 © IWA Publishing 2008 Water Science & Technology—WST | 57.9 | 2008

Upgrading of wastewater treatment plants for nutrient removal under optimal use of existing structures

S. Winkler, M. Gasser, W. Schättle, D. Kremmel, P. Kletzmayr and N. Matsché

ABSTRACT

Upgrading of wastewater treatment plants under maximum use of existing structures is often an important requirement, but also useful due to a number of aspects. Because of a change in legal effluent requirements, a number of plants in Austria, typically aged 20+ years, were required to be extended. The two stage activated sludge HYBRID®-process often provides an interesting design alternative for such plant upgrades, especially in case an anaerobic sludge treatment stage already exists. It provides high nutrient removal capacity at low area demand. The latter is especially important in cases where no or very limited extension area is available making it the key factor to preserve a site for future use. Based on two full stage case studies the adaptation of the plant layout, first operation results and a synthetic cost comparison to a conventional (single stage) plant extension are given.

Key words | cost-efficiency, nutrient removal, sludge volume index, space limitation, two stage activated sludge process, WWTP extension

S. Winkler
N. Matsché
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*

M. Gasser
Rudhardt + Gasser—Ziviltechniker,
Felchenstraße 7, A-6904 Bregenz
Austria
E-mail: *m.gasser@rgzt.at*

W. Schättle
Wasserverband Region Hohenems,
Im Sand 10, A-6845 Hohenems,
Austria
E-mail: *wasserverband@arahohenems.at*

D. Kremmel
A. Plank-Bachselten Ziviltechniker GmbH,
Mariazellerstraße 1a, A-8605 Kapfenberg,
Austria
E-mail: *kremmel@apb-plank.at*

P. Kletzmayr
Abwasserverband Knittelfeld,
Reifersdorf 41, A-8720 Knittelfeld,
Austria
E-mail: *office@awv-knittelfeld.at*

INTRODUCTION

The erection of a wastewater treatment plants (WWTP) is a considerable effort for a municipality, not at least from a financial perspective. In case an adaptation or extension of an existing WWTP becomes necessary, it is often of high importance to maximise future utilisation of existing structures. Additionally, in some cases there is no or only very limited extension area available. Extension concepts which are capable to be integrated into existing structures provide a means to substantially improve the plant performance without the necessity of simultaneously enlarging the enclosed site area.

The HYBRID®-process (Winkler *et al.* 2004), is a special type of two stage activated sludge process including controlled exchange of biomass between both stages. It therefore combines advantages of single- and two-stage plants providing high nutrient removal efficiency at low volume demand. The process has been applied for the extensions of WWTP Hohenems and WWTP Knittelfeld; in the following the two plant extension projects are described in detail.

Case study 1: WWTP Hohenems

WWTP Hohenems was constructed in the years 1979–1981; at that time for carbon and phosphorous removal–the latter because of its location within the basin of Lake Constance.

doi: 10.2166/wst.2008.226

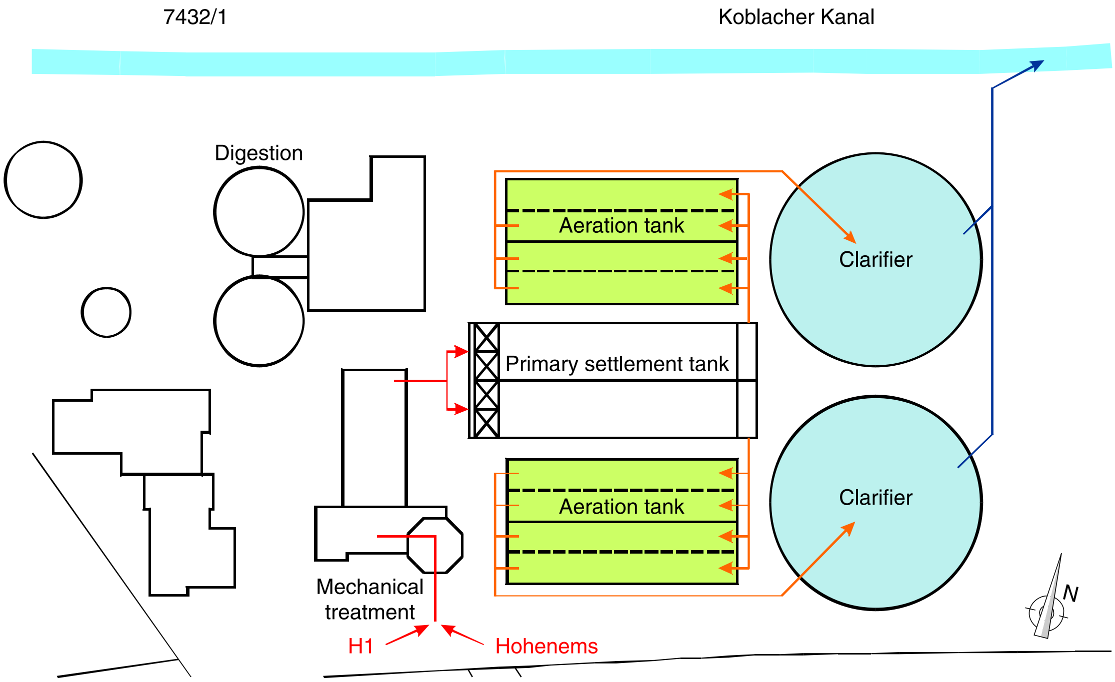

Figure 1 | Initial layout of WWTP Hohenems (1981).

The plant has been initially designed for 150,000 PE, of which two thirds were of industrial origin (mainly textile industries). Figure 1 shows the original plant layout of WWTP Hohenems (1981).

The plant scheme included a mechanical stage comprising of a screening station, aerated grit chamber and primary sedimentation (HRT $= 3$ h). The biological stage included two rectangular aeration tanks, each divided into two parallel lines operated with step-feed. Because of severe bulking problems the aeration tanks were later adapted to include aerobic selector tanks; the feeding regime was changed to head end feed. The final sedimentation tanks were built as circular tanks. All plant stages are designed in two parallel lines, which ensures redundancy during maintenance periods. Sludge treatment was carried out by anaerobic digestion and subsequent dewatering by means of a chamber filter press.

Due to stricter effluent requirements an extension of the plant for nitrogen removal became necessary. Initially, also a shutdown of the plant and a redirection of the sewage to a neighbouring plant were discussed; a detailed scenario analysis showed that this solution would have not been economical. After an evaluation of different design concepts for the plant extension, a two-stage activated sludge plant according to the HYBRID®-process was chosen as the optimum solution. Applying this concept, it was possible to adapt the plant performance to the new legal requirements without the necessity of erection of additional tanks–except one new tank for external nitrification of sludge liquor. Within this context it has to be emphasized, that at the site of WWTP Hohenems no extension area for construction of additional tanks was available.

Table 1 gives the design data and effluent limits applicable for the initial plant design (1977), operation data for the year 2002 and design data for the plant extension (2002).

For implementation of the two-stage activated sludge process the following main steps were taken.

- The grit chamber effluent is directly fed to the high loaded first stage aeration tanks.
- The hydraulic height between the existing grit chamber and the original primary clarifier tanks is utilised to accommodate the hydraulic losses of the first stage aeration tanks.
- Of the existing aeration tanks, a section of 25% was separated for use as the high load first stage.
- The water level of that part (stage 1) was increased by elevating the tank walls of that section.

Table 1 | Design data and effluent limits (1977 and 2002) and operation data (2002) of WWTP Hohenems

	Design data (1977)			Operation data (2002)			Design data (2002)		
Q_d [m^3/d]	24,000			17,355			24,000		
Q_{max} [l/s]	470			351†(−800‡)			600		
	Design load [kg/d]	Effluent imit [mg/l]	Removal efficiency [%]	Influent load [kg/d]	Effluent concentration [mg/l]	Removal efficiency [%]	Design load [kg/d]	Effluent limit [mg/l]	Removal efficiency [%]
BOD_5	9,000	15	93%	9,400	7	98%	10,300	15	95%
COD	12,000	60		20,800	36	96%	22,700	60	90%
TP		0.30	95%	258	0.24	97%	210	0.50	95%
NH_4-N							780	5§	
TN									70%‖

†yearly average.
‡maximum.
§at T > 8°C.
‖at T > 12°C.

- The existing primary clarifier tanks were rededicated to intermediate clarifier tanks. An additional return sludge pumping station for the first activated sludge stage was installed.
- The remaining part of the existing aeration tank was used as low loaded second stage for nitrification and denitrification. No changes of the water level were applied for this section.
- In both aeration tank sections, the dividing walls for the parallel lines were removed and new diversion walls were erected to achieve a cascade structure.
- No changes were necessary for the existing final clarifiers. They are now used as clarification for the second stage; the V-notch weir was replaced by perforated submerged effluent pipes.
- New blower stations were erected on top of the first stage aeration tanks.
- A cylindrical tower (440 m^3) was erected as external nitrification stage for the sludge dewatering filtrate.

Figure 2 shows the new plant layout after adaptation according to the HYBRID®-process. All plant stages remain as two parallel lines; hence the redundancy concept was preserved. This was also essential during the construction phase of the plant extension.

Case study 2: WWTP Knittelfeld

WWTP Knittelfeld has been operated since 1983 including carbon removal and anaerobic sludge digestion. Figure 3 shows the original plant layout.

For the plant extension, one line of the existing primary clarification was rededicated for treatment of sludge dewatering supernatant; the remaining line of the primary clarification has now a HRT = 50 min (at Q_{DW_MAX}). One line of the existing final clarification is now used to accommodate the first stage aeration tank; the remaining two lines are now used as intermediate clarification. An intermediate pumping station was installed to lift the primary clarifier effluent into the first stage aeration tank ($H = 3.1$ m).

The existing aeration tank is now used as second stage aeration tank. A new final clarification stage was erected (vertical flow type tank with suction scrapers, Siegrist *et al.* (1995)). Due to the very high ground water level at the WWTP site, it was decided to install another new pumping station to lift the second stage aeration tank effluent into the

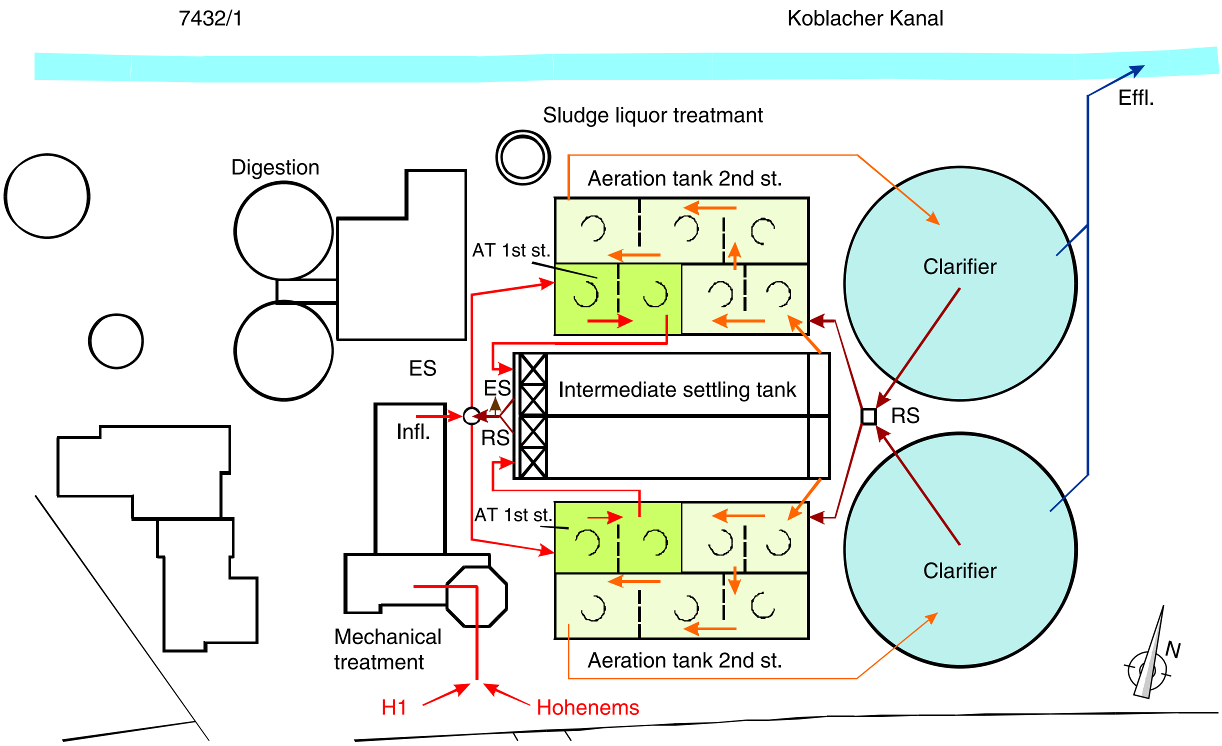

Figure 2 | New layout of WWTP Hohenems as two stage activated sludge plant according to the HYBRID®-process.

new final clarifier tanks ($H = 3.5$ m). With this measure no return sludge pumping station for stage 2 was necessary; the return sludge flows back to the second stage aeration tanks by gravity. Additionally, a flood pumping station could be omitted, which would have become necessary in case the final clarifiers would have been erected at a lower elevation.

Figure 4 and Table 2 show the layout of the extended plant and operation and design data of the old and extended plant, respectively.

RESULTS AND DISCUSSION

Plant performance

At both plants only recently full operation of the extended plant has been started; still start-up problems concerning mechanical equipment and plant control remain. Thus, yet only limited operation data is currently available.

The upper graph in Figure 5 shows the nitrogen removal capacity and the temperature in the aeration tank after the start-up of the extension of WWTP Knittelfeld. The effluent requirements (nitrogen removal $\geqq$ 70% on average for all periods of $T > 12$°C) are met. The nitrogen removal is depicted as weekly average values; in some weeks only single values were available. The impact of the aeration tank temperature on the nitrogen removal performance is low. Process control is not yet entirely optimised; continuing problems related to the refurbishment of the sludge digestion stage impose operational restrictions on the management of excess sludge withdrawal.

Figure 6 shows the sludge volume index before (2000/2001) and after the plant extension. In comparison

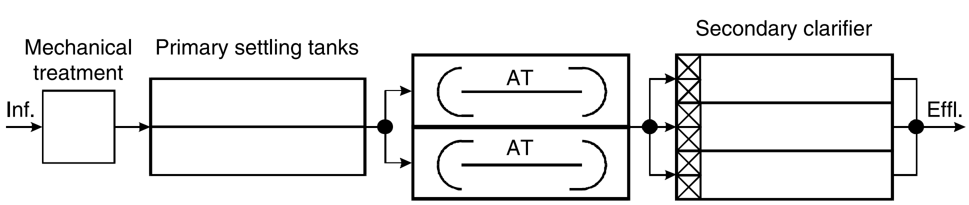

Figure 3 | Initial layout of WWTP Knittelfeld (1983).

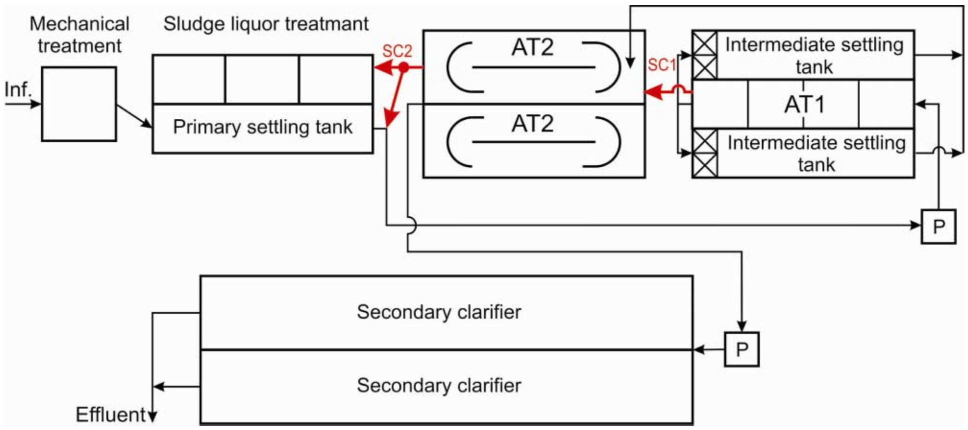

Figure 4 | Layout of WWTP Knittelfeld after plant extension according to the HYBRID®-concept.

with the previous single stage operation, the sludge volume index is reduced to approximately half the values observed before the plant extension. This is due to the fact that the high loaded first stage is dominant for the sludge properties; filaments do not have a competition advantage in that stage (F:M $= 0.5\,\mathrm{kg_{BOD5}/(kg_{MLSS} * d)}$, Knoop & Kunst (1998)). The sludge production of the low loaded second stage is so low, that the sludge properties remain almost unchanged in comparison to the first stage.

Cost aspects

Table 3 gives an overview of the tank volumes of the previously existing plant, the extended two stage plant and an alternative extension concept as single stage plant–for both case studies.

For WWTP Hohenems a saving of aeration tank volume of 12,360 m^3 could be achieved, which corresponds to 91% of the tank volume that would have been required for a single stage plant extension. This high volume saving is mainly caused by the favourable (TKN:COD)-ratio in the influent due to the high percentage of industrial wastewater. Concerning the sedimentation stages the two extension alternatives are equal, assuming that the final sedimentation for the single stage extension can be designed based on a SVI = 120 ml/g–which appears reasonable with respect to operation results of the 'old' plant (SVI2002 = 80 ml/g, LWB (2003)).

Table 2 | Design data and effluent limits (1978 and 2001) and operation data (2001) of WWTP Knittelfeld

	Design data (1978)			Operation data (2001)			Design data (2001)		
Q_d [m³/d]	8,500			4,800			10,000		
Q_{max} [l/s]	525*/350†						630		
	Design load [kg/d]	Effluent imit [mg/l]	Removal efficiency [%]	Influent load [kg/d]	Effluent concentration [mg/l]	Removal efficiency [%]	Design load [kg/d]	Effluent limit [mg/l]	Removal efficiency [%]
BOD_5	3,000	25		2,800	8	99%	4,200	15	95%
COD		90		4,350	42	95%	8,400	60	90%
TP				56			126	1.0	
NH_4-N								5‡	
TN				310	22	66%	770		70%§

*Mechanical stage.
†Biological stage.
‡at T > 8°C.
§at T > 12°C.

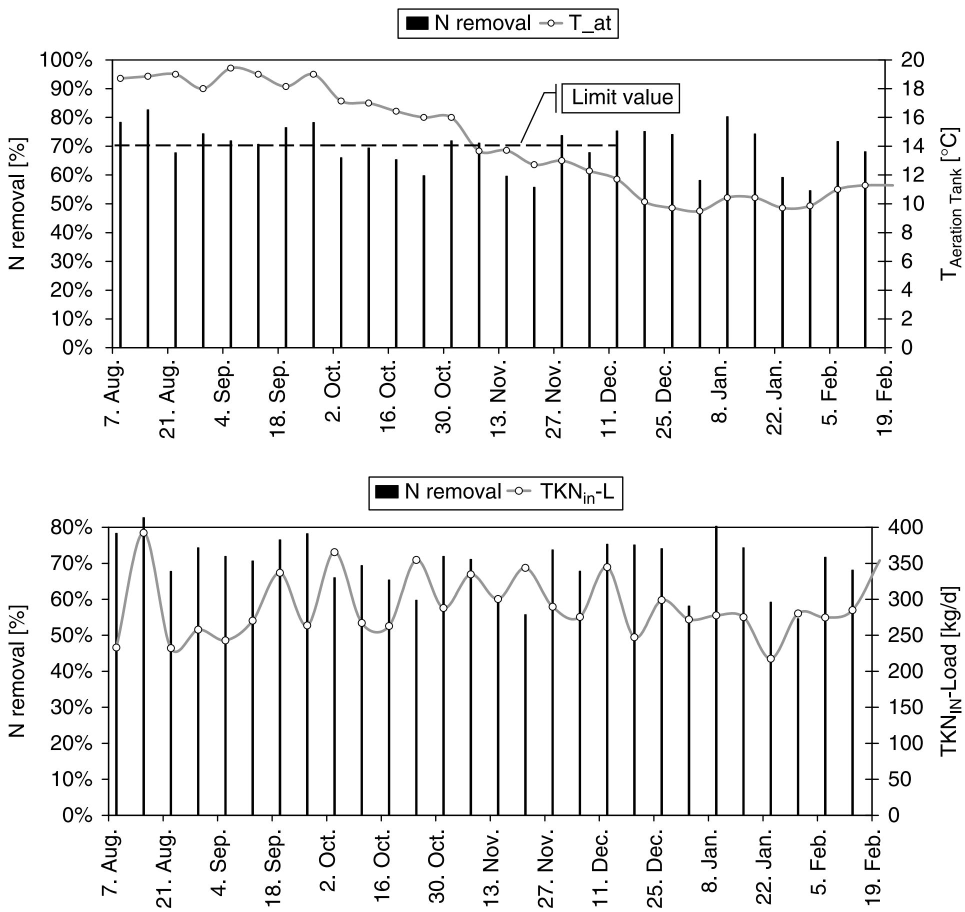

Figure 5 | WWTP Knittelfeld: total nitrogen removal, aeration tank temperature (upper figure) and TKN-influent load (lower figure) for the period Aug 2006–Feb 2007.

For WWTP Knittelfeld a saving of aeration tank volume of 3,930 m^3 could be achieved; no new tank had to be built to accommodate both aeration tanks for the two stage concept. Concerning the final sedimentation, the sludge volume index during single stage operation is the decisive factor (Figure 6); it was well above 150 ml/g for extended periods of the single stage operation. The plant also receives wastewater from a dairy. Assuming that within a single stage plant extension measures could be implemented which would secure a future SVI $\leq$ 150 ml/g approximately 30% of the influent flow could be directed to the existing final clarifiers. Subsequently, also for a single stage plant extension new final clarifiers would have become necessary. If again vertical flow type tanks were chosen, the additional tank volume would be 9,800 m^3. Also here, the aspect of installing an additional lifting station versus a new return sludge pumping station and a new flood pumping station applies.

Within this context it is also noteworthy that a study recently conducted in Austria showed that during the cold period (wastewater temperature below 12°C) a considerable

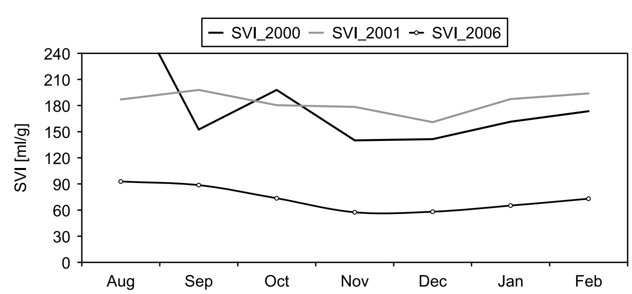

Figure 6 | WWTP Knittelfeld: sludge volume index before (2000/2001) and after (2006) extension of the plant.

Table 3 | Comparison of tank volume demands for plant extension alternatives

[m³]	WWTP Hohenems Existing	Two-stage	Single stage	WWTP Knittelfeld Existing	Two-stage	Single stage
Primary clarification	3,160		3,160	1,400	700	1,400
Aeration, stage 1	6,900	2,200	20,500	4,120	1,400	8,050
Intermediate clarification		3,160			2,800	
Aeration, stage 2		5,500			4,120	
Final clarification	4,400	4,400	4,400*	4,200	7,000†	4,200 + 9,800‡
Sludge dewatering filtrate nitrification		440†			460	
Volume savings						
Aeration tanks	$V_{AT\_SAVE} = 20{,}500 - 6900 - 440 + (6{,}900 - (2{,}200 + 5{,}500)) = 12{,}360\,m^3$			$V_{AT\_SAVE} = 8{,}050 - 4{,}120 = 3{,}930\,m^3$		
Sedimentation tanks	–			$V_{ST\_SAVE} = 9{,}800 - 7{,}000 = 2{,}800\,m^3$‡		

*Assuming a SVI = 120 ml/g.
†Newly erected tank.
‡Assuming a SVI = 150 ml/g.

number of low loaded plants showed sludge volume indices above 150 ml/g (Kreuzinger 2006).

CONCLUSIONS

For two WWTP's in Austria an extension became necessary because of stricter effluent limits requiring higher nutrient removal performance. At one of the plants no plant extension area was available; additionally more than half of its influent is of industrial origin–showing a high COD-content. At the second plant the extension area was also very limited; due to wastewater from a dairy severe bulking problems have been observed in the past.

For both cases, a plant extension adapting a two stage activated sludge concept according to the HYBRID®-process could meet the project requirements of (i) meeting stricter effluent limits, (ii) maximum utilisation of existing structures and (iii) accommodating the extended plant within the limited area of the WWTP site.

The two-stage activated sludge extension concept provided high nutrient removal capacity at low volume demand and significantly improved the sludge properties. Additionally, the specific sludge production per removed COD-load in the first stage is higher compared to a low loaded stage, which subsequently leads to a higher specific gas production. Both aspects contribute towards a higher degree of energy autarky of the plant.

These advantages come at the expense of an increased demand of mechanical equipment. On the other hand, the more complex structure of the plant provides a broad range of operational strategies allowing flexible responses to changing loading conditions.

REFERENCES

Knoop, S. & Kunst, S. 1998 Influence of temperature and sludge loading on activated sludge settling, especially on Microthrix parvicella. *Water Sci. Technol.* **37**(4–5), 27–35.

Kreuzinger, N. 2006 *Bulking and foaming in municipal WWTP's in Austria–a review study*, Intermediate report, Institute for water quality, Vienna University of Technology.

LWB–Landeswasserbauamt Bregenz 2003 *Abwasserreinigungsanlagen in Vorarlberg–Jahresbericht 2002*, http://www.vorarlberg.at/pdf/jahresbericht2002.pdf [in German].

Siegrist, H., Krebs, P., Buehler, R., Purtschert, I., Roeck, C. & Rufer, R. 1995 Denitrification in secondary clarifiers. *Water Sci. Technol.* **31**(2), 205–214.

Winkler, S., Matsché, N., Gamperer, T. & Dum, M. 2004 Sewage-treatment under substantial load variations in winter tourism areas–a full case study. *Water Sci. Technol.* **50**(7), 147–155.