the biofilter.

The system was recovered 10 d later by increasing the HRT to 1.5 d. The COD removal efficiency gradually returned from 48% to a normal level within 15 days (Fig. 2). The stabilized COD removal efficiency of 85% was comparable to that before reducing the HRT to 1 d, indicating that the biofilter was fully recovered.

CONCLUSION

The biofilter packed with FECSs could be initiated within 300 d after seeding. The average COD and grease removal efficiencies were 85 and 53%, respectively, at 1.5 d of HRT. Immobilized biofilms enabled the biofilter to have stable treatment performance, and to recover easily from shock loadings and process failure.

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