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Cost-effective upgrading of a biological wastewater treatment plant by using lamella separators with bypass operation

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ABSTRACT

Based on a comprehensive cost analysis for the expansion of the Finnentrop WWTP, integration of lamella separators in the biological treatment stage was given priority as optimal solution to increase the solids concentration. The overall expansion project included the reconstruction of the former primary clarifier into a primary settling tank with short retention times and the use of the remaining volume for pre-denitrification. Four lamella separators were positioned in the existing carousel-type activated sludge tank. With the lamella assemblies ensuring it was possible to continue operation of the existing secondary settling tanks. To control an adequate solids concentration in the activated sludge tank and to avoid any overloading of the secondary settling tank, a newly developed bypass strategy was applied. With a controlled mixing of direct effluent from the lamella separators and the contents of the activated sludge tank, the solids concentration of the influent to the secondary settling tank could be maintained at a value of 2.2 kg/m^3. The lamella separator concept did not account for any significant changes in the sludge characteristics, and the overall elimination of nutrients and organic carbon was found to be excellent upon optimisation of the operational lamella strategy.

Key words | activated sludge, bypass operation, lamella separators, nitrogen removal

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INTRODUCTION

The Finnentrop WWTP was commissioned in 1987 and serves a population of nearly 15,000 inhabitants and several industrial enterprises. Figure 1 shows the site plan of the plant. Constructed as a single-stage activated sludge plant with separate anaerobic stabilisation the Finnentrop WWTP was designed for carbon elimination only. Due to a loading well below the design capacity of 26,500 PE the plant achieved excellent carbon elimination and nitrification results during the summer months. To meet the German requirements for wastewater treatment plants with a design capacity greater than 10,000 PE, nutrient removal is mandatory. The effluent criteria are set to 18 mg/l N_{tot} and 2 mg/l P_{tot} for nitrogen and phosphorus, respectively.

During a comprehensive screening process several alternatives for the extension of the Finnentrop WWTP were investigated in detail. Besides an extension by creating new tank volumes for nitrogen removal and building of a new secondary settling tank, also the integration of lamella separators in the existing activated sludge tank was considered, based on a total cost estimation which included investment and operating costs. Lamella separators have proved to be attractive upgrading alternatives in cases when new structures can be avoided (Krogh Andersen 1996; Plaß 1998; Schönberger *et al.* 2001; Kolisch & Schirmer 2004). The main idea of this approach is to retain activated sludge within the biological reactor. In this case, the lamella separators act as a "pre-settler", thereby increasing the biological treatment capacity due to a suspended solids concentration higher than that achieved by a conventional mode of operation without lamellas. The cost comparison

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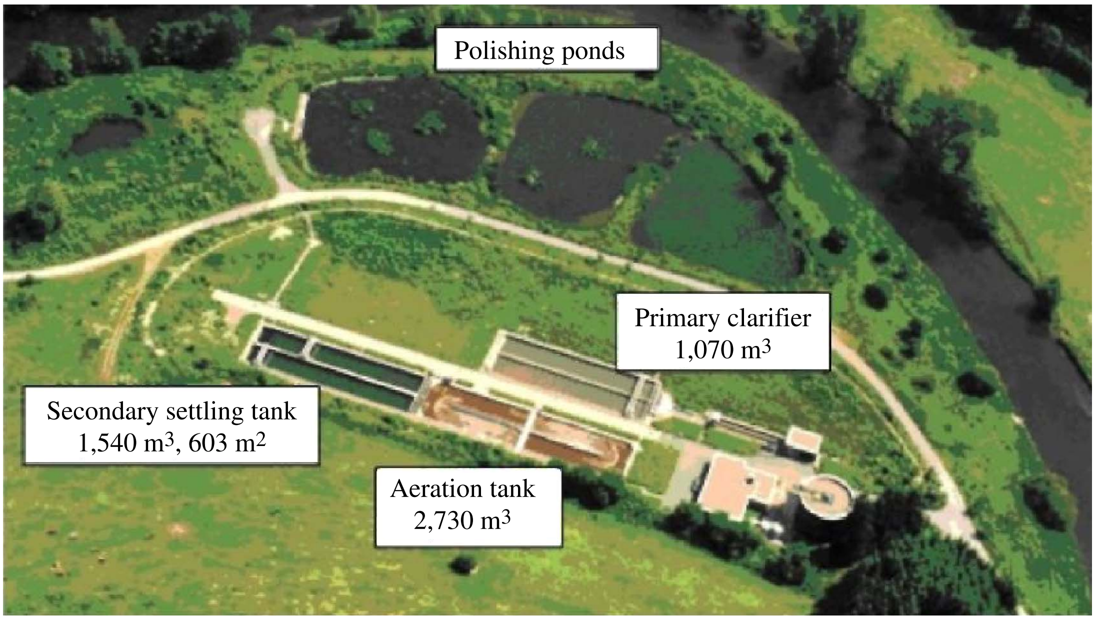

Figure 1 | Plant layout of the Finnentrop WWTP before upgrading.

clearly showed that integration of lamella separators in the activated sludge tank is the most cost-efficient upgrade scenario. Therefore, the Finnentrop plant was retrofitted, from 2004 to 2005, in accordance with this concept.

In the following, the main design and construction criteria for the implementation of lamella separators will be given, complemented by an introduction to the newly developed strategy for the lamella operation to achieve nearly constant inflow conditions for the secondary settlers. Furthermore, the operational results will be presented and discussed.

Loading situation before upgrading

Based on regular monitoring of the wastewater composition in the influent of the treatment plant, the design loadings shown in Table 1 were determined prior to the extension of the plant in 2001. Table 1 also summarizes the actual loading situation for the years 2002 to 2006. As a consequence of production changes in the industries located in the catchment area under review, recent years showed a slight decrease in organic and nutrient loads in the inflow to the treatment plant. The wastewater is mainly of municipal origin and strongly diluted due to elevated amounts of infiltration water which explains the comparatively low organic and nutrient concentrations.

The upgrading concept for the Finnentrop WWTP encompassed the integration of lamella separators in the activated sludge tank to increase the solids concentration in the biological reactor and the further usage of the existing secondary settlers. Compared to the currently applicable design rules for secondary settlers laid down in the working sheet A 131 (ATV-DVWK 2000), the existing settling tanks, with a depth of 2.5 m, are relatively shallow. Therefore, it was necessary to find out to what extent solids retention can be reinforced by the lamella settlers in order to avoid an overloading of the downstream secondary settling tank. To estimate the settling capacity, an analysis of the sludge characteristics was performed, supplemented by application of the 1-D flux theory.

Figure 2 shows the frequency distribution of the sludge volume index for the years 1997 to 2001. It becomes evident that there is a remarkable trend toward lower sludge volume indexes in the last years without the typical high fluctuation rates formerly registered throughout the year. This change in sludge settleability corresponds to major changes in the composition of the industrial wastewater. The main reason for this development is the shutdown of slaughtering operations in one of the largest meat factories in the region. By using the operating data from the plant prior to upgrading it was shown that with sludge volume

Table 1 | Loading situation before upgrading and actual loading situation

	Design loading (2001)	Actual loading (2002–2006)			
	85-percentile (kg/d)	average (kg/d)	85-percentile (kg/d)	average (mg/l)	85-percentile (mg/l)
BOD_5	1,590	1,099	1,369	156	230
COD	3,180	2,348	3,030	326	466
NH_4—N		107	121	15.2	21.0
N_{org}		91	116	12.6	17.5
TKN	294	198	230	27.8	38.0
NO_3—N	40	10	26	0.8	2.1
N_{tot}	334	208	251	28.6	38.1
P_{tot}	53	39	48	5.5	7.6
SS	1,700	1,032	1,414	147	205
ADWF* l/s	78				
PDWF† l/s	119				
PWF l/s	250				

*Average dry weather flow.
†Peak dry weather flow.

indexes that do not exceed 150 ml/g, a sludge concentration of 2.7 kg/m^3 could be upheld in the activated sludge tank without deteriorating the effluent quality of the WWTP and without overloading the secondary settling tank.

A final validation of the settling capability was made by using state point analysis based on the flux theory as described by Ekama *et al.* (1997). For the purpose, the settling flux curves were calculated using the fitted constants of the UCT DSVI family (Ozinsky & Ekama 1995; Ekama *et al.* 1997) lowered to 75%, as recommended by Ekama & Marais (2004) for shallow settling tanks. Figure 2 demonstrates that a safe operation of the settling tank with a solids concentration in the influent of 2.7 kg/m^3 is possible, on the assumption that the sludge volume index does not exceed 150 ml/g.

This preliminary analysis of the settling capacity reveals that the design concept for the lamella process should ensure a suspended solids concentration in the influent of the settling tank not greater than 2.7 kg/m^3 under design load conditions.

UPGRADING CONCEPT

The main purpose of the lamella separators in the activated sludge tank is to retain solids in the reactor and, thereby, to

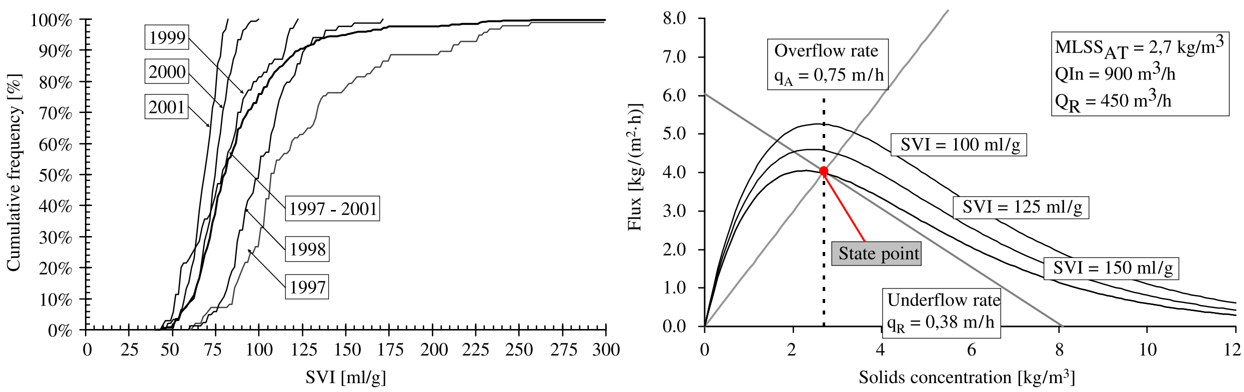

Figure 2 | Frequency distribution of sludge volume index and operating chart for the secondary settling tank.

increase the suspended solids concentration. Considering the design load for the treatment plant and taking into account that the whole reactor volume of the existing activated sludge tank can be used for nutrient removal, a suspended solids concentration of 4.2 kg/m^3 is necessary to comply with the German design rules (ATV-DVWK 2000). With a maximum of 2.7 kg/m^3,this means the lamella separators should provide a separation efficiency of 36%. This seems a feasible approach, based on the experiences from full-scale operation with lamella settlers (ATV-DVWK 2003).

Besides the biological reactor volume of the existing activated sludge tank, additional volume has to be provided by reconstructing the primary clarifier. One third of the available space will be used as sedimentation tank, while the remaining volume will serve as pre-denitrification tank. The total biological reactor volume finally accounts for some 3,600 m^3.

One of the main problems in the reliable operation of lamella settlers, integrated into activated sludge tanks, is on the one hand to limit the effluent suspended solids concentration. This is of importance in order to avoid an overloading of the secondary settling tank which otherwise could occur at high hydraulic loading rates. On the other hand, the lamella operation should maintain constant high rates of effluent solids concentration to facilitate flocculation prior to settling.

To control the suspended solids concentration in the activated sludge tank, the authors have developed a new bypass strategy in which the effluent from the activated sludge tank consists of two streams: the direct effluent of the activated sludge tank and the effluent of the lamella separators. Figure 3 shows the principle of the bypass operation. Without the bypass, the influent suspended solids concentration to the secondary settling tank would tend to values below 1 kg/m^3, at low hydraulic loading rates of the lamella separators. To avoid high retention rates of suspended solids in the activated sludge tank, a bypass valve is used to mix the low solids effluent from the lamellas at low hydraulic loadings with the higher concentrated effluent coming directly from the biological reactor. This is done to achieve solids concentration levels high enough to allow substantial flocculation prior to secondary settling. The control strategy of the bypass valve was designed to constantly feed the secondary settling tank with an average suspended solids concentration of 2.2 kg/m^3.

The installation of the lamella separators into the activated sludge tank is shown in Figure 4. Due to the circular activated sludge flow, the sludge settled within the lamella separators is carried away with the sludge stream underneath the lamella assembly. This ensures the almost complete

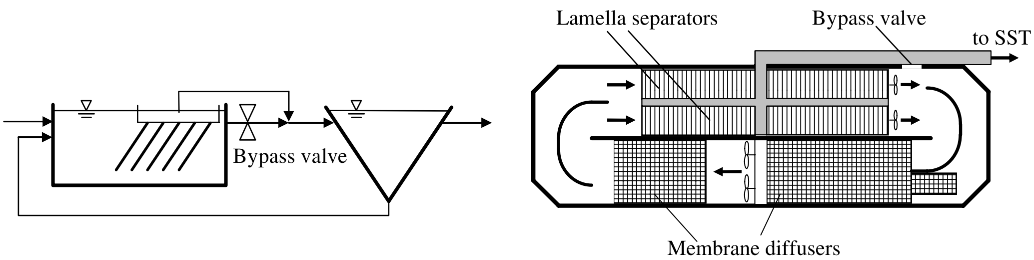

Figure 3 | Schematic diagram of the bypass valve (left) and schematic layout of the activated sludge tank equipped with four lamella separators and membrane diffusers (right).

Figure 4 | Installation of lamella separators in the activated sludge tank.

mixing of the tank volume. The effluent system consists of overflow weirs and a centred channel to collect the effluent from the lamella separators. All four lamella packages can be put out of operation independently for maintenance and cleaning purposes. To avoid plugging of the lamella separators, coarse bubble aerators are installed underneath the packages. Flushing frequency is usually once a day.

One of the major problems incurred by this retrofitting approach was the installation of diffusers and mixers within the tank. Figure 3 shows the proportional coverage of lamella separators and plate fine-bubble diffusers and the arrangement of the mixers. The banana-type mixers located between the membrane diffusers provide a specific mixing energy of 2.5 W/m^3 and are mainly responsible for the circulation of the activated sludge. Two additional mixers with a specific mixing energy of 1.6 W/m^3 are located just behind the lamella packages to avoid an accumulation of sludge underneath the lamellas. A variation of the mixing energy of these additional mixers did not have any significant influence, neither on the separation efficiency of the lamella, nor on the accumulation of settled sludge underneath the packages. The design parameters of the lamella packages are summarised in Table 2.

OPERATING EXPERIENCES

The expanded Finnentrop WWTP was taken into operation in autumn 2004. During the following start-up phase the main emphasis was laid on the optimisation of the lamella separators and the control strategy of the bypass valve.

Table 2 | Design of lamella separators

Parameter	Value	Unit
Required separation degree	36	%
Suspended solids concentration in the activated sludge tank	4.20	g/l
Suspended solids concentration in the effluent of the activated sludge tank	2.70	g/l
Max. overflow rate without by pass valve	1.20	m/h
Effective settling area	1,124	m^2
Angle of inclination	55	°
Space between lamellas	0.10	m
Number of lamella packages	4	
Length of one lamella package	11.20	m

Investigations with a closed bypass valve showed that the separation efficiency of the lamella settlers during dry weather conditions was relatively constant at approximately 60% and with that, notably higher than the required efficiency of 36%. With higher hydraulic loading rates of up to 1.1 m/h during a wet weather event the separation efficiency decreased to 50%, a figure still well above the required value.

During the optimisation phase of the bypass valve, the strategy was adapted in order to keep the suspended solids concentration at 2.2 kg/m^3. Figure 5 shows the effect of the implemented strategy during a long term dry weather period with an inflow between 30 and 100 l/s. Although the solids concentration in the activated sludge tank shows significant fluctuations of between 3.5 and 4.5 kg/m^3, control by the bypass valve leads to a remarkably constant total solids concentration of 2.2 kg/m^3 in the inflow to the secondary settling tank.

Preliminary problems with a suboptimal function of the control strategy occurred initially during short and prolonged wet weather periods. During such periods with high inflow rates persisting over several days and typically occurring during winter time, the bypass valve tended to close the bypass stream completely. As a result the lamella separators were stressed with the whole wastewater flow. And the influent solids concentration reached values greater than 2.7 kg/m^3 due to the decreasing separation efficiency. On the opposite, during peak flow conditions, typical of heavy thunderstorms, the bypass valve opened completely to keep a constant level of suspended solids in the influent of the secondary settler. Unfortunately, after opening of the bypass stream, the suspended solids concentration decreased, in a short period of time, from 4.5 kg/m^3 to 2.2 kg/m^3, thereby limiting the biological elimination capacity of the reactor. To avoid these operational problems with the complete closing and opening of the bypass valve, the control strategy was modified in such a way that above a flow rate of 150 l/s the valve opens to a fixed value without any further control regarding the influent concentration of the secondary settler.

Figure 6 shows the optimised operation of the lamella separators after modification of the control strategy.

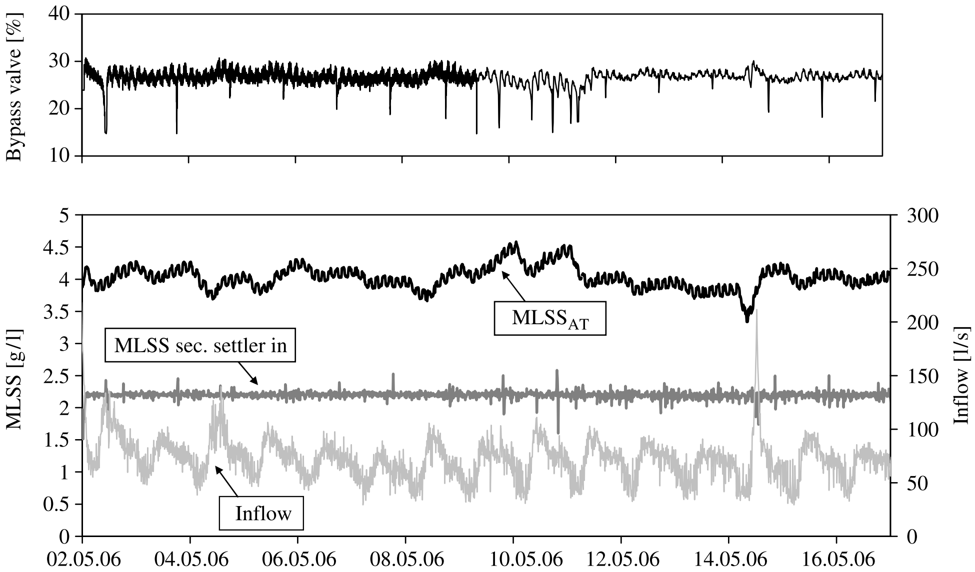

Figure 5 | Suspended solids concentration in the activated sludge tank and in the influent of the secondary settling tank under dry weather conditions.

Although substantial flow fluctuations occurred during the period depicted in Figure 6, it was possible to keep the influent solids concentration in a narrow range of 1.5 to 2.7 kg/m^3 without exceeding the upper limit of 2.7 kg/m^3. In addition, the suspended solids concentration remained relatively stable.

After two years of operation the median suspended solids concentration in the activated sludge tank has settled down at 4.1 kg/m^3 and the 10-percentile, as an indicator of the stability of activated sludge operation, has stabilized at a level of 3.5 kg/m^3. Contrary to expectations in the past, the sludge characteristics did not significantly deteriorate by the use of lamella separators. Formerly it was thought that, as a possible result of an enhanced particle distribution by the lamella settlers, smaller particles would be retained in the activated sludge tank leading to an increase of the sludge volume index.

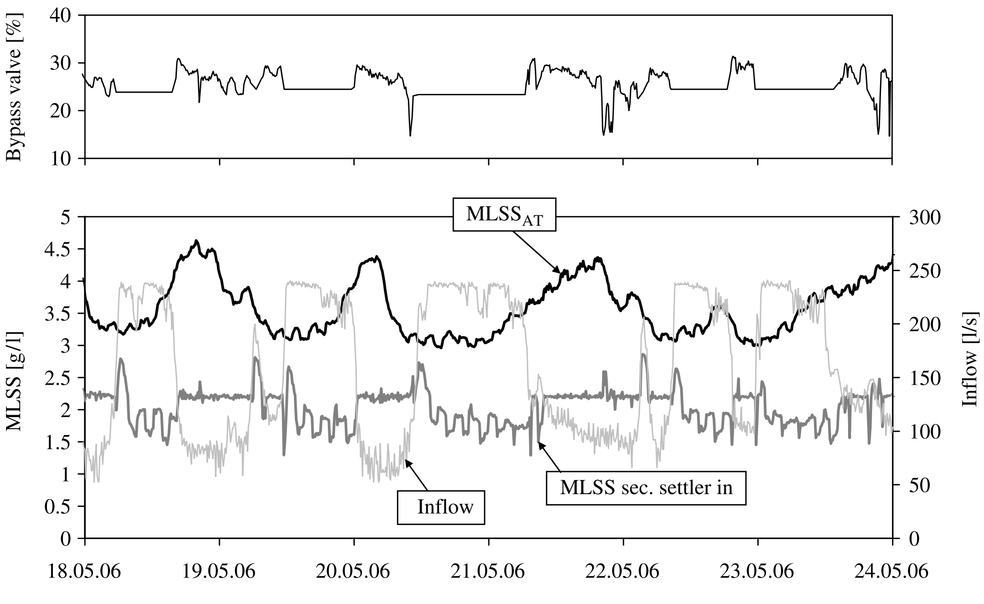

Figure 6 | Suspended solids concentration in the activated sludge tank and in the influent of the secondary clarifier during wet weather conditions—horizontal lines in the upper graph show the fixed opening of the bypass valve at flow rates above 150 l/s.

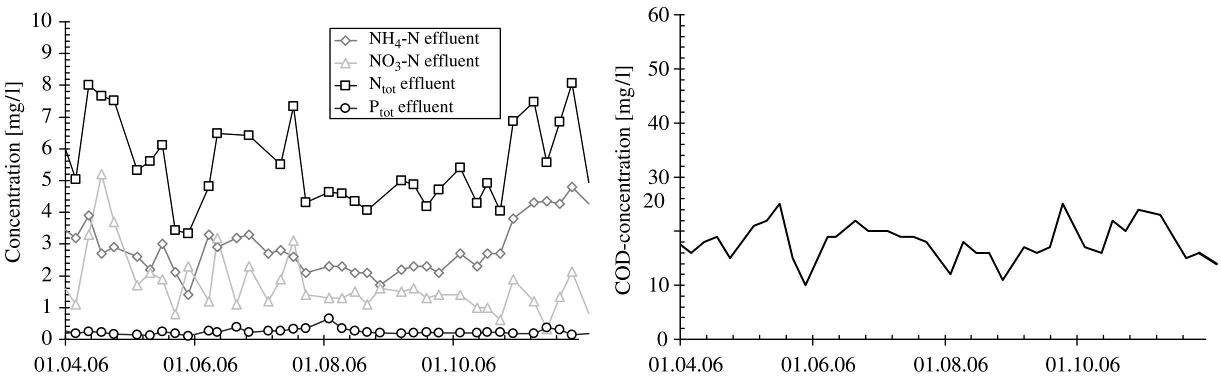

Figure 7 | Nutrient and COD concentrations in the effluent after optimisation of the lamella operation.

The median sludge volume index of the last two years has been determined to be 99 ml/g, and with a value of 115 ml/g, the 90 percentile shows that there is no significant indication for a negative impact of the lamella separators.

Nutrient removal is ascertained by using intermittent denitrification in the main activated sludge tank, with 70 minutes aeration and 90 minutes mixing only, and pre-denitrification in the former primary settling tank. Because of the comparatively low denitrification capacity in the pre-denitrification reactor which is due to the limited tank volume, it was not necessary to establish an internal recycle between the activated sludge and the pre-denitrification tank. The nitrate load of the return sludge recycle is high enough to satisfy the denitrification demands of the pre-denitrification tank at any time. Figure 7 shows the effluent nutrient and COD concentrations after optimisation of the lamella operation and supplies evidence of the excellent biological removal of nutrient and organic carbon.

CONCLUSIONS

With the integration of lamella separators, a cost-effective alternative was found for the expansion of the Finnentrop WWTP, compared to earlier plans which included the construction of additional tanks. Of crucial importance for a reliable operation is the control of the influent suspended solids concentration of the secondary settling tank to avoid overloading of the settler on the hand and to maintain a sufficient solids concentration for sufficient flocculation prior to the settling tank. With the newly developed bypass mode of operation and a site-specific special control strategy it was possible to achieve almost constant suspended solids concentrations in the biological reactor and the influent of the secondary settling tank. After upgrading and optimisation of the WWTP, the nutrient and carbon elimination obtained to date shows excellent results.

REFERENCES

ATV-DVWK 2000 *Bemessung von einstufigen Belebungsanlagen*. Arbeitsblatt ATV-DVWK A 131. Mai 2000, GFA-Gesellschaft zur Förderung der Abwassertechnik, Hennef.

ATV-DVWK 2003 Einsatz von Lamellenabscheidern in Belebungsbecken. Arbeitsbericht der ATV-DVWK-Arbeitsgruppe KA-6.5. *Korrespondenz Abwasser* **50**(1), 82–88.

Ekama, G. A. & Marais, G. v. R 2004 Comparison of the 1D flux theory with a 2D hydrodynamic secondary settling tank model. *Water Sci. Technol.* **50**(7), 195–204.

Ekama, G. A., Barnard, J. L., Günthert, F. W., Krebs, P., McCorquodale, J. A., Parker, D. S. & Wahlberg, E. J. 1997 *Secondary Settling Tanks. Theory, Modelling, Design and Operation*. Scientific and Technical Report No. 6. IAWQ, London.

Kolisch, G. & Schirmer, G. 2004 Lamella separators in the upgrading of a large urban sewage treatment plant. *Water Sci. Technol.* **50**(7), 205–212.

Krogh Andersen, K. 1996 Secondary sedimentation of activated sludge by a lamella separator placed in an oxidation ditch. *Eur. Water Pollut. Contr.* **6**(4), 37–44.

Ozinsky, A. E. & Ekama, G. A. 1995 Secondary settling tank modelling and design. Part 2. Linking sludge settleability measures. *Water SA* **21**(4), 333–350.

Plaß, R. 1998 *Untersuchungen zur Erhöhung des Trockensubstanzgehaltes im Belebungsbecken durch den Einsatz von Lamellenpaketen*. Dissertation an der TU Hamburg-Harburg. Hrsg. GFEU, Hamburg, ISBN: 3-930400-20-0.

Schönberger, D., Köhne, M., Plaß, R. & Sekoulov, I. 2001 Einsatz von Lamellenpaketen im Belebungsbecken zur Erhöhung des Trockensubstanzgehaltes. *Korrespondenz Abwasser* **48**(1), 54–61.