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TRIAL OPERATION OF A SELECTOR AT THE NORTHPEST WASTEWATER TREATMENT PLANT[1]

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Abstract

The goal of the experiments was to establish a bioreactor configuration that enables an enhanced nitrogen removal at the Northpest Wastewater Treatment Plant. At first lab-scale experiments were performed to determine the effect and size of a selector installed in the first part of the existing aeration tank. On the basis of the model experiment an anoxic selector was established in one of the trains of the full-scale plant. During the field experiment three trains were operated simultaneously, train I with the new configuration and trains II and IV without having a selector.

Installation of an anoxic selector in the first part of the flow-through activated sludge basin proved to be effective both in the model experiment and consequent field studies. The reconfiguration of the system resulted in low and stable SVI values and facilitated an enhanced nitrogen removal originating from a high rate nitrification and an effective denitrification. All of the different reference systems proved to be less stable and provided relatively poor performance in sludge settling characteristics and nitrogen removal. The reconfigured system maintained its favorable results also at a 30% increased load.

Keywords: activated sludge, bioreactor configuration, selector, nitrogen removal, sludge settling.

1. Introduction

Budapest has two large wastewater treatment plants. The newer one, the Northpest Wastewater Treatment Plant, that receives influent also from various industries (pharmaceutical, tanning, metal plating etc.) was established in 1986 with a conventional high-load activated sludge unit and no requirement of nutrient removal. Following the mechanical treatment, the wastewater enters a battery of basins including preaeration tanks; longitudinal flow primary clarifiers, aeration tanks, secondary clarifiers, and chlorinating basins. In the battery, there are four identically designed trains. The Budapest section of the Danube belongs to category #2 of the

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Hungarian treated effluent regulations. This requires a COD value of 75 mg/l, an ammonia-N concentration of 5 mg/l, a nitrate concentration of 50 mg/l and phosphorus concentration of 2 mg/l. The regulations do not refer to a BOD limit. The Northpest Wastewater Treatment Plant has been granted by temporal special effluent requirements, which prescribe 25 mg/l for ammonia-N and does not contain a restriction for nitrate concentration.

Ever since the start of the operation, engineers of the plant have challenged to upgrade the performance. In the first few years this effort was focussed on improving the general technical condition: the screens, diffusers, blowers as well as the sludge dewatering machinery were replaced and the electric equipment was refurbished. From the early nineties the main goal was to find the optimal way of operation of the activated sludge unit. This has been accomplished in a cooperation between the experts of the Budapest Municipal Sewerage Company and the Dept. Agricultural Chemical Technology of Technical University of Budapest.

2. Goals of the Experiment

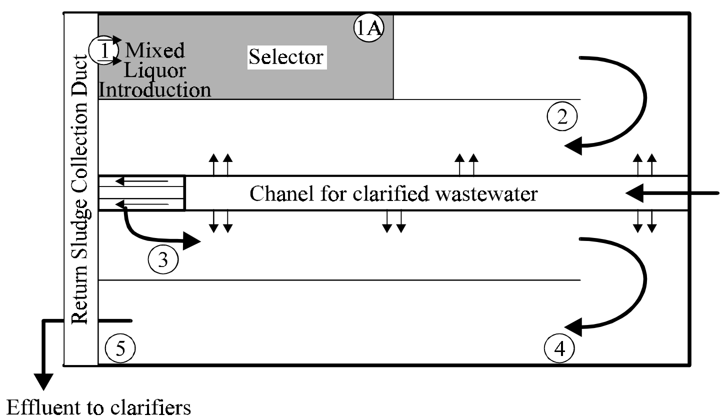

Fig. 1. Schematic of the flow-through activated sludge basin demonstrating the installation of a selector in Train I

Each of the four treatment trains contains a flow-through, labyrinth-like activated sludge basin, as illustrated in *Fig. 1*. The original design suggested to introduce the clarified wastewater into the second and third sections through altogether 12 sluice gates, whereas leaving the first section for regeneration of the returned activated sludge. This bioreactor arrangement had proved to be inefficient both in pilot-scale and in field studies. Consequently, the introduction of the clarified wastewater was shifted to the head of the activated sludge basin, i.e. to the return sludge collection duct. At the same time a new control strategy was established in the aeration system, which facilitated to individually regulate the amount of the air supplied into the four sections of the activated sludge basin. Through the reconfiguration of the feeding pattern and the upgraded aeration control system, a significantly improved COD-removal could be achieved. The effluent COD values decreased from 150–160 mg/l to 50–60 mg/l.

The next step in upgrading the performance was to achieve an enhanced nitrogen removal. However, maintaining an appropriately high MLSS concentration for an effective nitrification was hindered by often-high SVI values. Moreover, whenever an efficient nitrification occurred, there could be both a severe sludge floating in the secondary clarifiers and a scum formation on the surface of the activated sludge basins observed. It is important to mention, that the design as well as the capacity of the secondary clarifiers is fairly poor and the activated sludge basins favor scum retaining, since the mixed liquor flows into the following sections under the surface.

The basic goal of our experiments for upgrading the nitrogen removal of the Northpest Wastewater Treatment Plant was to establish a bioreactor configuration that enables possibly low SVI values for maintaining appropriately high MLSS concentrations for an efficient nitrification. It was hypothesized that installing a selector in the flow-through basin would considerably improve the sludge settling characteristics (CHUDOBA et al., 1973; DAIGGER and NICHOLSON, 1990). Moreover, it was assumed that scum formation might also be repressed by establishing a relatively high substrate gradient throughout the system. In order to avoid sludge floating in the poor capacity secondary clarifiers (with a designed average overflow rate of 0.9 m/h) a possibly efficient denitrification was also to be accomplished.

3. Model Experiment

Measurements throughout the aeration basin showed that due to overall backmixing there was no significant substrate gradient in the system. Consequently, lab-scale experiments were performed to determine the effect and size of a selector installed in the first part of the existing aeration tank. Four experimental systems fed directly by the clarified influent were operated simultaneously. As shown in *Fig2*, one of the systems served as a reference without having a selector. Based on prior studies the size of the selectors was set to one eighth of the total volume. One of the experimental systems contained an aerobic selector and two ones contained one anoxic selector each. One of the systems having an anoxic selector was arranged as shown in *Fig. 2*. The other one was staged, i.e. it contained three reactors after the anoxic selector, with aerated volumes of 3 *1*, 2 *1* and 2 *1*, respectively.

The hydraulic retention time of the wastewater was set to 7.2 hrs according to the average value in the plant. The SRT (Sludge Retention Time) was maintained at approx. 8 days by daily elimination of one eighth of the reactor volume from the last reactors of the systems. This also facilitated to maintain the MLSS (Mixed Liquor

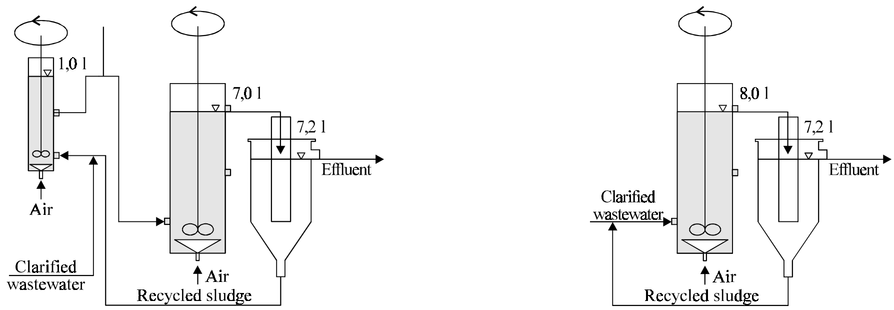

Fig. 2. Arrangement of the system with the aerobic selector and the reference system containing no selector

Suspended Solids) concentration most of the time close to the value (2.2–3.2 g/l) measured in the plant. The effluent was collected and measured as daily average.

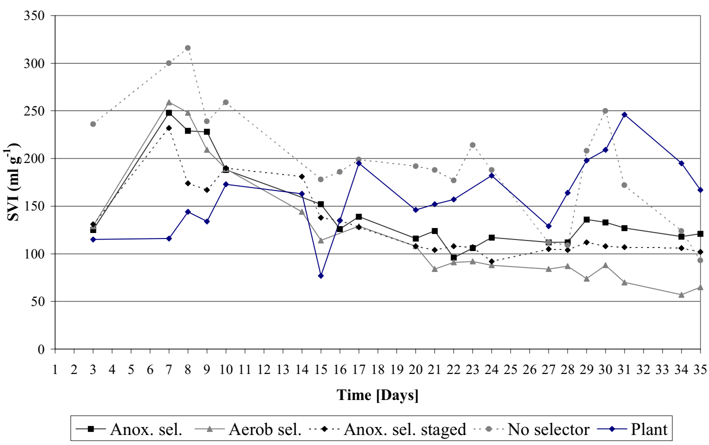

Fig. 3. SVI values obtained from the experimental systems and from the full-scale plant

SVI (Sludge Volume Index) values of the sludge entering the secondary clarifiers of the model systems and of the full-scale plant are shown in *Fig. 3*. It is obvious, that after the first 15 days, the behavior of the plant was simulated very well by the lab-scale system having no selector. In both cases, relatively high and characteristically fluctuating SVI values were obtained. Regarding the limited capacity of the secondary clarifiers, this behavior severely restricts the MLSS concentration maintainable in the system and thereby the effectiveness of the treatment. After a start-up phase of about 20 days, all of the model systems containing a selector provided even and relatively low SVI values. The experiment unambiguously showed that installing a selector in the existing flow-through basin would considerably improve the sludge settling and thereby allow an increased load in the secondary clarifier. Although all of the selectors had their effluent channels under the surface, as shown in *Fig. 2*, and this arrangement was also applied in the second and third reactors of the staged system, no scum formation was observed in any of the experimental systems.

The ammonia concentrations of the influent, clarified wastewater and of the effluents of the model systems are shown in *Fig. 4*. From the 23rd day of the experiment a full nitrification was achieved in all of the four systems at a temperature of 21 °C. In the start-up phase different ammonia removal efficiency was detected in the differently arranged systems. Besides the obvious advantage of a higher aerobic SRT, the better nitrification efficiency could also be related to the higher grade of compartmentalization.

The effluent nitrate concentration data are included in *Fig. 5*. The aerated system having no selector obviously showed the highest values. The unexpectedly good nitrate removal rate of the system containing an aerated selector can be attributed to the low (< 1 mg/l) dissolved oxygen (DO) concentration in the selector stage measured from the 21st day. This result, however, also suggests the presence of an appropriate amount of readily biodegradable substrate in the clarified influent. It can be assumed that the primary clarifier allows a considerable fermentation of the influent wastewater.

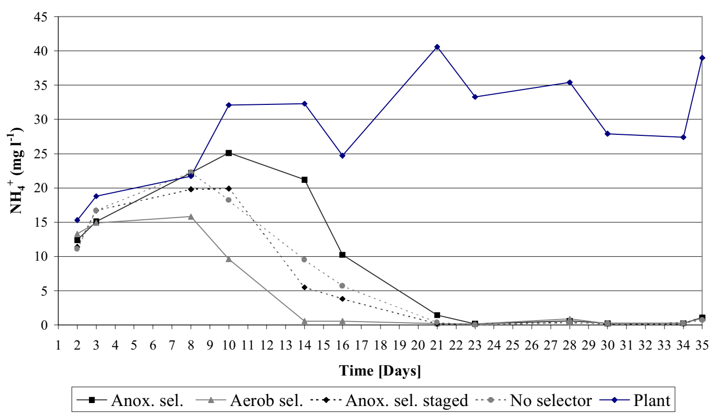

Fig. 4. The measured influent and effluent ammonia concentration

The availability of a considerable amount of fermented substrates can also be assumed based on the increased phosphorus removal efficiency of the systems having an anoxic selector (see *Fig. 6*). In these selectors, the nitrate recycled by the returned activated sludge was fully removed in most of the time of efficient nitrification. As an illustration of the processes occurring in the staged system having an anoxic selector, profiles of the different parameters averaged in the period of the full nitrification are shown in *Fig. 7*.

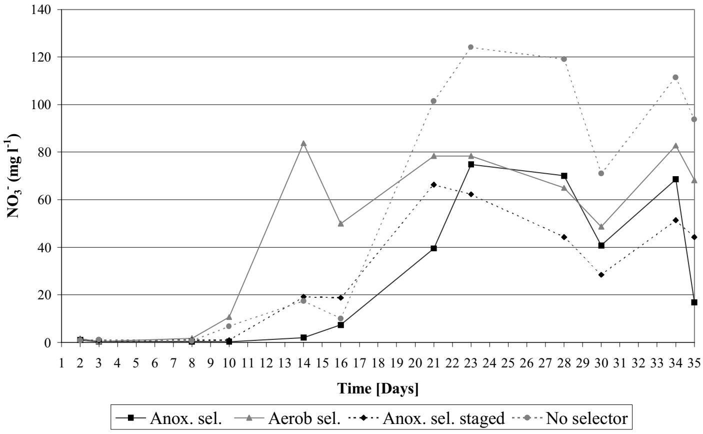

Fig. 5. The measured effluent nitrate concentrations

On the basis of the model experiment it was concluded, that the installation of a selector within the existing flow-through activated sludge basin would considerably improve the sludge settling and thereby allow an increased MLSS concentration and thus a better performance of the system. Since the denitrification capacity of the aerated selector proved to be dependent on its dissolved oxygen concentration determined by the fluctuating load, installation of an anoxic selector promised a safer nitrogen removal and an eventual possibility of an increased phosphorus removal.

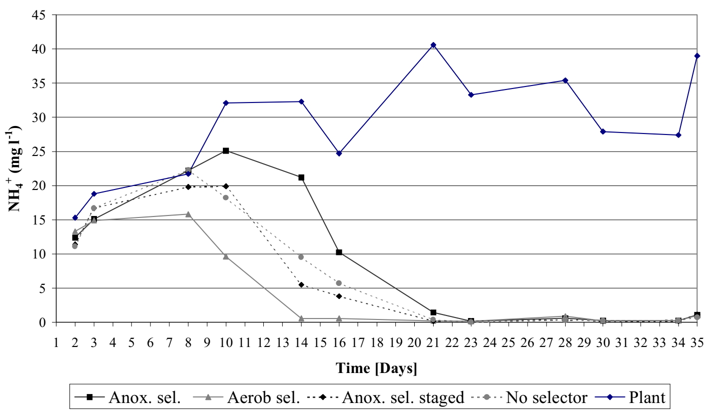

Fig. 6. The measured effluent phosphate concentrations

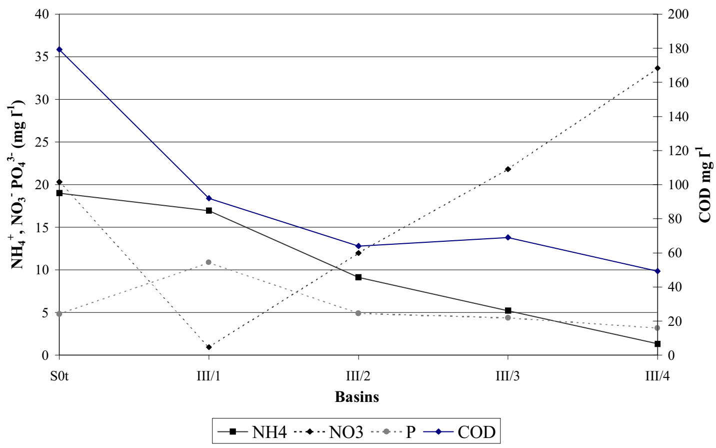

Fig. 7. The measured COD, ammonia, nitrate and phosphate profiles in the staged system having an anoxic selector

4. Field Experiment

In April 1994, an anoxic selector was established in the activated sludge basin of Train I, as shown in *Fig. 1*. The trial operation was carried out from May 1 until July 18. In this period there were three trains operating simultaneously at the plant. Trains II and IV had no selector. For technical reasons and in order to achieve a more complete denitrification, approx. 80% of the clarified wastewater of each system was introduced into the return sludge collection duct, whereas 20% was fed to the mixed liquor through the last gates prior to entering the fourth section of the flow-through basin. It was not possible to control the above ratio accurately. At the start of the trial operation the temperature values measured in the activated sludge basins were around 20 °C and increased up to $>$ 23 °C by the end of the experiment.

Train IV was used as a reference with a relatively low DO level. In the first section of this activated sludge basin the DO concentration was maintained at $<$ 1 mg/l. In the first part of the experiment the DO level was set to 3–4 mg/l in the aerated sections of the selector system (Train I), it was set to 2 mg/l in Train II and it was increased by the fourth section from the above mentioned low level to 3 mg/l in Train IV. On June 10 the DO concentration in the last three sections of Trains II and IV was increased to 3–4 mg/l. On June 14, a severe sludge floating occurred in the secondary clarifier of Train II. Consequently, the dissolved oxygen level in the third and fourth sections of Trains I and II was decreased to 2 mg/l and on June 16 it was further reduced in the third sections to 1.5 mg/l. On July 7, the load of Trains I and IV was increased by 30% through redirecting the wastewater from Train II. Effluent data measured at the plant using samples taken regularly in

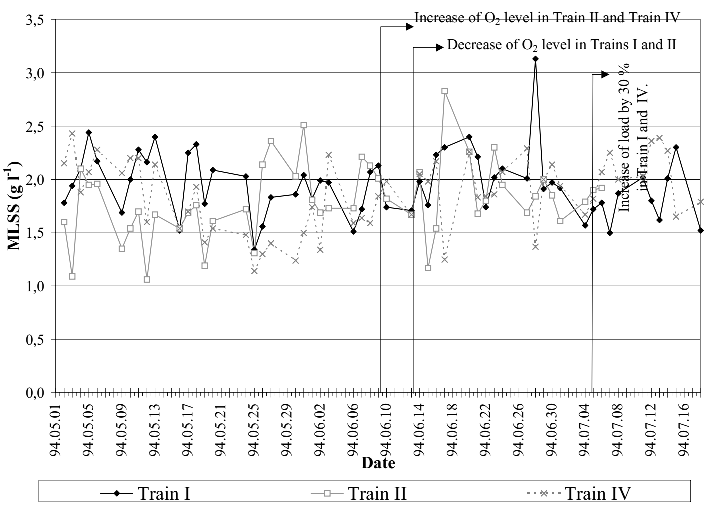

Fig. 8. Measured values of MLSS concentration

the mornings from the secondary clarifiers in the period of the field experiment are included in *Figs. 8–12*. Out of the three trains the selector system showed the most stable operation coupled with the best long-term results in every respect.

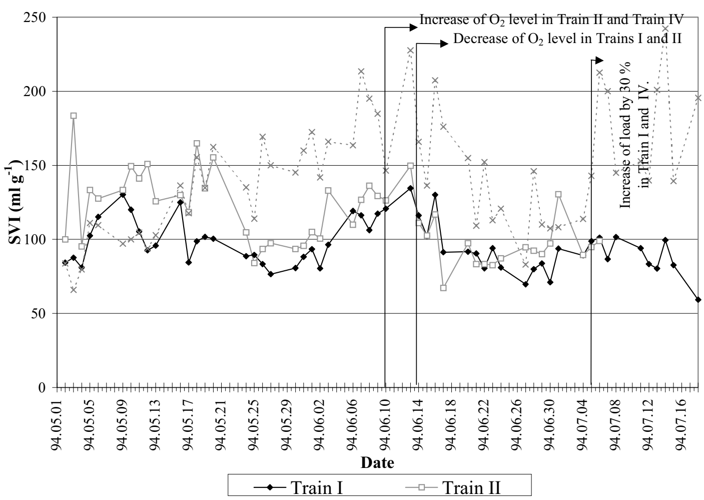

Fig. 9. SVI values in the selector system (Train I) and in the reference systems

SVI values measured in Train I after the start-up phase of the new configuration proved to be relatively low and even verifying the results obtained in the model experiment (see *Figs. 3* and *9*). Train IV having low DO values in the first section of the activated sludge basin provided high and fluctuating SVI values. Sludge settling in Train II was considerably better than in Train IV, nevertheless, the obtained SVI values often exceeded the values of Train I.

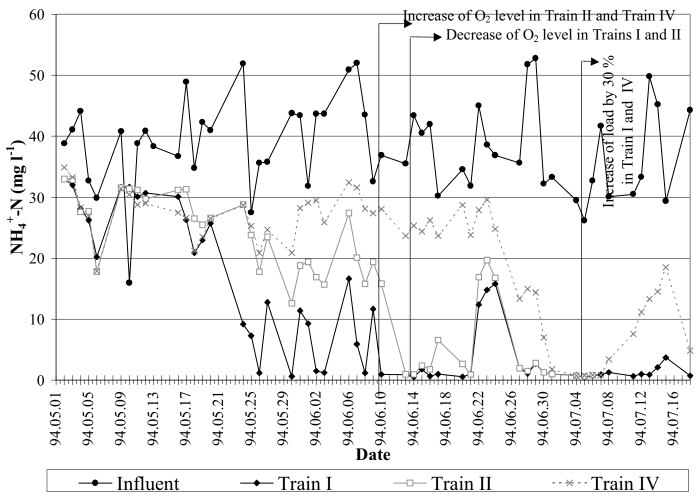

Fig. 10. Measured values of influent and effluent ammonia concentrations

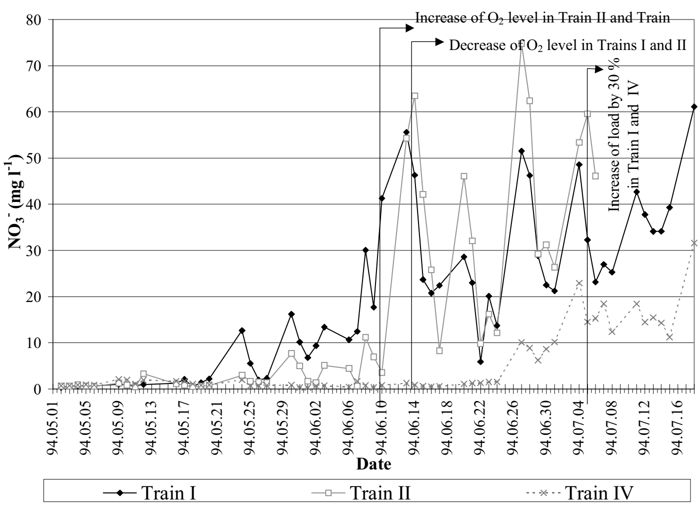

Fig. 11. Measured values of effluent nitrate concentration

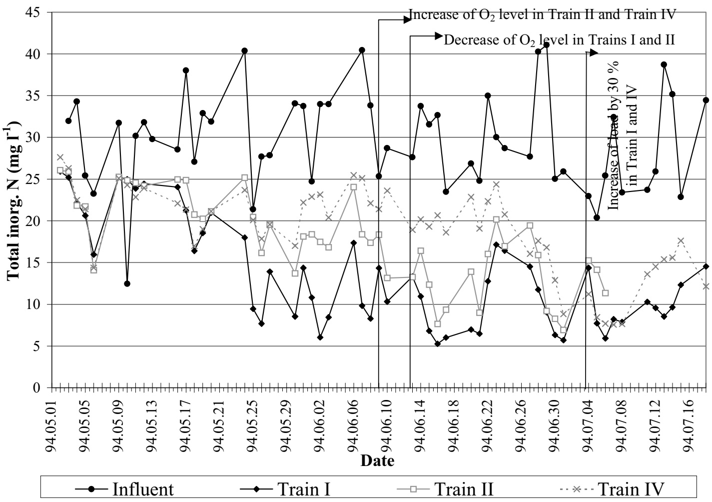

Fig. 12. Total influent and effluent inorganic nitrogen concentrations

Although the MLSS concentration in Train I was maintained at about the same level as in the reference trains (see *Fig. 8*), the reconfigured system provided an enhanced nitrogen removal considering nitrification, denitrification and also the resulting effluent values of total anorganic nitrogen. Train II proved to be considerably less stable than Train I. The increased oxygen supply of this system resulted in a good nitrification efficiency, however, as a consequence, a severe sludge floating could be observed in the secondary clarifier due to the high effluent nitrate concentration. Decreasing the DO level in order to avoid this phenomenon resulted in a temporarily increased effluent ammonia concentration. In the period of efficient nitrification the effluent nitrate concentration of Train II significantly surpassed the values measured in Train I. The system having an anoxic selector was void of secondary clarifier sludge floating throughout the whole period of the trial operation. Due to low effluent nitrate concentration, Train IV proved to be relatively stable, i.e. practically exempt from sludge floating in the secondary clarifier but did not provide a good nitrification efficiency. This behavior can be attributed to the low DO concentration maintained in the first section of the activated sludge basin. The selector system maintained its favorable performance also at the 30% increased load.

Fig. 13 represents the profiles of COD, ammonia, nitrate and phosphate concentrations measured using filtered samples taken from the activated sludge basin of the selector system as indicated in *Fig. 1*. Sampling was started at 11 a.m. and was accomplished by considering the estimated hydraulic retention time of the mixed liquor in the system. This period of the day can be generally characterized by the highest hydraulic and organic load of the activated sludge unit. The similarity of

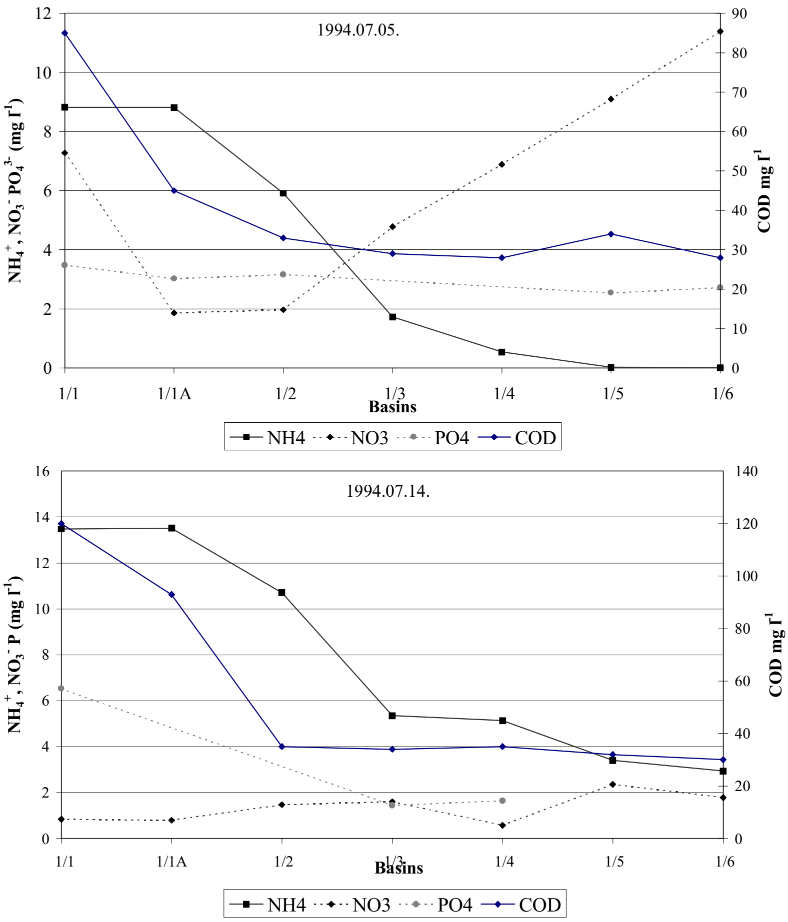

Fig. 13. The measured COD, ammonia, nitrate and phosphate concentration profiles throughout the selector system on July 5 (top) and July 14 (bottom)

the measured profiles to those obtained in the model experiment (see *Fig. 7*) is obvious. This result supports that the behavior of a full-scale plant can be very well mimicked by an appropriately designed model equipment (JOBBÁGY et al., 1997). Profiles obtained on July 14th at the increased load show a significant simultaneous denitrification in the aerated basin due to relatively low DO level and an apparent excess phosphorus removal initiated by the nonaerated selector. All of the effluent data have proved to be outstandingly good thus referring to an optimum operation of the system.

5. Conclusions

Installation of an anoxic selector in the first part of the flow-through activated sludge basin of the Northpest Wastewater Treatment Plant proved to be effective both in a model experiment and in consecutive field studies. The cost-effective reconfiguration of the system resulted in low and stable SVI values and facilitated an enhanced nitrogen removal originating from high rate nitrification and effective denitrification. All of the different reference systems proved to be less stable and provided relatively poor performance in sludge settling characteristics and nitrogen removal. The reconfigured system maintained its favorable results also at a 30% increased load.

The significantly improved SVI values allowed the application of an increased MLSS concentration in the selector system. However, at the basic load of the system, this might have resulted in a decreased efficiency of the selector. It can be assumed that a staged selector would further improve the performance regarding the uneven distribution of both the hydraulic and organic load. In order to optimize the operation of the improved configuration of the activated sludge unit, an appropriate control of the flow distribution as well as a fitted control strategy of the aeration is recommended.

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References

[1] CHUDOBA, S. – GRAU, P. – OTTOVA, V., Control of Activated Sludge Filamentous Bulking – II. Selection of Microorganisms by Means of a Selector, *Water Research*, **7** (1973), pp. 1389–1406.

[2] DAIGGER, G. T. – NICHOLSON, G. A., Performance of Four Full-Scale Nitrifying Wastewater Treatment Plants Incorporating Selectors. *Research Journal, Water Pollution Control Federation,* **62** (1990), pp. 676–683.

[3] JOBBÁGY, A. – NÉMETH, N. – ALTERMATT, R. H. – SAMHABER, W. M., Encouraging Filament Growth at an Activated Sludge Treatment Plant of the Chemical Industry. 2^{nd} *International Conference on Microorganisms in Activated Sludge and Biofilm Processes*, Berkeley, California, USA, July 20–23, 1997, Proc. pp. 653–656.