Control of bulking sludge caused by Type 021 N and Type 0961 in an industrial wastewater treatment plant with an aerobic selector

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Abstract
Over a period of 6 months, pilot plant investigations were carried out with the purpose of bulking sludge control with different aerobic selectors. The wastewater was dominated by industrial dischargers, containing volatile fatty acids up to 450 mg/l. With complete-mix-selectors it was not possible to achieve a stable SVI below 150 ml/g. The bulking sludge could only be controlled with a sectionalized selector (HRT 5–8 minutes per section). The SVI decreased to values below 100 ml/g. Shock-loads and increased VFA-concentrations (by dosing NaC2H3OO) did not cause filamentous growth.

Keywords Aerobic selector; bulking sludge; sectionalized selector; Type 021 N; Type 0961

Introduction
Over a period of seven months, research on bulking sludge prevention and control was carried out at a municipal wastewater treatment plant (WWTP) in Germany (250,000 population equivalents) with high industrial COD-load (70%). The activated sludge of this WWTP suffered regularly from bulking sludge caused by Type 021 N. The WWTP is dimensioned only for C-elimination. The causes for the bad settling ability of the activated sludge were considered to be:
- a suboptimal BOD:N:P ratio
- a high concentration of easy degradable COD (up to 450 mg/l acetic acid)
- fluctuating BOD loads.

Methods
On-site pilot plant investigations with aerobic selectors were carried out. The flow sheet of the pilot plant is shown in Figure 1. The selector was only charged with the industrial wastewater from the equalisation tanks and the return sludge (0.7 Q), whereas the municipal wastewater was led into the aeration tank (0.3 m³). The sludge loading was about 0.2 kg COD/kg MLSS/d.

Four different selectors were tested. At first, complete-mix selectors with different volumes were tested (4, 6, 10 litres). The mean hydraulic retention time (HRT) in the selector was between 10 and 40 minutes. Moreover, a sectionalized selector (3 sections, 2 litres of volume/section) was used in the last period of the investigations. The mean contact time in this selector was 15 to 24 minutes (5–8 minutes per section).

The pilot plant was started up with activated sludge from the WWTP. The experiments are divided into four periods. In the first three periods, the complete-mix selector was used. In the final period, the selector was sectionalized into three chambers.

Results and discussion

Complete mix selector; HRT 20 minutes
The dominant species in the activated sludge from the WWTP was Type 021 N. The SVI was about 120 ml/g (Figure 2); the sludge quality, however, was poor. On a filaments
abundancy scale from 1 to 7 (1 = almost no filaments, 7 = only filaments), the abundancy of Type 021 N lay between 4 and 5 (Figure 3). After 20 days, the SVI slowly rose. On Day 30, nitrogen (urea) was added to the industrial wastewater, to make sure that the growth of the filaments was not caused by lack of nitrogen. The effect was a more rapid rise of the SVI up to 750 ml/g (Figure 2)! After 4 weeks of experiments, suddenly a new filament, Type 0961, was discovered in the activated sludge of the pilot plant. Type 021 N and Type 0961 were the dominant species in the activated sludge. No extra nitrogen was added to the wastewater after Day 40.

**Complete mix selector; HRT 40 minutes**

New sludge from the WWTP was added to the pilot plant. At a HRT of 40 minutes, the SVI went up to almost 350 ml/g, also caused by lack of oxygen in the selector due to technical problems with the compressor. After that, the SVI stabilised at low values below 100. However, from Day 80 onwards the SVI slowly rose up to 200 ml/g, caused by the simultaneous growth of Type 021 N and Type 0961. The low abundancy of these filaments from Day 65 to 80 was most probably caused by changes in the influent, because in the WWTP itself also low filament abundancy was observed.

**Complete mix selector; HRT 15 minutes**

The HRT then was lowered to 15 minutes. The SVI lay between 150 and 250, the dominant filament was Type 0961. Bulking sludge due to Type 0961 could not safely be controlled.
Sectionalized selector; HRT 15–25 minutes

Because of the unsatisfying results with the complete-mix selector, a new selector with three sections was installed. The overall HRT at the beginning of this period was 25 minutes. The SVI immediately went down to stable values around 100 ml/g. The abundance of both Type 021 N and 0961 decreased to 2, which is a value representing good sludge quality.

In order to test the stability of the system with a sectionalized selector, 4 test periods were carried out. In Phase 4b, the influent flow (industrial wastewater) was increased (50%). In Phase 4c, the HRT was lowered to 18 minutes by increasing the return sludge flow. In Phase 4d, the concentration of acetic acid was increased by at least 100% (HRT still 18 minutes), and in the last period 4e the HRT was lowered to 15 minutes (further increase of the return sludge flow) with the same addition of acetic acid as in 4d. The results are obvious (Figure 2): the SVI eventually decreased further to 80 ml/g. Instead of an increase in filaments abundance, a further decrease was observed. Finally Type 0961 disappears, Type 021 N is observed in a very low abundancy (Figure 3). In Period 4, no extra nitrogen was added. Moreover, from time to time a nitrogen deficit was calculated, which had no effect on filament abundance.

COD-elimination in the selector

The COD-elimination rate of the sludge was normally stable between 0.05 and 0.15 g COD/g MLSS/h (Figure 4). The operation of the selector had no influence on this rate. The sludge from the WWTP showed the same COD-elimination rate. The sludge from the selector system did not develop any higher rates. Only in the first period of operation at HRT 20 minutes did the COD-elimination rate go up to 0.3 kg COD/kg MLSS/h. This was caused

**Figure 3** Frequency of occurrence of 2 filamentous organisms

**Figure 4** COD-elimination rates
by clogging of biomass onto the aerators in the selector. The elimination rate was calculated with the measured MLSS in the selector, which was an underestimation due to the high amount of biomass on the aerators in the selector. After regular cleaning of the aerators, the calculated elimination rate decreased to normal levels.

Several authors investigated the use of selectors. In Table 1, results of other selector-systems are shown. The complete-mix-selectors are not able to control bulking sludge, as can be seen from Table 1. Only van Niekerk (1987) could control bulking sludge for about 50 days with 16 minutes retention time in the selector. The concentration of VFA (volatile fatty acids) in the influent however was more or less constant. At a shorter HRT (8 minutes) the selector couldn’t control the growth of Type 021 N.

Chudoba could not control bulking sludge with a sectionalized selector with 15 minutes retention time per section. Only with 5 sections and 9 minutes HRT the filamentous microorganisms disappeared. All other sectionalized selectors listed in Table 1 did control bulking sludge. The retention time per section varied from 1.5 to 9 minutes.

The question is why the sectionalized selectors can control bulking sludge when the hydraulic retention time per section is small. The COD removal rate in a selector is high. For Type 021 N and Type 0961, the substrate is VFA. In this case, the uptake rate for VFA is important. In a complete mix selector, the HRT mostly is longer than 10 minutes. In this case, the concentration of VFA in the bulk of the selector will be small due to the high uptake rate. This concentration balance determines the growth rate (Monod-kinetics) of filamentous organisms like Type 021 N and flock-forming microorganisms. This concentration can be calculated when the half-saturation constant for the substrate (VFA) for both organisms is known as well as their maximum growth rate. For example with $k_s = 1.5 \text{ mg/l}$ and $\mu_{max} = 5 / \text{d}$ for an assumed floc-former and $K_S = 0.5 \text{ mg/l}$ and $\mu_{max} = 4 / \text{d}$ for Type 021 N, the concentration above which the floc-former can yield a higher growth rate is 5 mg/l.

Measurements of VFA in the complete mix selector of our investigations show that this concentration was $< 1 \text{ mg/l}$ most of the time, even at a HRT of only 15 minutes. The uptake rate of VFA is so high that in such a short time almost all VFA is eliminated. Only in selectors with a HRT $< 15$ minutes can the needed VFA-concentration be achieved. As the VFA-concentration in the influent can strongly vary, bulking sludge control can only be effective with a sectionalized selector with a short HRT per section. In case of low influent VFA concentrations, the concentration balance in the complete mix (dimensioned for a mean loading of VFA) selector is too small for maximum growth rates of the floc-forming bacteria. At high influent VFA concentrations, too much VFA is leaving the selector, which causes also bulking sludge due to growth of filaments in the aeration tank.

In a sectionalized selector at low influent VFA concentrations, only the first section is needed to eliminate the VFA at maximum growth rates of the floc-forming microorganisms. A high enough concentration in this section can be achieved also at low influent

<table>
<thead>
<tr>
<th>Author</th>
<th>Fil. organism</th>
<th>Selector type</th>
<th>HRT (min)</th>
<th>SVI without selector</th>
<th>SVI with selector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chudoba et al. (1973)</td>
<td>S. natans</td>
<td>sectionalized (3)</td>
<td>45</td>
<td>50-770</td>
<td>50-300</td>
</tr>
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<td>Chudoba et al. (1973)</td>
<td>S. natans</td>
<td>sectionalized (5)</td>
<td>45</td>
<td>50-770</td>
<td>50-75</td>
</tr>
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<td>van Niekerk et al. (1987b)</td>
<td>Type 021 N</td>
<td>sectionalized (6)</td>
<td>4-20</td>
<td>75-110</td>
<td>70-110</td>
</tr>
<tr>
<td>Linné (1989)</td>
<td>Type 021 N</td>
<td>sectionalized (6)</td>
<td>4-20</td>
<td>75-110</td>
<td>70-110</td>
</tr>
<tr>
<td>Rensink and Donker (1991)</td>
<td>S. natans</td>
<td>complete mix</td>
<td>13</td>
<td>120-650</td>
<td>100-600</td>
</tr>
<tr>
<td>Rensink and Donker (1991)</td>
<td>S. natans</td>
<td>sectionalized (8)</td>
<td>8-10</td>
<td>90-400</td>
<td>90-300</td>
</tr>
<tr>
<td>Prendl (1997)</td>
<td>Type 021 N</td>
<td>sectionalized (4)</td>
<td>16-20</td>
<td>–</td>
<td>50-90</td>
</tr>
</tbody>
</table>
concentrations. At higher VFA concentrations, the next sections are needed. In these sections also optimal VFA concentrations are achieved.

Conclusions
The results of the pilot plant investigations with complete mix and sectionalized selectors show that only a sectionalized selector with short HRT per section (about 5 minutes) could control bulking sludge. The HRT in the complete mix selectors was too high, therefore the VFA concentration in the selector was too low to support the growth of floc-forming microorganisms. From this point of view, the HRT per section should be as short as possible and the number of sections should be at least 3. The more sections, the better the selector can cope with strongly varying influent VFA concentrations. The minimum HRT for the whole selector can be calculated when the VFA uptake rate and the VFA load to the WWTP are known (Prendl, 1997). VFA measurements with three different sludges showed that this rate varied between 0.1 and 0.2 kg VFA-COD/kg MLSS/h. Prendl (1997), however, achieved much higher rates with wastewater from a sugar refinery. He recommends a COD uptake rate of 0.2 kg/kg MLSS/h in case the rates are not known.

References