Water Science and Technology: **Vol 44 No1 pp 137–144**

Comparison of different operational modes of a two-stage activated sludge pilot plant for the extension of the Vienna STP

H. Müller-Rechberger, G. Wandl, S. Winkler, K. Svardal and N.Matsché

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

Abstract A pilot plant has been operated over a period of two years in order to investigate the performance and the operating characteristics of the plant concept developed for the extension of the main Vienna STP and to develop a simulation model which will be applied for operation support of the full stage plant. The pilot plant is a two stage activated sludge plant, each stage comprising of four aeration tanks and a clarifier tank. The pilot plant layout allows three different operational modes, each of which has been operated for several periods. The performance of the pilot plant during these periods is described and the different operational modes are compared to each other.

Keywords Two-stage activated sludge plant; nutrient removal; sludge volume index; Hybrid®-concept; Bypass-concept

Introduction

A pilot plant has been operating over a period of two years in order to investigate the performance and operating characteristics of a plant concept developed for the extension of the main Vienna STP. A second goal of the pilot plant experiments was to develop a simulation model which is capable of describing the specific conditions as they occur in this special type two stage activated sludge plant (Winkler *et al*., 2000). The existing part of the Vienna STP has been put into operation in 1980 and is designed for 2.5 Mio PE. It includes a primary clarification, four aeration tanks equipped with cone surface aerators and the final clarifier tanks. The excess sludge and the primary sludge is mechanically dewatered and then pumped to a sludge incineration plant next to Vienna STP. The goal of the plant extension was to meet the national laws regarding nutrient removal and integrates the existing activated sludge plant into the new plant. Since the available extension area is very tight a two-stage concept has been chosen.

Existing plant

The existing part of the Vienna STP is a single stage activated stage plant. The total aeration tank volume is 42,000 m^3. It has been designed for a COD-load of 270 t/d, a solids load of 165 t/d, an average flow of 600,000 m^3/d and a maximum wet weather flow of 12 m^3/s (von der Emde, 1982). Although the existing plant has been designed for carbon removal only, the nitrogen removal rate achieved today is up to 40% due to the primary clarification and the nitrogen removal by excess sludge withdrawal. The excess sludge and the primary sludge is dewatered and then incinerated. With this measure only a small return load, the filtrate water from the dewatering station, is imposed on the biological stage. The current excess sludge production is approximately 150 t/d.

New plant concept

The new plant has to fulfil effluent standards according to the Austrian water protection legislation, which stipulates a total nitrogen removal rate of 70% on average over all periods with temperature above 12°C. The maximum NH_4-N effluent concentration is 5 mg/l (daily composite sample), the maximum total phosphorus effluent concentration is 1 mg/l (yearly average of daily composite samples).

One goal of the new plant concept was to integrate the existing plant into the new plant, additionally the extension area is limited. Thus, a two stage concept has been chosen which is suitable for nutrient removal. Different concepts of two stage plants for nutrient removal have been investigated by the ATV-Task Group 2.6 (ATV, 1994). For the Vienna STP a two stage concept has been chosen, which allows three different operational modes: Hybrid®-, Bypass- and conventional-two-stage operation. The main operational modes will be Hybrid®- and Bypass-mode, conventional-two-stage-mode has been operated at the pilot plant for comparison purposes. At the Vienna STP the total specific aeration tank volume of the new plant is about 65 l/PE. For a single stage design according to the ATV A 131 guideline the required specific aeration tank volume would have been in the range of 150–200 l/PE. Figure 1 shows the layout of the existing plant and the plant extension, which currently is under construction.

Hybrid®-mode can mainly be operated during dry weather conditions (7 m^3/s), since the maximum hydraulic load to the existing biological stage of the treatment plant is limited to 12 m^3/s. If the influent flow to the plant exceeds this limit, the excess water bypasses the first stage and is directly sent to the second stage. The second stage is designed for a maximum flow of 18 m^3/s.

In the Bypass-mode a portion of the incoming flow bypasses the first stage under all weather conditions. In the new plant, under normal operating conditions, the excess sludge is withdrawn from the first stage only. The excess sludge of the second stage is pumped into the first stage. Sludge containing nitrifying bacteria from the second stage enters the first stage and thus enables nitrification in the first stage. The first stage is operated at a sludge

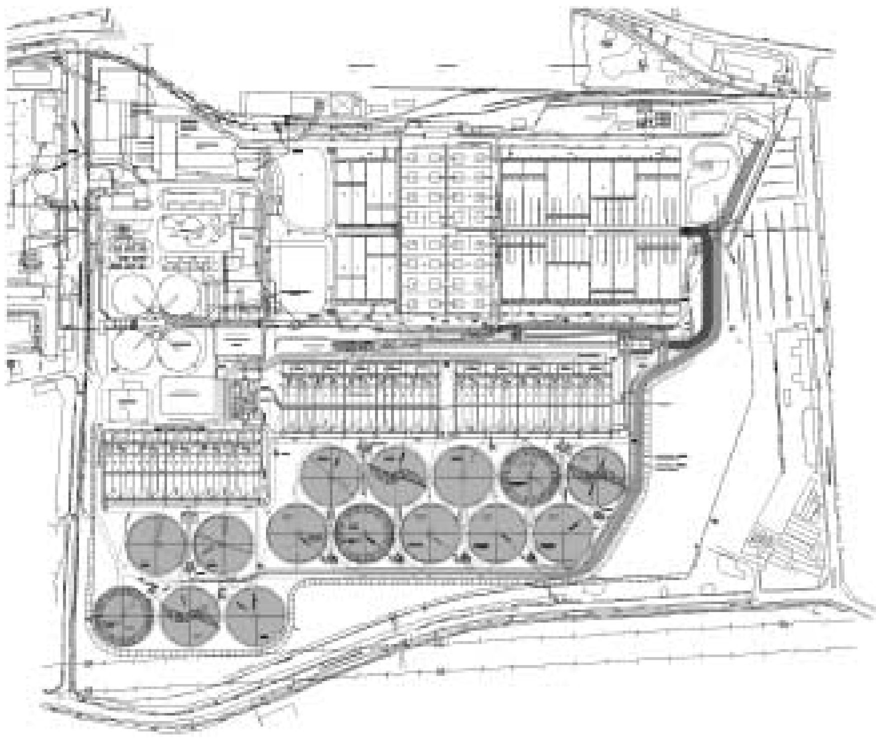


Figure 1 Vienna STP existing plant (upper part) and plant extension (lower part, under construction)

age of about one day. If the sludge transfer from the second to the first stage were not operated, this sludge age would be too short to grow nitrifiers. The ammonia concentration in the first stage is at a level which allows a maximum nitrification process rate.

A recirculation line will be installed, which delivers nitrate containing final clarifier effluent back to the first stage. In the first stage sufficient substrate for denitrification is available. The recirculation flow is adjusted automatically so that the sum of incoming and recirculation flow is constant. This measure minimises hydraulic load variations to the plant, which minimises the solids loss from the clarifier tanks (Armbruster *et al*., 2000).

Two main operational modes will be possible for the new plant.

1. *Operation according to the Hybrid®-concept (Matsché and Moser, 1993)*. The Hybrid®-concept is a two stage activated sludge plant comprising the exchange of activated sludge between the two plant stages. The sludge transfer between the two stages is carried out by means of two additional sludge circulation lines. Variation of the sludge circulation flow between the two stages allows us to operate the Hybrid®-mode within a broad range of operational characteristics. In the case that the exchange sludge lines are shut off, it equals a conventional two stage plant. In the case that the exchange sludge lines are operated at a high level, the biomass of the two stages gets mixed to a high degree, almost representing a single stage plant. In any case it has to be pointed out that the exchange sludge flow never exceeds a ratio of approximately 5% of the plant influent flow. Hence, the exchange sludge flow does not impose an additional hydraulic load to the plant. The Hybrid®-concept has the following advantages.

Highly loaded activated sludge from the first stage is brought into the denitrification zone of the second stage. The first stage is operated at a high sludge loading and a sludge age shorter than one day. The ratio of carbon removed by sludge withdrawal to carbon removed by respiration is approximately 80:20 in the first stage. This means that in the first stage 80% of the total COD removed is incorporated in the sludge by physical and biological processes. Thus, the sludge withdrawn from the first stage by means of sludge circulation line 1 is an excellent carbon source for denitrification in the second stage. The organic load transferred from the first to the second stage has to be chosen in a way which secures sufficient sludge age for nitrification in the second stage. If the organic load imposed on the second stage by means of sludge circulation line 1 is too high, the sludge age in the second stage decreases. The better nitrification performs in the second stage, the greater the volume of the second stage that can be assigned for denitrification. But it has to be kept in mind that the operational goal of the second stage is complete nitrification, i.e. a maximum nitrifying population should be maintained in the second stage in order to maximise the capability to handle ammonia peak loads. Sludge containing nitrifying bacteria from the second stage is transferred to the first stage. This measure induces a nitrifying population into the first stage. This is original to the Hybrid®-concept but, as described above, the sludge circulation line 2 is operated in all modes utilising the benefits of this measure under all operational modes.

The first stage achieves more than 70% of the total carbon removal, 15% of the nitrification performance and 40% of the total nitrogen removal rate of the whole plant. The second stage can be built as a low load nitrification/denitrification stage and is operated at a sludge age of approximately 6 days.

2. *Operation according to the Bypass-concept*. In the Bypass-concept a part of the plant influent flow is directly transferred to the second stage bypassing the first stage of the activated sludge plant. The bypass flow is operated within the range of 10 to 40% of the total influent flow. With this measure carbon substrate for denitrification in the second stage is

provided. Additionally, since a smaller share of the influent flow is sent to the first stage, the nitrate containing recirculation flow from the effluent of the final clarifier can be increased. Hence, a higher nitrate load is returned to the first stage, where there is sufficient carbon substrate for denitrification.

Since a part of the influent flow bypasses the first stage the incoming load to the first stage is decreased, whereas the incoming load to the second stage is increased. The bypass flow has to be set at a level which secures a sufficient aerobic sludge age in the second stage for growth of nitrifying bacteria. If the bypass flow is increased, the incoming load to the second stage is increased, which results in a decrease of the sludge age. The second stage has to be operated in a way which secures complete nitrification but maximises the denitrification capacity at the same time in order to maximise the overall nitrogen removal.

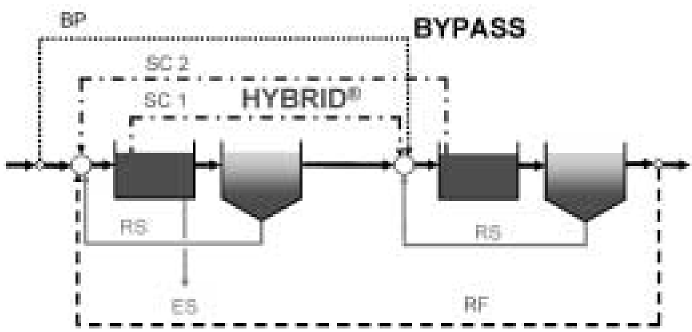
The bypass flow can also be adjusted to compensate for characteristic load changes. During the two years of operation of the pilot plant, a characteristic lower load on weekends has been observed. This is due to discontinuous operation of industry and trade and out of city activities of the population. The decreased load on weekends sometimes caused a shortage of substrate for denitrification in the second stage, which resulted in higher nitrate effluent concentrations. Increasing the bypass flow on weekends could be a possible measure to avoid this effect.

Figure 2 shows the principal layout of the pilot plant and shows all possible operational modes.

Operational results from the pilot plant

Nutrient removal

The pilot plant has been operated in different operational modes over several periods since the beginning of 1998. The temperature in the aeration tanks never fell beyond T = 12°C, therefore the tight nitrogen removal requirements had to be fulfilled all year long. Despite short periods of snow melting conditions, when peak loads of urea containing road de-icing agents reached the treatment plant the nutrient removal target could be achieved without any problems (Figure 3). It has been found that the total nitrogen removal performance during Bypass- and Hybrid®-operational periods has been similar, considering the different temperatures within these periods. Conventional two stage operation could not meet the nitrogen removal standards. From operational data it has been concluded that this is mainly caused by insufficient substrate supply for denitrification in the second stage. The sludge age of the second stage always has been sufficient for nitrification. Figure 3 shows two periods in May '99 where a total nitrogen removal of more than 80% could be achieved during conventional two stage operation. During those periods considerable amounts of



BP	Bypass line	**SC 1**	Sludge circulation line 1	**RS**	Return sludge
RF	Recirculation flow	**SC 2**	Sludge circulation line 2	**ES**	Excess sludge

Figure 2 Principal layout of the pilot plant of the extended main Vienna STP

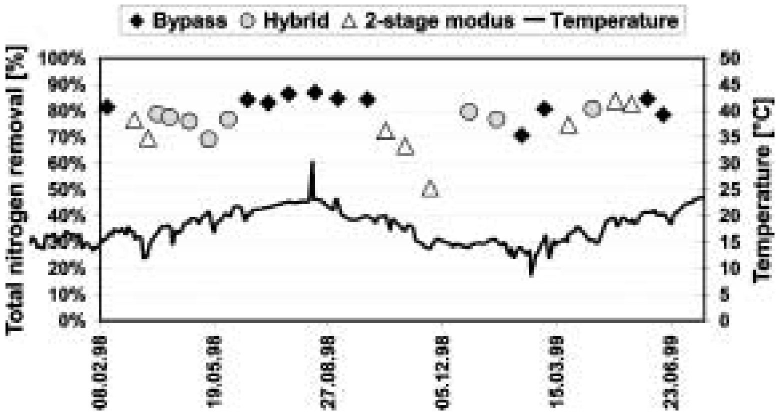


Figure 3 Nitrogen removal performance of the pilot plant during different operational periods

sludge entered the second stage due to sludge loss from the intermediate clarifier. Hence, those periods can be considered as quasi Hybrid®-mode operation periods.

Bypass-mode yielded a better nitrogen removal performance than Hybrid®-mode, which has been due to temperature effects and the increased nitrate return load to the first stage by means of the recirculation line. In Bypass-mode a higher percentage of the produced nitrate is denitrified (Figure 4).

On the other hand nitrification can be operated more stably in Hybrid®-mode than in Bypass-mode, due to two causes. First, if raw wastewater is fed directly to the second stage the sludge age there is decreased, thus the safety-factor for nitrification is reduced. Second, raw wastewater seems to have an inhibiting influence on the nitrifying population of the second stage. A change to Bypass-mode always caused an intermediate drop of the nitrification efficiency since the bacteria of the second stage had to adapt to raw wastewater. Also an increase of the bypass flow after the system already had been adapted to Bypass-mode resulted in a temporary drop of the nitrification efficiency.

Figure 5 shows the percentage of soluble TKN-load in the effluent relative to the total nitrogen influent load applying Hybrid®- and Bypass-mode over a temperature range of 16–22°C. It can be seen that in Hybrid®-mode lower effluent loads can be achieved. In winter, nitrification inhibition was observed at times, which might be due to the use of selected de-icing agents. In this case Bypass operation was inferior to Hybrid® operation, as the inhibiting substrate could directly enter the second stage.

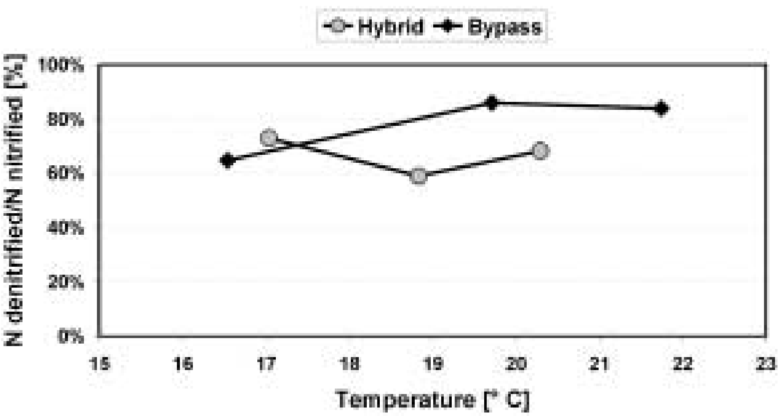


Figure 4 Percentage of denitrified nitrogen load relative to the nitrified nitrogen load during Bypass- and Hybrid®-operation

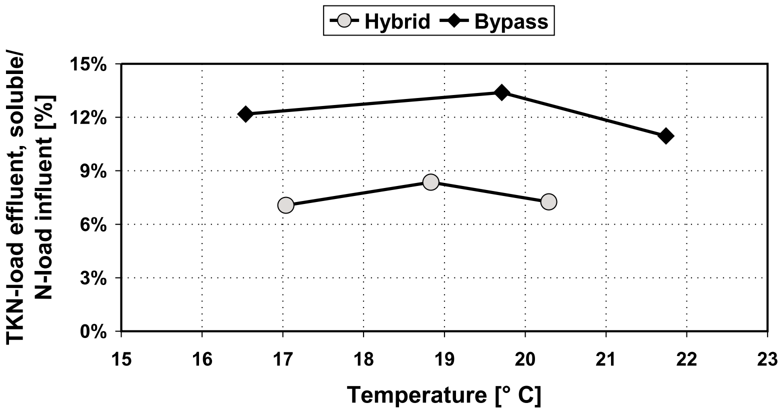


Figure 5 Percentage of soluble TKN in the effluent relative to the total nitrogen influent load during Bypass- and Hybrid®-operation

Carbon removal

Figure 6 shows a comparison of the COD removal performance of the different operational modes. COD is removed by excess sludge withdrawal from the first stage and by respiration in both stages. The COD removal performance has been found to be greater than 93%. The COD-load removed by means of respiration in the first stage is at its minimum in Hybrid®-mode, which suggests a maximum substrate uptake into the sludge in this mode.

Operational data show a completely different behaviour of the two stages with regard to carbon degradation. In the first stage 75–80% of the COD-load is removed by means of excess sludge withdrawal, while only 20–25% of the COD-load is removed due to carbon oxidation. In the second stage the contribution of sludge withdrawal and carbon oxidation to the total COD removal is approximately equal (Figure 7).

Sludge loading and sludge volume index

Investigations already published in 1964 (Stewart, 1964) show a dependency of the sludge volume index on the sludge loading. Within the range of approximately 0.5 to 1.5 kg_{BOD5}/kg_{MLSS} the sludge volume index shows a significant increase. The peak value of the sludge volume index in this investigation was found at a sludge loading of approximately 0.7 kg_{BOD5}/kg_{MLSS}.

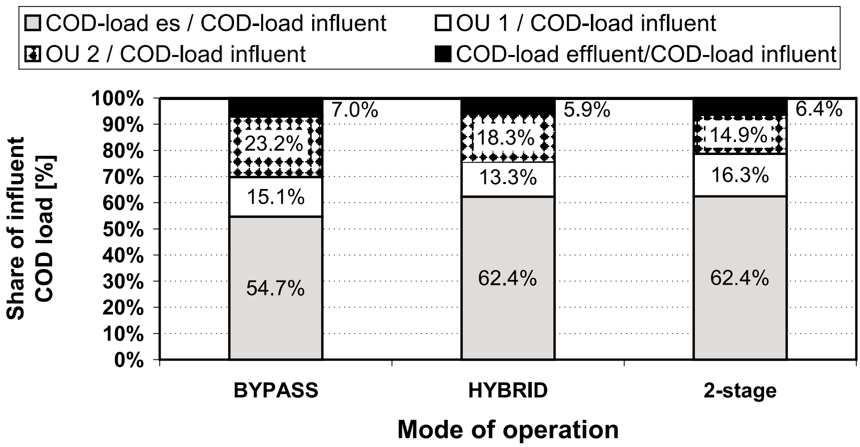


Figure 6 Pathways of COD-removal of the entire plant. Shares of COD-load removed by means of excess sludge withdrawal from the first stage (COD-load es), respiration in both stages (OU I, OU II) and COD effluent load (COD-load effluent) respective to the COD influent load (COD-load influent) to the plant

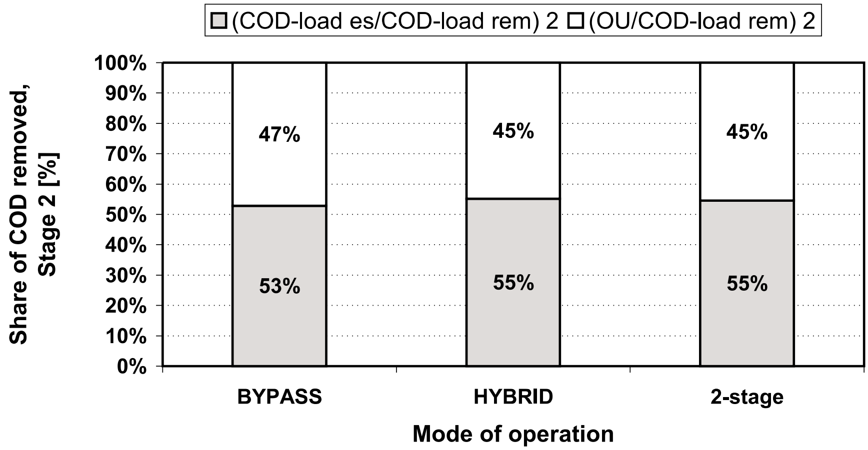


Figure 7 Pathways of COD-removal of the second stage. Shares of COD-load removed by means of excess sludge withdrawal from the second stage (COD-load es, pumped into the first stage) and respiration (OU) respective to the total removed COD-load (COD-load rem) of the second stage

The operational results from the pilot plant proved these investigations (Figure 8).

Over the entire temperature range the sludge volume index increases if the sludge loading approaches the lower or upper critical limit value. From Figure 8 it is obvious that Hybrid®-mode is favourable for a lower sludge volume index. This is due to the higher sludge loading of the first stage and the lower sludge loading of the second stage in comparison to the Bypass-mode. Additionally, in Hybrid®-mode, raw influent, including fat, is fed to the first stage only, where the sludge age is too low for growth of filamentous bacteria like Nocardia. The incoming fatty components are incorporated into the sludge in the first stage, thus they are no longer available for growth of Nocardia in the second stage. On the contrary, in Bypass-mode raw influent, including fat, reaches the second stage, where the sludge age is sufficient for growth of Nocardia.

In Hybrid®-mode the first stage is operated under similar conditions as the existing plant, which has been in operation without problems regarding the sludge volume index for

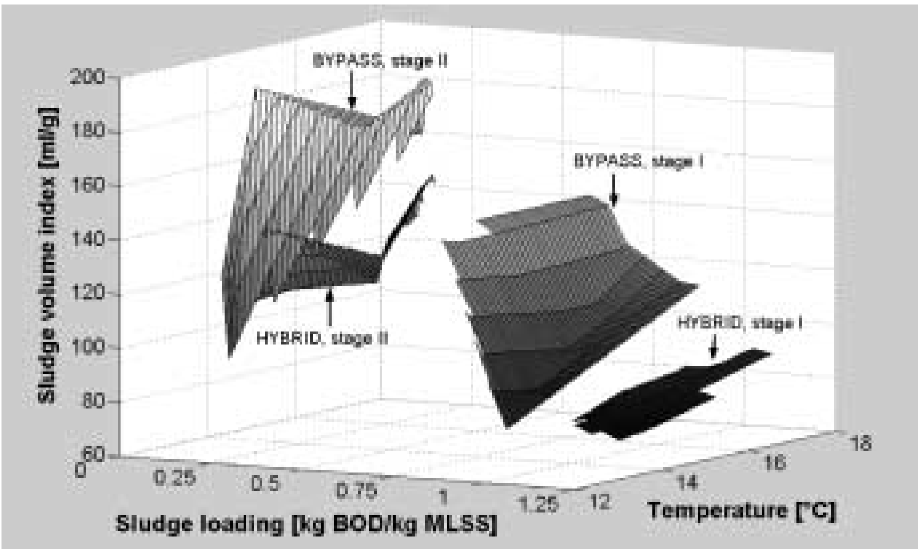


Figure 8 Sludge volume index of the two stages of the pilot plant at main Vienna STP during different operational modes

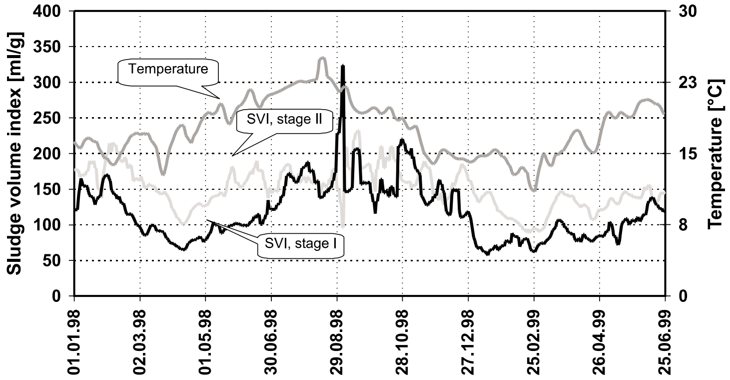


Figure 9 Sludge volume index and temperature during the course of operation of the pilot plant

twenty years now. Since no filamentous bacteria are grown in the first stage, the sludge of the second stage also shows a low sludge volume index, because no filaments are induced from the first stage.

The sludge volume index also shows a strong dependence on the temperature (Figure 9).

Conclusions

For the extension of the main Vienna STP a two stage concept has been tested by means of a pilot plant of the scale 1:10.000. The new concept includes two main operational modes (Bypass, Hybrid®) which enable an extensive nitrogen removal in contrast to nitrification only in conventional two stage activated sludge plants. The required specific aeration tank volume could be reduced to as low as 65 l /PE only, compared to 150–200 l/PE for single stage processes. Results from more than two years of pilot plant operation proved that the nitrogen removal requirements could be met with both operational modes. Nitrification performance was more stable in Hybrid®-mode, which is due to the fact that no raw waste-water enters the second stage; contrary to Bypass-mode where up to 40% of the influent flow bypasses the first stage. On the other hand, denitrification has been achieved more thoroughly in Bypass-mode. The Bypass-mode leads to a decreased sludge loading of the first stage and an increased sludge loading of the second stage resulting in a higher SVI in both stages in comparison to the Hybrid®-mode.

Acknowledgement

This research project has been funded by the Entsorgungsbetriebe Simmering (EbS) and the Forschungs-förderungsfond der gewerblichen Wirtschaft (FFF). The research proposal has been initiated by the Umwelttechnik Wien GmbH (UTW). We would like to thank the staff of the Vienna STP for their help and support in operating the pilot plant.

References

Armbruster, M., Krebs, P. and Rodi, W. (2001). Numerical modelling of dynamic sludge blanket behaviour in secondary clarifiers. *Wat. Sci. Tech.*, **43**(11), 173–180.

ATV-Taskgroup 2.6 (1994). Umgestaltung zweistufig biologischer Kläranlagen zur Stickstoffelimination. *Korrespondenz Abwasser 41 (1/94)*, 95–100, AbwasserTechnischeVereinigung, GERMANY [in German].

Matsché, N. and Moser, D. (1993). Operation of a two-stage activated sludge plant for high efficiency treatment. *Wat. Sci. Tech.* **28**(10), 299–307, IAWQ, London, UK.

Stewart, M.J. (1964). Activated sludge process variations – the complete spectrum – part III. *Water & sewage works Vol III, No. 6,* June 1964, 295–297, Scranton Publishing, Chicago, USA.

von der Emde, W. (1982). Design and operation interaction – an example: Main treatment plant Vienna. *Wat. Sci. Tech.* **14**(1–2), 493–506, IAWQ, London, UK.

Winkler, S., Müller-Rechberger, H., Nowak, O., Svardal, K. and Wandl, G. (2001). A new approach towards modelling of the carbon degradation cycle at two-stage activated sludge plants. *Wat. Sci. Tech.*, **43**(7), 19–27.