Swim-bed Technology as an Innovative Attached-growth Process for High-rate Wastewater Treatment

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Abstract

Swim-bed technology using the novel acryl-fiber biomass carrier--biofringe (BF) attachment material--demonstrated effective treatment of high-strength organic wastewater with 80% COD removal efficiencies at high volumetric loadings up to 12 kg/m³/d with a hydraulic retention time of 3 h. BF material allowed for attachment of large amounts of biomass in a matrix that flexes with the wastewater flow, thus providing a high degree of contaminant-biomass contact in a fully retainable biofilm. As much as 133 g of biomass per meter of BF was retained for an equivalent 13.3 g/l with respect to the BF retention or reaction zone. Limited evidence for nitrification occurred only at low COD loading rates (ca. 1.6 kg/m³/d). In addition, filamentous biomass growth was very heavy at the lower loading rates, but was avoidable at COD loadings of 8 kg/m³/d or greater. The levels of extracellular polymers--proteins in particular--in the biofilm were very high compared to levels reported for flocculent or granular sludges. While treatment in this study focused on industrial level applications, the possibility of using this technology in other treatment scenarios involving lower organic loadings was discussed.

Key words: biofilm, acryl-fiber biomass carrier, biofringe (BF), industrial treatment, organic wastewater, filamentous biomass, extracellular polymers

INTRODUCTION

For aerobic wastewater treatment, fixed-bed attached-growth processes (biofilters) offer advantages over suspended-growth processes such as reduced sensitivity to toxicity, co-existence of aerobic and anoxic metabolic activities and compactness. Newly developed fluidized-bed (or moving-bed) attached-growth processes have further demonstrated elimination of head losses with absence of clogging and channeling, improved mass transfer and the potential for upgrading existing treatment plants without new construction1−4). In addition, Lazarova and Manem5) introduced the circulating floating-bed reactor using gas-lift technology, which demonstrated a synergy between hydrodynamic characteristics and biological treatment performance countering the negative influence of solid media hold-up that can occur in fluidized-bed processes.

In this paper, swim-bed technology involving the novel acryl-fiber biomass carrier--biofringe (BF)--is presented for high-rate treatment of organic wastewater. BF allows for attachment of large amounts of biomass on a flexible matrix in a fixed position. By
this approach, flexing of the matrix induced by wastewater flow creates a "swimming" motion that enhances mass transfer of nutrients to the attached growth (i.e., biofilm). Thus, the potential benefits of fluidized-bed reactors stated above are retained without dependence on hydrodynamic conditions to avoid settling or floating of the attachment medium and without the requirement of screens or traps to prevent washout. It is our hypothesis that using this method, high treatment efficiencies will be possible coupled with simple reactor design and uncomplicated operation.

The objective of this study is to investigate the treatment potential of BF process primarily with respect to the removal of organic carbon from wastewater. This objective was met by conducting loading-rate studies at various influent organic carbon concentrations and wastewater flow rates. In addition, the influence of wastewater velocity in the biomass retention matrix was investigated and the composition of extracellular polymers in the sludge was determined.

MATERIALS AND METHODS

Reactors and operational conditions

The two reactors used in this study were constructed of acryl resin, each having downdraft and updraft sections in a parallel upright arrangement as shown in Fig. 1. The mid-sized reactor had a cross-sectional plan with downdraft and updraft sections of 100 × 100 mm and 100 × 25 mm, respectively, and a height to effluent port of 630 mm for a total liquid volume of 7.7 l. The larger reactor had downdraft and updraft sections of 96 × 100 mm and 100 × 36 mm, respectively, and a height to effluent port of 1,640 mm for a liquid volume of 21.6 l. Both reactors had clear zones of approximately 70 mm at the bottom and 30 mm at the top (below and above the biofringe reaction zone in the downdraft section).

To each reactor, influent was introduced deeply within the updraft section using a peristaltic pump. Air was also introduced near the base of the updraft section, which served to mix and oxygenate the wastewater while circulating it through the reactor.

Tracer studies using polyvinyl alcohol beads (dia., 4 mm; s.g., 1.025; Kuraray Co., Ltd., Osaka, Japan) were used to establish a correlation between airflow rate (easily monitored using a gauge) and water flow velocity in the narrow updraft section, which was then used to estimate (by continuity) nominal average water velocities in the reaction zone of the downdraft section. Tracer studies using nitrate were conducted prior to biomass input to evaluate reactor flow behaviors. Even at relatively low airflow rates of 1 to 5 l/min (water velocities, ca. 5 to 10 cm/s), the breakthrough of continuous tracer input yielded Ct/Co values of 0.60 at the hydraulic retention time (HRT), indicating nearly complete-mix conditions (Ct/Co is 0.63 for complete mix, where Ct is the tracer concentration in the effluent at a select time and Co is the undiluted concentration of the input tracer6). Over most of the study, a small plastic shield was placed over the effluent port, the use of which resulted in a slight reduction of Ct/Co to about 0.5. The shield was not used during the final three weeks of operation for both reactors.

The influent solution consisted of a peptone and bonito fish-meat (extract Ehrlich)
mixture prepared as a stock solution at 40 and 60 g/l, respectively, and diluted in tap water to obtain planned influent concentrations. The 5-d biochemical oxygen demand (BOD) was 74% of the chemical oxygen demand (COD) for influent solutions. A buffer solution consisting of KHCO₃ was also added to a final concentration of 125 mg/l (62 mg CaCO₃/l alkalinity addition). The tap water used for mixing the influent was of groundwater origins and contained 19 mg Na⁺, 6 mg K⁺, 20 mg Ca²⁺, 7 mg Mg²⁺, 3 mg NO₃⁻, and 24 mg SO₄²⁻ per liter. The naturally occurring alkalinity was 70 mg CaCO₃/l (increased to ca. 130 mg CaCO₃/l with addition of the buffer) and total hardness was 70 mg CaCO₃/l. Influent pH for both reactors was near neutral throughout the study: 7.2 (s.d., 0.2) and 7.1 (s.d., 0.2) for the 7.7-l and 21.6-l reactors, respectively. Operation was conducted at room temperature (ca. 23°C) and relatively dark conditions were maintained (apart from sampling and inspection).

**Biomass seed and retention matrix** The reactors were initially seeded using activated sludge from a lab-scale fill-and-draw batch reactor. The synthetic medium used for the development and maintenance of the seed sludge was essentially the same as that used in this study.

The biomass retention matrix was a BF material composed of fringe yarns (dia., ca. 3 mm) attached to a support filament as shown in Fig. 2 and Fig. 3. The staple fiber of the fringe yarns was a hydrophilic acrylic composite. The material had a rough texture formed by bonding three threads with different heat resistances in a sinoidal pattern using a partial-melting process (NET Co., Ltd., Hyogo, Japan). The support filament for the 7.7-l reactor was 520 mm in length and contained 94 fringe yarns, each 100 mm in length. The support filament for the 21.6-l reactor was 1,540 mm in length and contained 245 fringe yarns, each 90 mm in length. The fringe yarns were symmetrically attached, extending equal distances beyond each side the support filament, and twisted to give an even 3-dimsional distribution.

**Extraction and analysis of extracellular polymers** Extraction of extracellular polymers from sludge was done by either the autoclaving method or the alkaline-washing method (below). For both methods, a 10-ml sample of sludge was collected and thick components were minced by tearing or cutting and then messed up to 100 ml in a glass beaker. For the autoclaving method, the sludge was autoclaved at 120°C for 30 min, which was determined by Bhatti et al. to be optimal with longer times resulting in lysis of cells, yielding erroneously high results including intracellular polymers. For the alkaline-washing method, the sample was messed up with tap water and a NaOH solution to a final NaOH concentration of 2 N (e.g., 67 ml of 3 N NaOH into 33 ml of diluted...
The sample was then mixed by gentle stirring (ca. 100 rpm) for 2 h prior to centrifuging at 3,000 \( \times \) g for 30 min. 50 ml of supernatant was then collected and mixed with 20 ml of water prior to adjusting the pH to a neutral value using 1 + 1 HCl, which was added slowly, with stirring, to avoid heating the sample. Finally, the extracted solution was mixed up to 100 ml with water.

In the extracted solutions, proteins were measured using the method of Lowry et al.\(^8\)) and carbohydrates by the method of Dubois et al.\(^9\)). Nucleic acids (combined RNA and DNA) were estimated by the UV absorption method of the Experimental Guidelines for Biotechnology\(^10\)) using the following equation:

\[
\text{Nucleic acids (g/l)} = 30.98A / (10,000 \cdot (0.09) b)
\]

where, 30.98 is the gram molecular weight of phosphorous, \(A\) is the absorbance of the sample solution at 260 nm, 10,000 is the constant of proportionality (absorbitivity) of phosphorous in nucleic-acid form (average of the RNA and DNA components), 0.09 is the weight fraction of phosphorous in nucleic acids and \(b\) is the absorbance light path (1.0 cm).

Other analytical methods Soluble COD was measured by the closed reflux colorimetric method according to Standard Methods\(^11\)), with prior centrifuging of effluent samples at 1,000 \( \times \) g for 15 min to remove undissolved components. BOD was measured using a respirometer (BOD Track; Hach Co., Ltd., Loveland, CO). The pH level was measured by the electrometric method using a pH meter (IM-22P; TOA Electronics, Ltd., Tokyo, Japan). Dissolved oxygen (DO) was measured using a DO meter (OM-51; Horiba, Ltd., Kyoto, Japan).

Ammonium (\(\text{NH}_4^+\)) was quantified by the phenate method of Kanda\(^12\)), with prior centrifugation of effluent samples at 1,000 \( \times \) g for 15 min. Nitrite (\(\text{NO}_2^-\)), nitrate (\(\text{NO}_3^-\)) and sulfate (\(\text{SO}_4^{2-}\)) ions were measured using an ion analyzer (IA-100 system; TOA Electronics, Ltd., Tokyo, Japan), with pretreatment by a 0.45-\(\mu\)m syringe filter for effluent samples. Total nitrogen (total-N) was determined by the persulfate method according to Standard Methods (4500-N\(\text{org}\))\(^11\)) with the digestion time extended to 60-min (which was found to be necessary to assure complete digestion of organic compounds). Effluent Total-N was determined on well-settled samples, thus not reflecting sludge-bound nitrogen (though not excluding the soluble organic component). By the persulfate method all nitrogen is oxidized to \(\text{NO}_3^-\), which was measured using the UV spectrophotometric screening method according to Standard Methods (4500-\(\text{NO}_3^-\)B)\(^11\)) (the use of an ion analyzer was ineffective due to interfering peak responses from compounds in the persulfate solution).

The suspended solids (SS) content was determined according to Standard Methods (2540 D)\(^11\)). The total sludge content was estimated as mixed-liquor suspended solids (MLSS) and biomass as mixed-liquor volatile suspended solids (MLVSS). For the determination of MLSS, a sludge sample of known volume was washed twice by centrifuging at 1,000 \( \times \) g for 15 min, decanting and resuspending in deionized water and then dried to a constant weight at 105\(\degree\)C (with cooling under desiccation). MLVSS and mineral (ash) contents of MLSS samples were determined following ignition at 550\(\degree\)C for 1 h.

**RESULTS AND DISCUSSION**

Reactor startup and biomass attachment

For startup of the 7.7-l reactor, 15.4 g of activated sludge was placed in the reactor with tap water for an initial total-sludge concentration of 2.0 g/l and airflow was set at 2 l/min for a circulation velocity through the biofringe reaction zone of 7 cm/sec. Attachment of sludge to the BF material (determined by the decrease of total sludge in solution) proceeded as shown in Fig. 4 and appeared to be asymptotically approaching a saturated condition following a one-day period. The attachment of 9.7 g of sludge during a 30-h period amounted to 18.6 g/m of biofringe support filament for the 7.7-l reactor. For the 21.6-l reactor, an initial total sludge concentration of 1.64 g/l was introduced with the same circulation conditions. Following 27 h, 13.0 g of sludge...
had attached, which amounted to only 8.4 g/m of support filament.

Following the sludge attachment periods, above, influent was started with an initial COD concentration of 700 mg/l and influent flow rates were set at 0.4 l/h and 0.8 l/h for the 7.7-l and 21.6-l reactors, respectively. During the first week, the airflow was maintained at a relatively low rate of 2 l/min and sludge solutions became clear within 2 d for the 7.7-l reactor and 4 d for the 21.6-l reactor as shown in Fig. 5. Following the first week, the reactors were considered acclimated and airflow rates were increased to 5 l/min and the influent flow rates were increased to 0.6 l/h and 1.7 l/h, for the 7.7-l and 21.6-l reactors, respectively, for a common HRT of 12 h.

**General treatment performance** The degradation of organic constituents in the 7.7-l and 21.6-l reactors was evaluated by COD removals as shown in Fig. 6 and Fig. 7, respectively. The COD removal rates for the 7.7-l reactor were very consistent during the first 40 d of operation. But, pronounced changes in the appearance of the biofilm and the amount of SS in the reactor occurred. On day 14, a heavy flocculent growth appeared, producing an SS of nearly 500 mg/l. The flocs consisted of large (3- to 5-mm diameter) snowflake-like particles that were very robust (not easily broken) and easily retained using a small plastic shield over the effluent port. By day 24, however, the floc content had greatly diminished and the attached growth became increasingly thick and pendulous. On day 32, a microscopic assay revealed an almost entirely filamentous growth with large numbers of protozoa and by day 40, the

![Fig. 4 Time course of total sludge attachment to the BF material in the 7.7-l reactor](image)

![Fig. 5 Activated sludge attached on BF material](image)

![Fig. 6 Time courses of influent and effluent COD concentrations and COD removal rate versus hydraulic retention time and water flow velocity in the BF zone for the 7.7-l reactor](image)

![Fig. 7 Time courses of influent and effluent COD concentrations and COD removal rate versus hydraulic retention time and water flow velocity in the BF zone for the 21.6-l reactor](image)
7.7-l reactor was nearly packed with sludge. On day 46, the BF material was withdrawn from the reactor and a 5.0-l settled-bed volume of thick slimy sludge was collected, which amounted to a total-sludge concentration of 12.2 g/l (biomass, 11.4 g/l) with respect to the reaction zone. Accounting for the original mass of attached sludge and SS lost in the effluent and a treatment efficiency of 80%, a rough estimate of 0.15 g biomass produced per g of COD removed (Yobs) is made, which with the organic substrate used in this study, would be about 0.2 g biomass/g BOD removed. The BF matrix, retaining only trace amounts of attached biomass, was then returned to the 7.7-l reactor and operation was resumed with twice the prior influent COD level in an effort to restrict growth of filamentous organisms and the water circulation velocity was doubled to prevent accumulation of excess sludge and favor selection of more strongly attaching biofilm. Within 8 d, the attached growth appeared to be at a normal level and testing was resumed (day 52, Fig. 6).

During a parallel period of operation, the 21.6-l reactor followed a similar pattern of performance with very consistent COD removal rates (Fig. 7). An early (day 12) microscopic assay revealed an abundance of protozoa with very little evidence of filamentous growth (as shown in Fig. 8). By day 14, a heavy flocculent growth (ca. 4 mm diameter snowflake-like particles) appeared, producing a SS in the reactor of 200 mg/l, which persisted for about 10 days. As with the other reactor, abatement of the floculent biomass was linked with the appearance of a thick slimy biofilm and a microscopic assay on day 25 showed an almost entirely filamentous growth, though with fewer protozoa. With the taller 21.6-l reactor, however, crowding due to sludge accumulation did not occur and the slimy filamentous biomass appeared to function well by flexing with the water flow and allowing for effective substrate-biomass contact, especially with the increase in circulation velocity from 15 to 20 cm/s on day 44 (Fig. 7).

With subsequent increases in COD loading rates, removal rates increased in a linear manner over the entire range of testing for both reactors as shown in Fig. 9. Removal efficiencies were consistent at approximately 80% up to the highest loading rates of 11 to 12 kg/m3/d (removal rates, 9 to 10 kg/m3/d) with HRTs of only 3 h, which is well within a range of high-rate industrial treatment applications. The rates obtained in this study range from three to ten times higher than those of a wide range of suspended growth (activated sludge) process modifications. Only a high-rate aeration process with an MLSS of about 10 g/l can offer similar treatment performance; this, however, typically requires a high return flow-to-plant flow ratio of up to 5.

Following day 60 the SS contents of both reactors again increased with appearance of
extremely high flocculent SS levels surpassing 1,000 mg/l; thus, on day 70 the shields over the effluent ports were removed and the water circulation velocities were again increased. A free flow of suspended solids through the reactors was thus allowed and the reactor SS and effluent SS levels were both about 200 mg/l for the remainder of the study.

At the end of the study, microscopic assays revealed a biomass with very few protozoa and only a few pockets of relatively short-stranded filamentous growth in both reactors. These results suggested that filamentous growth was avoidable at the higher loading rates of 8 kg/m$^3$/d or greater. A total sludge volume of 5.5 l was collected from the 7.7-l reactor, which was corroborative of the amount collected when this reactor was previously emptied. The total biomass retrieved had a dry weight of 69.0 g (ash, 6.3%), which amounts to 133 g/m of BF support filament or 13.3 g/l with respect to the reaction zone of the 7.7-l reactor. From the 21.6-l reactor, a 15.0-l bed of sludge was collected with a total biomass of 175.8 g (ash, 6.2%), which is 114 g/m of BF support filament or 11.4 g/l with respect to the reaction zone.

The narrow, constricting configurations of the reactors used in this preliminary investigation, though, were not suitable to thoroughly evaluate potential treatment applications. BF elements spaced evenly in an activated sludge basin would consistently have maximized substrate-biomass contact due to unhindered flexing action and be able to obtain (and maintain) a steady-state equilibrium between the sessile and planktonic phenotypes. Yu et al.\textsuperscript{14} demonstrated that non-attached biomass plays a larger treatment role than its portion of the total reactor biomass (including attached growth) would account for; thus, with a less restraining process configuration the potential for additional treatment benefit from suspended biomass is considered. In addition, with lower organic loadings, as common with domestic activated sludge systems, filamentous biofilm (if it occurs) may not be a drawback in a treatment system with a predominantly attached-growth process that retains suspended sludge by membrane filtration rather than sedimentation. These and other applications are avenues of further study.

Nitrogen transformations

Summaries of nitrogenous compounds across the 7.7-l and 21.6-l reactors are shown in Tables 1 and 2, respectively. Total-N was not determined for the sampling events with low COD loadings; however, by calculation, the influent total-N concentrations can be estimated to be about 70 mg N/l in those cases. The low levels of oxidized nitrogen (NO$_2^-$ + NO$_3^-$) in the influent were due to NO$_3^-$ in the tap water used for mixing influent solutions. Evidence of nitrification activity only occurred under low COD loadings (1.6 kg/m$^3$/d or less) and NO$_2^-$ was the predominant form of oxidized nitrogen. During the periods of high COD loadings when oxidized nitrogen did not accumulate in the effluents, the DO levels were 7.2 (s.d., 0.7) mg/l and 6.8 (s.d., 0.5) mg/l in the 7.7-l and 21.6-l reactors, respectively, indicating that enhanced activity of heterotrophic organisms was inhibiting nitrification rather than oxygen limitation. Effluent total-N concentrations were about 25% below influent levels, which could partially reflect nitrogen losses from denitrification (via cycling in aerobic and anoxic zones of the biofilm). However, these nitrogen losses would more likely be due to cell assimilation considering the lack of evidence for nitrification.
Table 1 Nitrogen components in influent and effluent solutions for the 7.7-l reactor with respect to influent COD concentration and loading rate

<table>
<thead>
<tr>
<th>Influent COD (mg/l)</th>
<th>COD load (kg/m³/d)</th>
<th>Influent (mg N/l)</th>
<th>Effluent (mg N/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total-N</td>
<td>NH₄⁺</td>
</tr>
<tr>
<td>680</td>
<td>1.4</td>
<td>-</td>
<td>1.2</td>
</tr>
<tr>
<td>640</td>
<td>1.3</td>
<td>-</td>
<td>8.8</td>
</tr>
<tr>
<td>690</td>
<td>1.4</td>
<td>-</td>
<td>5.7</td>
</tr>
<tr>
<td>780</td>
<td>1.5</td>
<td>-</td>
<td>1.3</td>
</tr>
<tr>
<td>1570</td>
<td>6.7</td>
<td>154</td>
<td>21.5</td>
</tr>
<tr>
<td>1580</td>
<td>6.8</td>
<td>134</td>
<td>82.4</td>
</tr>
</tbody>
</table>

a) Total-N represents combined NO₃⁻, NO₂⁻, NH₄⁺ and soluble organic-bound forms of nitrogen, but not biomass (see text). Analyses were not performed on relatively early term samples with low COD loadings; however, the influent values can be estimated to be ca. 70 mg N/l.

Table 2 Nitrogen components in influent and effluent solutions for the 21.6-l reactor with respect to influent COD concentration and loading rate

<table>
<thead>
<tr>
<th>Influent COD (mg/l)</th>
<th>COD load (kg/m³/d)</th>
<th>Influent (mg N/l)</th>
<th>Effluent (mg N/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total-N</td>
<td>NH₄⁺</td>
</tr>
<tr>
<td>730</td>
<td>1.5</td>
<td>-</td>
<td>2.2</td>
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<tr>
<td>740</td>
<td>1.5</td>
<td>-</td>
<td>1.4</td>
</tr>
<tr>
<td>740</td>
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<td>-</td>
<td>2.0</td>
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<td>800</td>
<td>1.6</td>
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<td>750</td>
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<td>20.4</td>
</tr>
<tr>
<td>1580</td>
<td>6.3</td>
<td>134</td>
<td>82.4</td>
</tr>
</tbody>
</table>

a) See footnote with Table 1.

Characterization of extracellular polymers

Extractions of extracellular polymers from biofilms of relatively early term, extremely filamentous growths and late term, non-filamentous growths were performed and analyzed for nucleic acids, carbohydrates and proteins. As shown in Table 3, the results were very consistent for the early term, filamentous samples analyzed by different methods and also for the late term, non-filamentous samples drawn from different reactors. While carbohydrates did not change significantly among all the samples, nucleic acids and proteins were considerably higher for the late term, non-filamentous samples. Because the 7.7-l reactor had been cleaned and restarted mid-way through the study (following day 47), the time of enrichment or maturation of the sludges would not be the reason for the noted observations; thus, it appears that levels of nucleic acids and proteins can serve as indicators of the different types of growths dominating in the biofilms, i.e., nucleic acids and proteins in non-filamentous sludge (ca., 13% and 50%, respectively) being about twice that in filamentous sludge (ca., 7% and 35%, respectively).

Extracellular polymers are known to exist in most biologically active environments and to aid in microbial aggregation and adhesion as with the attached growth on the flexible biofringe matrix. The total extracellular polymers in the attached growth of this study (46% to 73%, Table 3) are considerably higher than reported values of 10 to 24% for anaerobic granular sludges, 7.8% for a denitrifying granular sludge, and 1% to 10% for various activated sludges. However, the protein contents reported here for the filamentous samples are comparable to a range of 25% to 35% reported for extracellular polymers of an attached growth in a circulating floating-bed reactor.

Thus, it appears that these relatively higher levels of extracellular polymers—proteins in
Table 3 Compositions of extracellular polymers in biofilm samples. All values are reported as percent (% of dry biomass (i.e., MLVSS). Ash contents were approximately 6% for all samples

<table>
<thead>
<tr>
<th>Extraction method</th>
<th>7.7-l reactor, day 47 (filamentous)</th>
<th>7.7-l reactor, day 47 (filamentous)</th>
<th>21.6-l reactor, day 94 (non-filamentous)</th>
<th>7.7-l reactor, day 96 (non-filamentous)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nucleic acids</td>
<td>Autoclaving 6.7</td>
<td>Alkaline-washing 7.7</td>
<td>Alkaline-washing 13.3</td>
<td>Alkaline-washing 12.1</td>
</tr>
<tr>
<td>Carbohydrates</td>
<td>Autoclaving 8.5</td>
<td>Alkaline-washing 9.0</td>
<td>Alkaline-washing 10.1</td>
<td>Alkaline-washing 9.5</td>
</tr>
<tr>
<td>Proteins</td>
<td>Autoclaving 30.8</td>
<td>Alkaline-washing 35.3</td>
<td>Alkaline-washing 50.3</td>
<td>Alkaline-washing 48.8</td>
</tr>
<tr>
<td>Total</td>
<td>46.0</td>
<td>52.0</td>
<td>73.7</td>
<td>70.4</td>
</tr>
</tbody>
</table>

a) The 7.7-l reactor had been opened and cleaned and restarted on day 47, thus a 49-d growth period is represented here.

particular—are characteristic of biofilms (i.e., growth on an attachment medium) as compared to flocculent or granular sludges.

SUMMARY AND CONCLUSIONS

Swim-bed technology using the novel BF material as an attachment matrix for biofilm growth was evaluated as a treatment method for high-strength organic wastewater. Assays were conducted using two reactors with different heights and volumes, from which the following conclusions are drawn:

1. The BF material allowed for attachment of large amounts of biomass in a matrix that flexes with the wastewater flow, thus providing a high degree of contaminant-biomass contact with a fully retainable biofilm while avoiding the hydrodynamic difficulties associated with a floating-bed media. As much as 133 g of biomass per meter of BF support matrix was retained or 13.3 g/l with respect to the BF retention (reaction) zone.

2. Effective treatment of organic wastewater with 80% COD removal efficiencies at volumetric loadings up to 12 kg/m³/d and hydraulic retention times as low as 3 h were obtained, which is within a range of industrial treatment applications.

3. Limited evidence for nitrification occurred only at low COD loading rates (1.6 kg/m³/d or lower).

4. Filamentous growth was very heavy at the lower loading rates, but was avoidable at COD loading rates of 8 kg/m³/d or greater. Apart from difficulties associated with the narrow reactor configuration used in this study, it appeared that filamentous growth is not necessarily undesirable for this process and its occurrence did not impact treatment efficiency.

5. A very low biomass yield of approximately 0.15 g per g COD removed was observed.

6. Characterization of extracellular polymers in the biofilms revealed that nucleic acid and protein levels in non-filamentous sludge (ca., 13% and 50%, respectively) were about twice as high as in filamentous sludge (ca., 7% and 35%, respectively). In addition, the levels of total extracellular polymers in the biofilm of this study (46% to 73%) were considerably higher than that of flocculent and granular sludges reported in the literature.

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REFERENCE


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