Sewage-treatment under substantial load variations in winter tourism areas – a full case study

S. Winkler, N. Matsché, T. Gamperer* and M. Dum**

Institute of Water Quality and Waste Management, Vienna University of Technology, A – 1040 Vienna, Karlsplatz 13/E 226, Austria (E-mail: swinkler@iwag.tuwien.ac.at)

* VA Tech WABAG GmbH, A – 1210 Vienna, Siemensstrasse 89, Austria (E-mail: Thomas.Gamperer@vienna.wabag.com)

** Reinhalteverband Pinzgauer Saalachtal, A – 5760 Saalfelden, Postfach 131, Austria (E-mail: rhv.saalfelden@aon.at)

Abstract The sewage-load variations in winter tourism areas are characterized by sudden increases – in the range of a factor two to three – within only a few days at the start and the end of the tourist season, especially at Christmas. The sudden load increases occur during periods of low wastewater temperatures, which is an additional demanding factor with respect to nitrogen removal.

A full case study was carried out at WWTP Saalfelden, which is located near one of Austria’s largest skiing resorts. The plant is designed for 80,000 PE and built according to the HYBRID®-concept, which is a special two stage activated sludge process for extensive nutrient removal.

Keywords Hybrid®-concept; nutrient removal; plant extension; seasonal load variations; sludge volume index; two stage activated sludge plants

Introduction

Particularities of WWTP’s in winter tourism areas

Wastewater treatment in winter tourism areas is a challenging task since sudden load increases – in the range of double to triple of the median load of the non-tourism season – are combined with low wastewater temperatures. These two boundary conditions are especially critical for the nitrification process. The growth rate of nitrifiers at a temperature of 8°C is only 0.25 d⁻¹, which means that even under optimum growth conditions the nitrifying population would only grow by approximately 20% per day considering autotrophic decay. Of course, such optimum growth conditions cannot be maintained within the entire aeration tank, subsequently there is simply no operational means to increase the nitrifying population to the increased load demands within the time span it actually occurs.

Instead, operational precautions have to be taken in order to maximise the nitrifying population well in advance of the occurrence of the load step change. The nitrification capacity of an activated sludge system is mainly determined by the nitrified load over the course of the SRT. Basically two measures can be taken: first, to operate the plant at maximum nitrification in the period before the load increase; second, to manage ammonium sources if possible – i.e. storage of sludge dewatering filtrate water – and controlled dosing of the stored high ammonium load water over one SRT before the load increase.

The specific load situation has to be considered already in the plant design phase. Conventional single stage plants do not seem to be the most appropriate solution, since they need to be built very large to be able to handle the increased load, which corresponds to aeration tank over capacities during the low loaded season.

Two stage plants can be considered a better choice for such load characteristics, but conventional two stage plants often encounter problems due to an insufficient substrate supply to the nitrifying stage for denitrification. Designing the plant for nitrification only during
the high load season can lead to alkalinity related nitrification inhibition due to low buffer
capacity of the wastewater – which is the case in some of the main skiing regions in Austria.

A possible solution can be found in a special two stage concept – the Hybrid®-concept –
which combines some of the advantages of single and two stage activated plants.

**Case study: WWTP Saalfelden**

WWTP Saalfelden was put into operation in 1986 with a capacity of 50,000 PE serving the
communities of Saalfelden, Maria Alm, Maishofen and Leogang. The plant load is charac-
terized by substantial variations over the course of the year due to winter skiing tourism.
Especially around Christmas and New Year and later in February the load to the plant
almost doubles within a few days, at times when the temperature in the aeration tanks is
usually in the range of 8–10°C. Another characteristic is that during snow melting season,
the influent temperature can drop significantly to a minimum of 6°C.

The initial plant was designed for carbon removal and included a mechanical pre-treat-
ment stage, primary clarification, aeration tanks and circular secondary clarifiers. For
sludge treatment a sludge digestion stage was installed.

Due to new legislation issued in 1991 – requiring nutrient removal – and load increases
an extension of the plant became necessary. Initially, a single stage activated sludge plant
for nutrient removal with a capacity of 50,000 PE was envisaged. Due to the inclusion of a
dairy factory a capacity increase to 80,000 PE was needed, which initiated a re-design of
the initial planning. As it turned out, with the Hybrid®-concept the capacity increase could
be accommodated with almost the same volumes as planned for the 50,000 PE single stage
plant. Additionally, the entire existing plant was integrated into the extension concept.

Table 1 gives the design load and effluent requirements for the extension of WWTP
Saalfelden.

**The Hybrid®-concept**

The Hybrid®-concept is a patented two stage activated sludge process which combines the
advantages of single and two stage activated sludge plants achieving extensive nutrient
removal. The main advantages of the concept are the small space demand, the robustness
against substantial load variations, great operational flexibility and the great potential of
integrating existing plant structures into an extension concept in case of upgrading to nutri-
tent removal is required.

In Austria, several treatment plants are operated with the Hybrid®-concept, currently the
largest operated plant is WWTP Saalfelden, which has a capacity of 80,000 PE. In 2005 the
central Vienna WWTP will start its operation, which is designed for 4 million PE.

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**Table 1** Design load (top) and effluent requirements (bottom) of WWTP Saalfelden

<table>
<thead>
<tr>
<th>Design load m³/d</th>
<th>16,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum wet weather flow m³/h</td>
<td>1,800</td>
</tr>
<tr>
<td>BOD₅ load kg/d</td>
<td>4,800</td>
</tr>
<tr>
<td>Total nitrogen load kg/d</td>
<td>880</td>
</tr>
<tr>
<td>Total phosphorus load kg/d</td>
<td>160</td>
</tr>
<tr>
<td>Design temperature °C</td>
<td>8</td>
</tr>
<tr>
<td>BOD₅ concentration mg/l</td>
<td>15</td>
</tr>
<tr>
<td>BOD₅ removal %</td>
<td>95%</td>
</tr>
<tr>
<td>COD concentration mg/l</td>
<td>75</td>
</tr>
<tr>
<td>COD removal %</td>
<td>85%</td>
</tr>
<tr>
<td>NH₄-N concentration mg/l</td>
<td>5</td>
</tr>
<tr>
<td>Total nitrogen removal %</td>
<td>70%</td>
</tr>
<tr>
<td>Total phosphorus concentration mg/l</td>
<td>1</td>
</tr>
</tbody>
</table>

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The improved nutrient removal is achieved by a specific exchange of sludge between the two activated sludge stages. The first stage serves for carbon removal (volumetric load 3–5 kg \( \text{BOD}_5/\text{m}^3\text{d} \)) and is usually operated at a sludge retention time (SRT) below one day. In the first stage around 80% of the removed COD is withdrawn with the excess sludge, only 20% is removed by instant respiration. Subsequently, the excess sludge provides a good carbon source for a later sludge digestion and boosts biogas production while the energy demand for aeration in the first stage can be kept low.

The first stage removes around 85% of the incoming organic load, subsequently the nitrifying second stage can be built comparatively small. Additionally, the high loaded first stage has a great potential for buffering and equalisation of load increases resulting in only moderate load variations in the more sensitive nitrifying stage. Another advantage is that substances that might have a negative influence on the nitrifiers or the sludge properties of the low loaded second stage are largely removed or incorporated into the sludge in the first stage. Subsequently, they are not or far less effective in the second stage (Wandl et al., 2002).

The second stage is a low loaded stage for nitrification/denitrification operated at a SRT above ten days. For denitrification sludge from the first stage – the Hybrid®-sludge-line 1 – is transferred into the second stage for substrate supply. With the help of the Hybrid®-sludge-line 1 the organic load and subsequently the SRT of the second stage can be adjusted. Thus, the operational mode of the second stage can be adopted to the actual conditions by emphasizing nitrification (high SRT, low sludge transfer) or denitrification (high sludge transfer). By adjusting the Hybrid®-sludge-line 1 the low growth rates of the autotrophic bacteria have to be considered.

The excess sludge of the second stage is transferred into the first stage by means of the Hybrid®-sludge-line 2. With this, nitrifying sludge enters the first stage, which is operated at a SRT too short to maintain autotrophic bacteria. The transferred nitrifiers find optimum milieu conditions in the first stage which results in simultaneous nitrification/denitrification in the first stage. It can be estimated that the first stage yields about 40% of the total nitrogen removal capacity of the plant.

It has to be mentioned, that the two Hybrid®-sludge-lines do not impose a considerable hydraulic load, usually they are operated in a range of 3–5% of the influent flow. If these lines are shut off, the plant is operated as a classic two stage plant. In case the lines are operated at maximum, the two stage plant increasingly behaves like a single stage plant.

**Case study: WWTP Saalfelden – plant description**

The implementation of the Hybrid®-concept at WWTP Saalfelden allowed the continued use of the existing plant structures (Geyer, 2001):
The mechanical pre-treatment stage remained mainly unchanged, a second screen was installed into the bypass channel of the existing screen. For increasing the hydraulic capacity of the plant, of the existing primary clarification (3 parallel lines) only one tank remained in operation as primary clarifier, while the other two tanks are now used as storm water tanks. If the influent flow exceeds 1,440 m³/h the excess flow is diverted into the storm water tanks. After the rain event the stored storm water is pumped back into the main treatment line. In case of very long rain events the storm water tanks are operated in flow through mode, diluted waste water is then directly fed into the second stage.

The existing aeration tank (3 parallel lines) is now used as first stage aeration tank (2 of the existing tanks) and for treatment of high ammonium loaded sludge dewatering filtrate water (1 of the existing tanks), which is carried out in a sequencing batch reactor mode.

The existing circular settling tanks, previously used as final clarifiers, now serve as intermediate settling tanks.

For the second stage new aeration tanks and new final clarifiers had to be constructed. The aeration tanks were built as oxidation ditch type tanks with fine bubble aeration, with the blower building situated on top of the aeration tanks which contributes to efficient use of the available plant area.

For the final clarification initially circular type tanks were planned. Due to the high groundwater level and the unfavourable soil properties this would have resulted in complex construction conditions and considerable measures for securing the tanks against groundwater buoyancy.

After careful considerations, the final clarifiers have been constructed as rectangular vertical flow through type tanks, due to the following reasons:
- Approximately 6 m less foundation depth (compared to the central sludge hopper of a circular type tank)
- Less complex measures for securing the tanks against buoyancy
- Reduction of the total required area which allowed to locate the final clarification outside of the “restricted construction zone” which is imposed by a 110 kV-power line crossing the plant area.

The existing sludge digestion stage remains in operation, in an earlier construction phase the digesters were equipped with new mixers. The primary sludge is thickened in an existing sludge thickening tank and then fed to the digestion stage. For thickening of the excess sludge a new thickening station with sieve belts was constructed.

The digested sludge is post-thickened in an existing sludge thickening tank. In order to increase operational flexibility an additional sludge storage tank was built.

For sludge dewatering a screw press (Japanese patent by ISHIGAKI Co.) was installed, which essentially consists of a cylindrical sieve which contains a slowly rotating (1.5 rpm) conical screw. Operational results show that the manufacturer guarantee value of 29% dry substance can be achieved or even surpassed with a moderate consumption of approximately 8 kg poly-electrolyte/kg dry substance and a very low energy consumption of 2 kWh. The achieved dry substance content of the sludge cake is predominantly in the range of 30–35%.

One of the existing aeration tanks was reconstructed to accommodate two sequencing batch reactor type tanks, which are used for treatment of the digested sludge dewatering filtrate water. For enhancing the nitrifying population, excess sludge from the second stage (Hybrid®-sludge-line 2) can be dosed into the SBR-tanks. For improving the denitrification and pH-control, supernatant from the primary sludge thickening tanks or activated sludge from the first stage (Hybrid®-sludge-line 1) can be fed to the SBR-tanks.

Table 2 shows a comparison of the initial and extended plant structure with the two stage Hybrid®-concept. It has to be emphasised that a single stage design would have required a
total aeration tank volume of 16,000 m³. This would have necessitated the construction of an additional aeration tank volume of 13,000 m³, which is 84% more than the built volume for the second stage aeration tanks.

Operational results

Plant performance considering seasonal load variations

During the Christmas holiday season 2002 the plant performance was investigated. This period imposes the most critical conditions onto the plant since a low wastewater temperature is combined with a step change of the load, approximately by a factor two. Figure 2 shows the load – expressed in PE – to WWTP Saalfelden during the period of week 48/02 through week 02/03. The load increases significantly after Dec 24 with a peak value above 80,000 PE on Dec 28 which was the first Saturday after the Christmas, the main arrival day of the skiing tourists. The COD-related values are even higher due to the contribution of the dairy factory discharging to the plant. From the plant lab data a ratio of COD:BOD₅ of 1.7 in the raw wastewater can be derived, which is caused by the high portion of readily biodegradable organic matter from the dairy wastewater. Therefore a value of 110 g COD/(PE*d) was assumed which is 8% below the standard value according to ATV for domestic wastewater. An additional load peak was caused by heavy rainfalls on Dec 22/23 just before the start of the Christmas holiday period.

In Figure 3 the influent load is depicted relative to the median load calculated for the period 01 Sep 02 through 20 Dec 2002. For the last four weeks before the Christmas holiday period the load stays within a range of 25% of the median load. During the rainfalls on
22/23 Dec the hydraulic load increases significantly up to a peak value of 3.8 relative to the median load, while the organic and nitrogen load doubles.

At the Christmas holiday period the load remains in a range of 1.8–2.6 of the median load and starts to decrease after 04 Jan 03, which was the first Saturday after the holidays, the main departure day of the skiing tourists. Another interesting observation is that the relative COD-load is lower than the relative N-load during the entire Christmas holiday period, while it is higher or equal in the period before. It is assumed that a reduced production of the dairy factory between 24 Dec and 31 Dec caused this effect.

Figure 4 shows the nitrogen removal performance of the plant during a period of 7 weeks around Christmas. The temperature during this period was always below 12°C with a minimum value of 7°C during the rainfalls on 22/23 Dec. According to Austrian law only nitrification ($\text{NH}_4-N_{\text{eff}} \leq 5 \text{ mg/l}$) is required for the temperature range $8^\circ \text{C} \leq T < 12^\circ \text{C}$.

During the last three weeks before Christmas the nitrogen removal rate was always well above 70 %, which is the legal limit for temperatures above 12°C. During the wet weather period on 22/23 Dec the nitrogen removal rate decreased, but immediately recovered after

![Figure 2](https://iwaponline.com/wst/article-pdf/50/7/147/419549/147.pdf)

**Figure 2** Hydraulic, organic and nitrogen load expressed in PE of WWTP Saalfelden during the period of week 48/02 through week 02/03

![Figure 3](https://iwaponline.com/wst/article-pdf/50/7/147/419549/147.pdf)

**Figure 3** Hydraulic, organic and nitrogen load to WWTP Saalfelden depicted relative to the median load calculated for the period 01 Sep 02 through 20 Dec 2002
the hydraulic load returned to an average level. Another decline of the nitrogen removal rate was observed before 31 Dec which was due to the significantly increased nitrogen load to the plant and subsequently the increased demand for mainly aerobic operation of the aeration tanks.

Finally, during week 02/03 a decline of the nitrogen removal rate was observed due to the steady decline of temperature below 8°C. According to Austrian law no nitrogen removal and even no nitrification is required at these temperatures.

The nitrogen removal performance was very good during the whole Christmas holiday period and exceeded the legal requirements by far.

The nitrogen effluent concentrations as ammonium ($\text{NH}_4\text{N}_{\text{eff}}$), nitrate ($\text{NO}_3\text{N}_{\text{eff}}$) and organic nitrogen ($\text{N}_{\text{org/eff}}$) are shown in Figure 5. The $\text{NH}_4\text{N}$ effluent concentration was mostly below 2 mg/l, with the exception of the period in week 02/03 when the temperature in the second stage dropped below 7°C. The nitrate effluent concentration varied in a range of 2-16 mg/l depending on how much anoxic volume could be operated under the given load and temperature conditions. Finally, it is important to notice that the organic nitrogen

![Figure 4](https://iwaponline.com/wst/article-pdf/50/7/147/419549/147.pdf)

**Figure 4** Nitrogen removal rate and temperature in the aeration tank of the second stage (T II) of WWTP Saalfelden during the period of week 48/02 through week 02/03

![Figure 5](https://iwaponline.com/wst/article-pdf/50/7/147/419549/147.pdf)

**Figure 5** Nitrogen effluent concentrations and temperature in the aeration tank of the second stage (T II) of WWTP Saalfelden
Effluent concentration did not rise significantly during the wet weather period of 22/23 Dec which is an indication that no noteworthy increase of solids loss under high hydraulic load conditions occurred.

Performance of the final clarification and sludge volume index
As already mentioned, rectangular final clarifier tanks with vertical cross flow were erected during the extension of WWTP Saalfelden. The tanks are similar in construction to the final clarifier tanks of WWTP Zuerich-Werdmöhlzli in Switzerland (Siegrist et al., 1995). The incoming sludge is fed to the bottom layer of the tank into the sludge bed, which acts as a floc filter, subsequently very high values for the secci depth are achieved (Figure 6).

Considering that WWTP Saalfelden receives a substantial wastewater load from a dairy factory (approx. 15,000 PE/d) the sludge volume index (SVI) can be regarded as very good. In the shown period (Figure 6) the SVI of the first and second stage is very similar and increases slightly from around 75 ml/g to values of approximately 100 ml/g over a course of more than 4 months.

Figure 6 also confirms, that due to the elimination of most of the substances, which could have a negative impact on the sludge properties, already in the first stage, the sludge properties of the low loaded stage II are almost identical to stage I.

Conclusions
A full scale study at a WWTP (80,000 PE) located in one of Austria’s main skiing tourism areas has been carried out. It could be shown that a load increase up to a factor of 2.5 could be managed maintaining complete nitrification and nitrogen removal rates up to 80% at a wastewater temperature of 7–10°C. In the investigated period the conditions were even more demanding since heavy rainfalls occurred just before the start of the holiday season on 22/23 Dec. The results are a strong evidence that the two stage HYBRID®-concept is capable of buffering considerable load variations in the first stage minimizing the impact onto the low loaded nitrifying second stage while extensive nitrogen removal can be maintained. Further it was shown that bulking sludge did not occur at the investigated plant, even so it receives a dairy wastewater load of approximately 15,000 PE/d.
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References
