Progress Report 2004

Preliminary investigations
for the Margaretenhöhe MBR demonstration plant

A study subcontracted by the Berlin Centre of Competence for Water for the EU-Life demonstration project ENREM
"Enhanced Nutrients Removal in Membrane Bioreactor"

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Abstract

As part of the EU-Life ENREM demonstration project the Department of Chemical Engineering, TU Berlin, was appointed to conduct the preliminary pilot trials in a representative site for verification of basic process designs and operation criteria of the full-scale MBR demonstration plant. In addition to conception and construction of the pilot plant, this investigation consists of two successive trial phases with distinct operation conditions: the first one being dedicated to the assessment of the "irregular sludge wastage strategy" (the biomass is accumulating in the reactor, which is partly emptied when the sludge concentration reaches a given value), and the second one being planned to verify normal operation conditions with daily sludge wastage. This progress report describes implementation and results of the first phase, for which a pilot plant of 140L was operated over 6 months with waste water of a decentralized area.

The influent contained high concentrations of nitrogen (100-200 mg/L), phosphorus (10-20 mg/l) and COD (1000-2000 mg/L). Also surprising were the high VFA concentrations (100-300 mg/L) which ensured a good EBPR process.

The COD and also the enhanced biological phosphorus removal (EBPR) were not impacted by the irregular sludge wastage. COD effluent concentrations were around 50 mg/L and TP effluent was 0.1 to 0.3 mg/L.

The high nitrogen influent concentrations were problematic. Due to changing TS concentrations and changing nitrification rates TN effluent was 10 to 30 mg/L with a NH_4-N content of 0 to 20 mg/L. Denitrification rates were measured between 1 and 3 mgN/gVS h and were depending on TS concentration, with higher rates at lower TS concentrations.

Polysaccharide concentrations in the sludge water phase were higher with low TS concentrations and low oxygen concentrations. Higher PS values led to faster fouling.

Results of the trials suggest that the oxygen concentration should be kept above 2mg/L to ensure both sufficient nitrification and lower fouling. Since also high TS concentrations are needed to ensure complete nutrients removal the optimum TS range is relatively small and it must be concluded that the irregular sludge wastage strategy was not beneficial in this case and the demonstration plant should be run with regular sludge removal.

Content

Nomenclature

DNR	specific denitrification rate, $\frac{\Delta NO_3 - N}{\Delta t \cdot VSS}$ (mgNO_3-N/gVS h)
DO	dissolved oxygen (mgO_2/L)
EPS	extracelluar polymeric substances
HCT	hydraulic contact time (h)
HRT	Hydraulic retention time (h)
NR	specific nitrification rate (mgN/gVS h)
PS	polysaccharides
TS	total solids (g/L)
VS	volatile solids (g/L)

1 Introduction

Aiming at the development of a high performance membrane activated sludge system for municipal waste water treatment in decentralized areas, the Berliner Wasserbetriebe (BWB), Veolia Water (VeW) and TU Berlin conducted the three year IMF project in the frame of the Kompetenzzentrum Wasser Berlin (KWB). Results of the IMF project suggest a system which combines enhanced biological phosphorus removal (EBPR) with post-denitrification without additional carbon dosing (Adam 2003, Lesjean et al. 2002, Gnirss et al. 2003). In October 2003 a proposal was submitted to the EU-Life program named “Enhanced Nutrients Removal in Membrane Bioreactor” (ENREM) in order to construct a demonstration plant with this innovative process. The proposal was accepted by the European Commission in September 2004 with official start in January 2004.

This study is part of the ENREM project. Major goals are the verification of basic process designs and operational parameters with a pilot plant erected on a representative site.

The central task for the first month was to test if it is beneficial to operate the plant with an irregular sludge removal. A preliminary study (Stumpf 2004), done for small plants up to 100 m^3/d, showed the financial benefit if the excess sludge is not daily removed, and stored in an extra tank, but stored in the biological reactor and wasted only every two weeks. Aimed was a removal of 2/3 of the total sludge in the plant. TS concentration should be between 5 and 15 g/L. Major advantages of irregular excess sludge wastage are:

- No extra storage tank
- Because of a slightly bigger plant (+ 2 h HRT) peak loading is better buffered
- Cheaper, if excess sludge is removed fortnightly

Starting the tests these disadvantages were considered:

- Inexperienced operation
- Disturbance of biomass
- Possible failure of EBPR because of high P content in the biomass at the end of each cycle
- Possible higher production of extra cellular polymeric substances (EPS) because of more stress for the mircoorganisms

Also a detailed raw water characterization was carried out. This was done on the selected testing site, but also in an area with a pressurized sewer, since the demonstration plant will be connected to such a sewer scheme.

2 Selection of testing site and raw water characterization

Three possible pumping stations were compared: ÜPw Jungfernheide (ÜPw Jhd, ca. 800pe), ÜPw Gatow C (ÜPw Gat C, ca. 2500pe) and ÜPw Grünau C (ÜPw Grü C, ca. 800pe). In the first weeks ÜPw Jhd was preferred for logistic reasons, since indoor operation was possible and it was the most central located one. But it was excluded for two major reasons: storm water fraction is up to 30% and waster water could only be taken from a 9 m deep main with just a thin water layer flowing through it.

Finally ÜPw Grü C (Figure 2-1) was chosen before ÜPw Gat C, since Grü C has a three times smaller catchment area and Gat C is still growing.

The catchment area of ÜPw GrüC is located in the south east of Berlin and contains mostly private houses. It exits also 3 small restaurants, one school, one hair dresser, one petrol station and a couple of boat houses. Pumping requirement is around 80m³/d. The pumping station is connected to a separated sewer and therefore storm water influence is about 10%. The pumping station main is 6.5 m deep and cleaned on a regular basis.

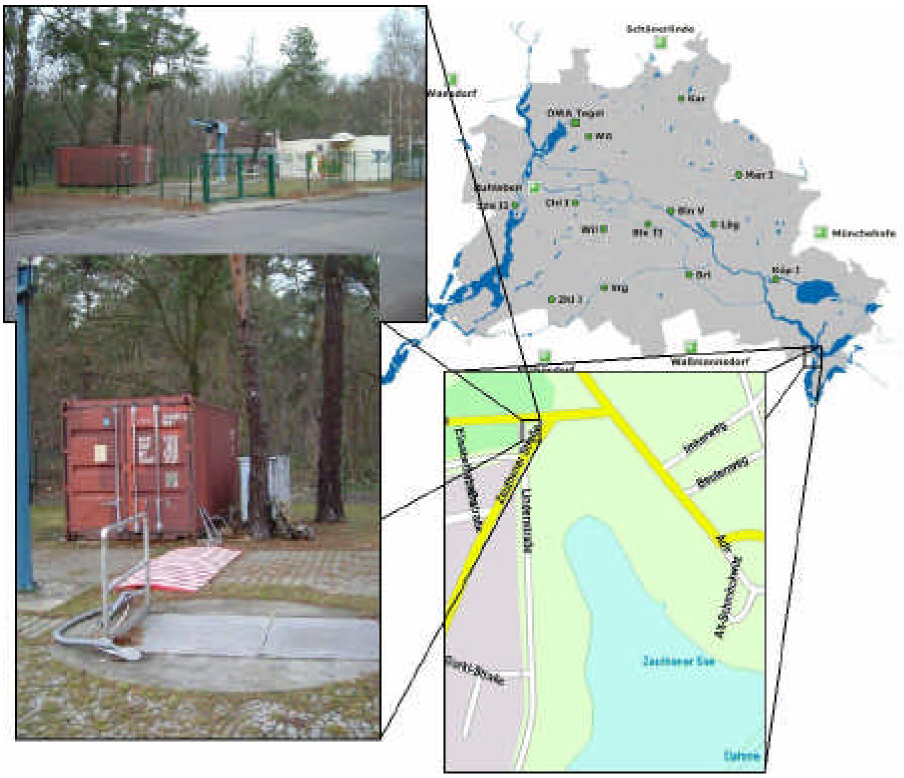

Figure 2-1 Chosen testing site ÜPw Grünau C

Margaretenhöhe will be equipped with a pressurized sewer. Since ÜPw Grü C is connected to a gravity flow sewer, a representative sewer network was selected. Rahnsdorf, Hessenwinkel, which is also located in the south east of Berlin, was selected. It is a separated pressurized sewer serving app. 500 inhabitants. 2h mixed samples were collected with an automated sampler and flow was measured with the ultrasonic-Doppler-method.

2.1 Hydraulic influent profiles

During the operational time the storage tank was fed with three different hydraulic profiles, one with constant influent in the storage tank and two with daily flow profile. The Rahnsdorf profile (Figure 2-2) was evaluated in Berlin-Rahnsdorf, an area with a pressurized sewer, with four flush events per day. They are clearly visible in four peaks during the day (6, 12, 17, 21h). The ÜPw GrüC profile (Figure 2-3) was evaluated at the testing site pumping station by averaging two dry weather working days. The decentralized character of the profile establishes in the very low influent during the night (0-4h), the sudden increase in the morning and a second peak in the evening (20h).

Period	Influent profile	Average Influent (L/h)
9.7.04 -13.9.04	constant	13
13.9.04 – 23.09.04	Rahnsdorf	13
23.9.04 – present day	ÜPw GrüC	13

Table 2-1 Periods of different hydraulic influent profiles

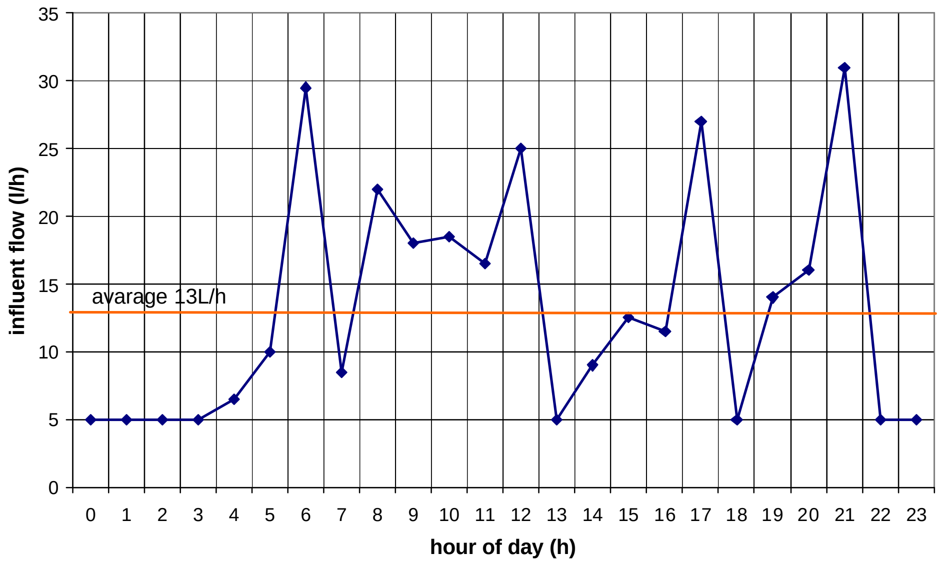

Figure 2-2: The hydraulic influent profile based on flow measurements in Rahnsdorf.

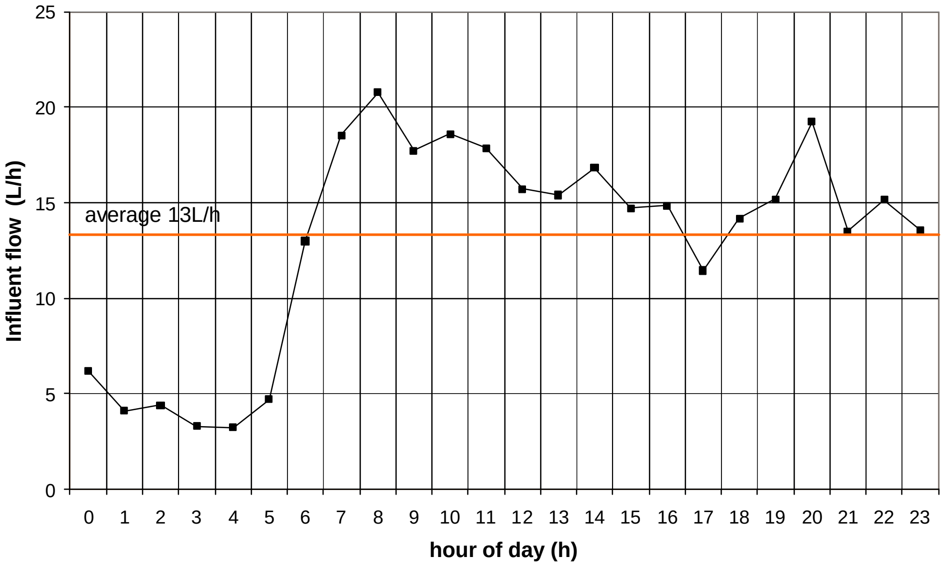

Figure 2-3 Hydraulic influent profile based on flow profile in ÜPw Grünau C

2.2 Raw water characterization and storage tank effect

Raw water characterization was done in Grünau and Rahnsdorf. In Grünau samples were taken from the influent to the storage tank and from the storage tank itself. Figure 2-4 and Figure 2-5 show typical data for the COD, nitrogen, and phosphate fraction in the influent and the storage tank (more data in Villwock, 2005). During these measurements the hydraulic influent profile in the storage tank was based on the Rahnsdorf profile. Lacks in the influent series resulted from poor sample volume, what was caused by the often very low flow rates of the Rahnsdorf profile. Figure 2-6 and Figure 2-7 show the same parameters but with the Grünau profile.

From the figures it becomes apparent that influent concentrations for both locations and all parameters were unexpected high and show a big variation: DOC 600-3000 mg/L, total N 90-150 mg/L, NH_4-N 70-120mg/L and total P 15-30 mg/L. But they also show that the storage tank with a maximum of 12h HRT reduced the range for each parameter by at least 50%.

Volatile fatty acids were in a range of 100 to 300 mg/L. This was surprisingly high, since the sewer in Grünau is relatively short (max. 1000m). Assumed was the development of anaerobic zones, due to deposits in the sewer, where the VFAs are fermented.

Raw water measurements from the Rahnsdorf pressurized sewer (Figure 2-8, Figure 2-9) show that the average value for all parameters was as high as in Grünau, but the range was smaller, due to the storage tank in the houses and the storage in the sewer. VFAs are around 100 mg/L.

From the gained data it can be concluded that enough VFA reach the treatment plant to ensure the EBPR process. The storage tank reduced concentration variations by 50% hence a relatively constant influent into the plant is possible. Especially for the nitrogen fraction very high concentrations must be considered for the design of the plant.

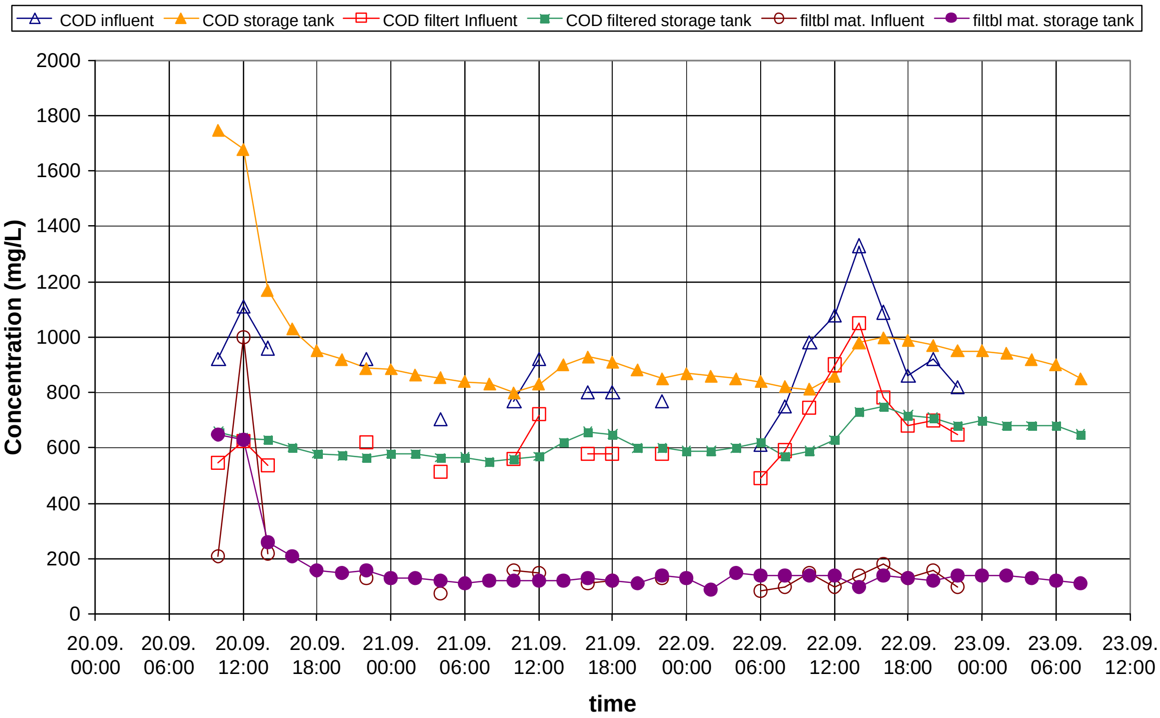

Figure 2-4 COD, filtered COD, and filterable matter in the influent and in the storage tank (Grü C). Hydraulic influent profile is the Rahnsdorf profile

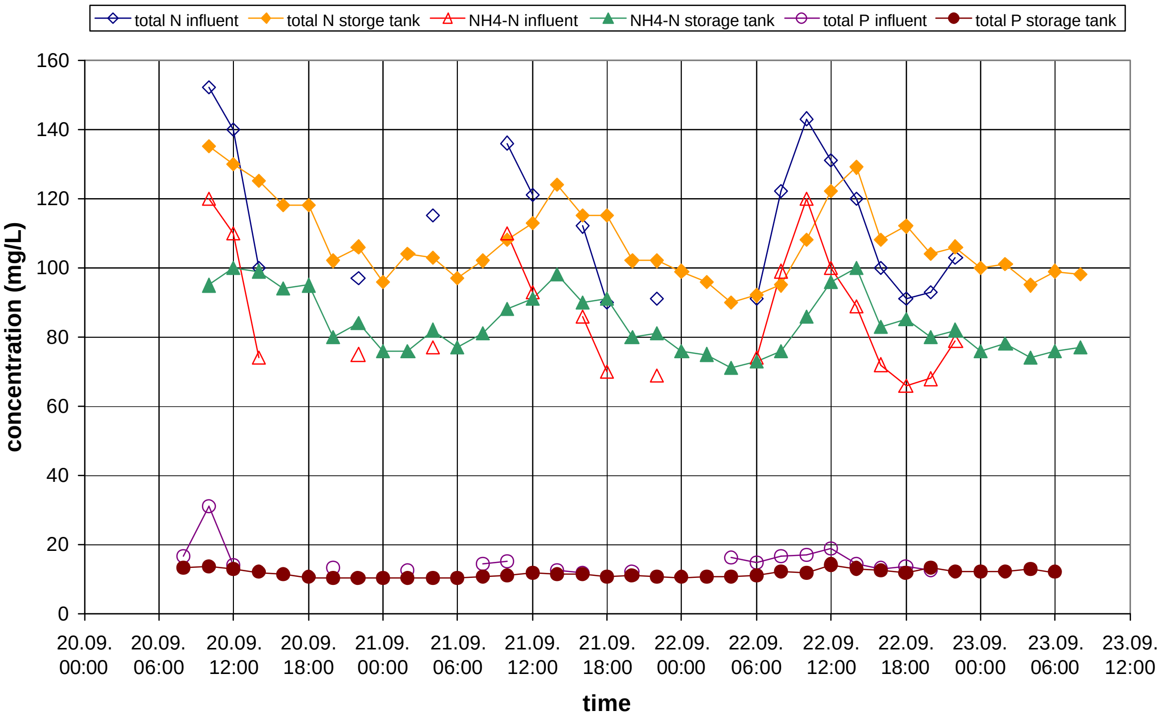

Figure 2-5 Total N, NH_4-N, and total P concentration in the influent and in the storage tank (Grü C). Hydraulic influent profile is the Rahnsdorf profile

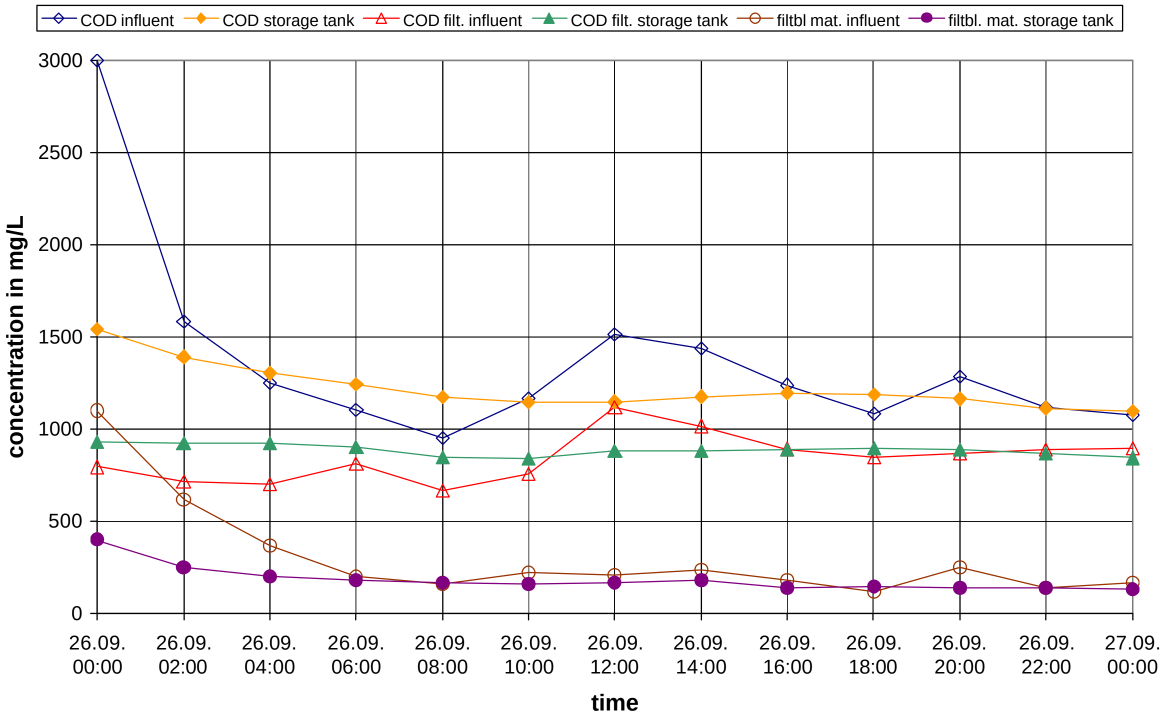

Figure 2-6 COD, filtered COD, and filterable matter in the influent and in the storage tank (Grü C). Hydraulic influent profile is the Grünau profile.

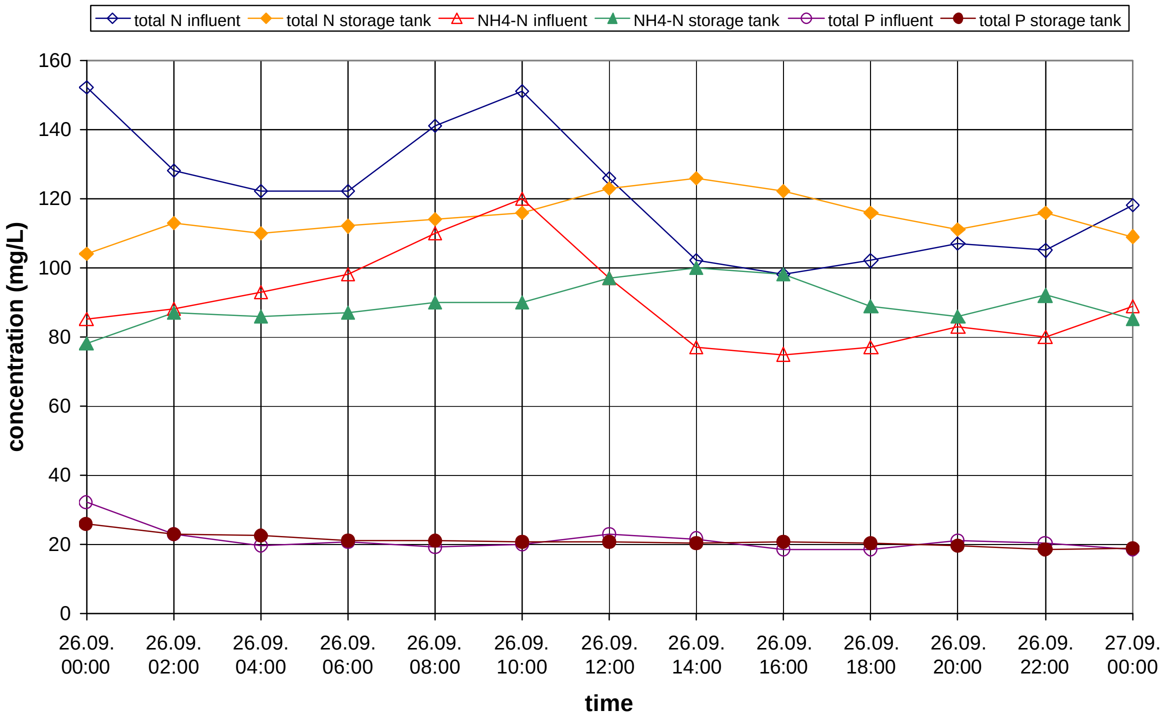

Figure 2-7 Total nitrogen, NH_4-N, and total phosphate concentration in the influent and in the storage tank (Grü C). Hydraulic influent profile is the Grünau profile.

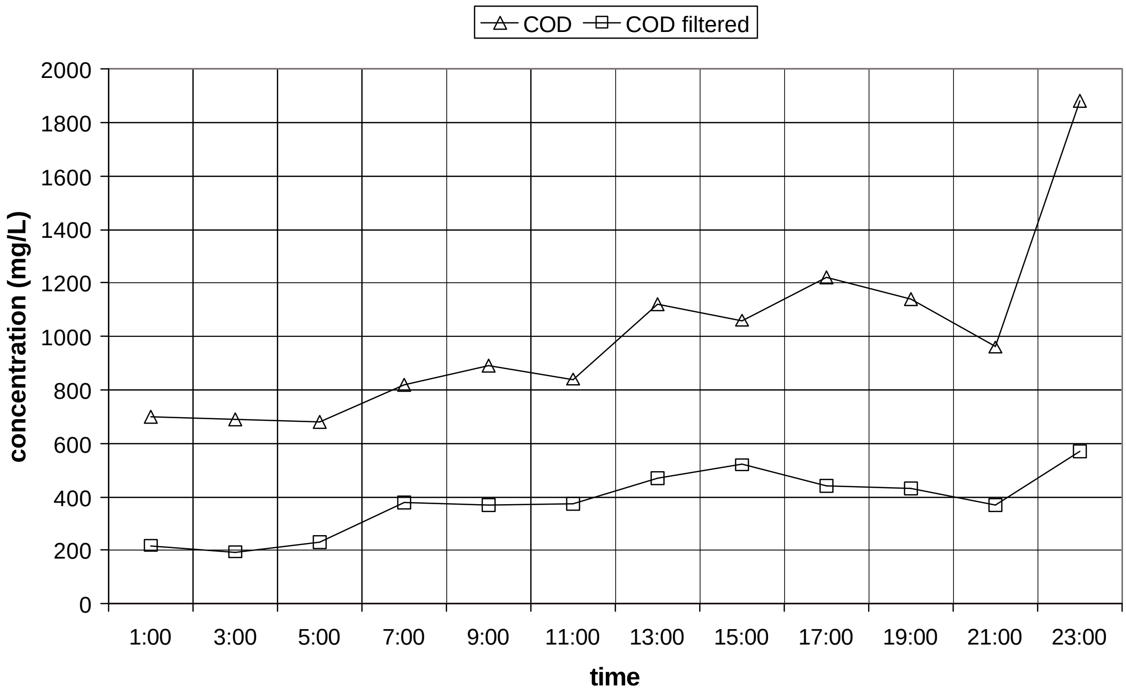

Figure 2-8: Rahnsdorf COD profile (2h mixed samples)

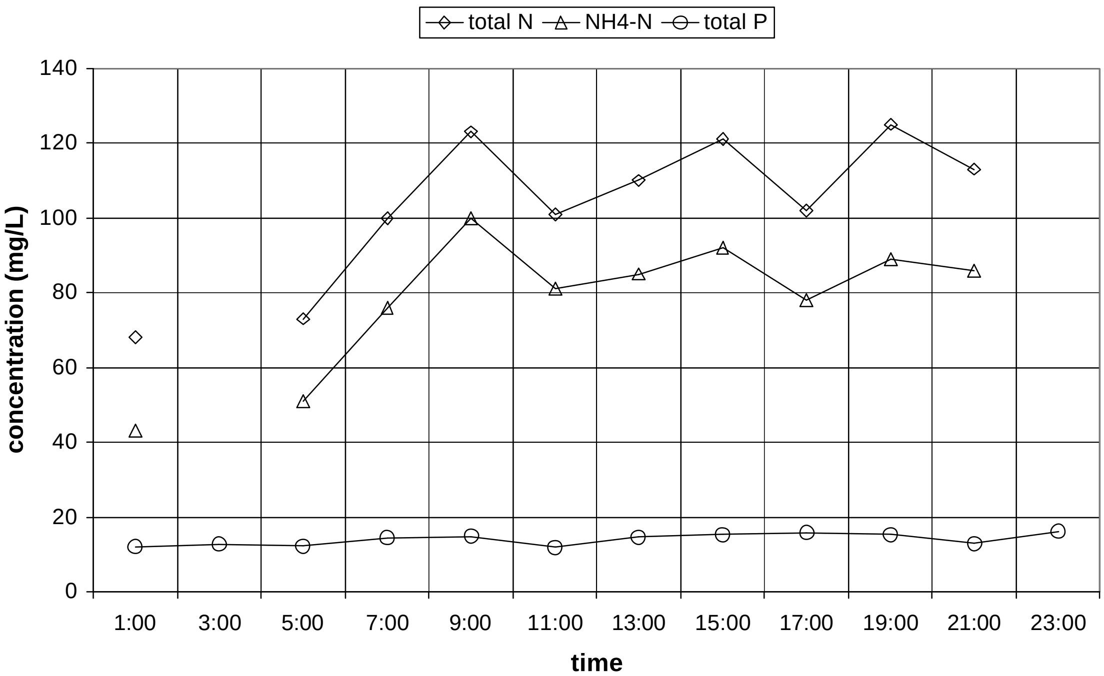

Figure 2-9 Total N, ammonium, and total P Rahnsdorf profile (2h mixed sample).

3 Material and Methods

3.1 Pilot plant

The pilot plant was constructed in the workshop of the department of chemical engineering, TU Berlin, and tested there with tap water for one week. Afterwards it was brought to the selected testing site and rebuilt there in a 20'' container. A flow sheet of the plant is shown in Figure 3-1 and Figure 3-2. Detailed plant data are given in Table 3-1.

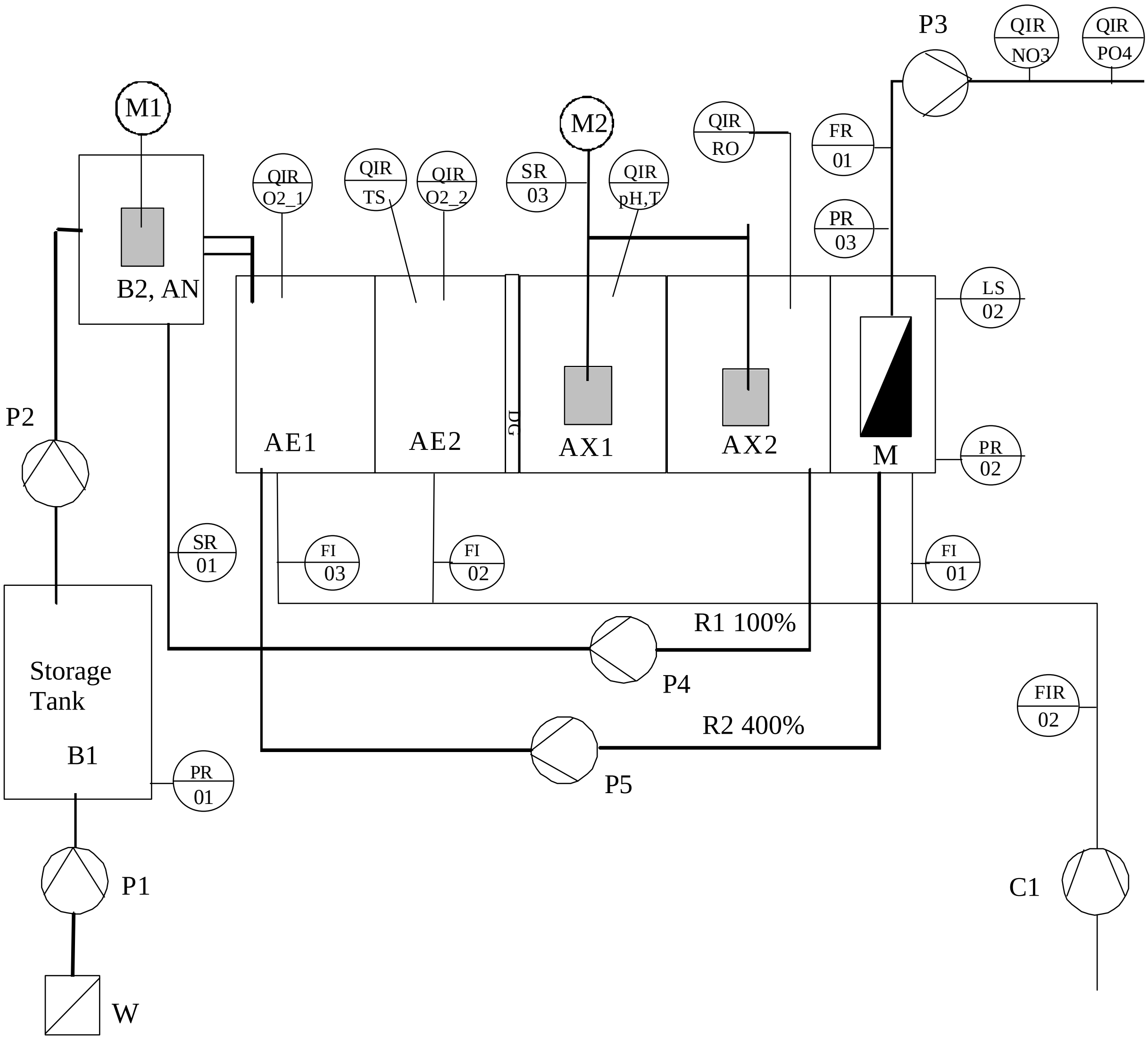

Figure 3-1: Flow sheet of the pilot plant. All pumps are peristaltic pumps. W=wastewater, AN=anaerobic, AE=aerobic, DG=degassing, AX= anoxic, M=membrane

Pump P1 sucked raw waste water through a screen with 1 mm slits directly from the pumping station main and discharged in the storage tank B1 (max. 156L, i.e. 12h HRT calculated with constant plant throughflow of 13L/h). Pump P2 delivered waste water from the bottom of the storage tank to the bottom of the anaerobic reactor with a constant throughflow of 13L/h. From then on mixed liquor flow was realized by gravity at the exception of the two recycling streams. In the aerobic zone oxygen transfer was realized with sintered fish tank aerators. After passing the aerobic zones, the sludge entered from the top a ca. 5 cm wide zone and left it from the bottom. The zone was meant for reducing oxygen transfer to the anoxic zones. Recycle stream R1 was taken from the second anoxic zone and discharged in the anaerobic tank with the same flow rate like the influent (P2). The last chamber was equipped with the membrane module. From here recycle stream R2 was pumped with 400% flow rate of the influent (P2) in AE1. The membrane was aerated from the bottom with sintered fish tank aerators. A membrane module was provided by the German research centre GKSS, Geesthacht, in a form of a cushion module with poly-acryl-nitrile (PAN) membranes of a 37nm nominal pore size. The permeate was sucked by pump P3. Filter cycle was 14 min filtration and 1 min relaxation break.

	V (L)	HCT (h)	HR T(h)	length (mm)
AN	26,3	2,0	1,0	
AE1	18,1	1,4	0,2	217
AE2	17,8	1,4	0,2	213
DG	5,0	0,4	0,1	45
AX1	26,7	2,1	0,3	320
AX2	26,7	2,1	0,3	320
M	19,5	1,5	0,3	210
Total	140,0	10,8	2,5	1325

Table 3-1 Volume, hydraulic contact time (HCT), hydraulic retention time (HRT), and length of each zone

Figure 3-2 Membrane module (left) and pilot plant (right) in the workshop

3.2 Batch tests

Batch tests were conducted in a tempered 1L batch reactor to evaluate biological kinetics. In most tests, sludge from the second anoxic zone was exposed to three different conditions: anaerobic, aerobic and anoxic to simulate the successive conditions present in the process. During the anaerobic and anoxic phase, the reactor was flushed with nitrogen. During the aerobic phase compressed air was pumped in the sludge. Acetate was first spiked, as well as ammonia and nitrate, respectively at the start of the aerobic and anoxic conditions. A more detailed description of the batch tests will be in the Diplomarbeit of Daniel Stumpf (2005).

3.3 Chemical analysis

Total nitrogen, total phosphate, total fatty acids and COD were measured with Dr. Lange test kits. Anions (PO_4-P, NO_3-N, NO_2-N) and cations (NH_4-N, C, Ka, Mg) were measured on Dionex DX 100 ion chromatograph. In some cases when the ion chromatograph was out of order, ions were measured with Dr. Lange test kits as well.

For the raw water characterization some analyses were done in the BWB laboratory in Berlin Ruhleben, with methods different from the above mentioned.

Extracelluar polymeric substances (EPS) analyses:

Sludge samples were taken in the membrane chamber twice a week. In order to minimize the influence of daily and weekly fluctuations, samples were always taken periodically on the same days and hours. Sludge was separated from the liquid phase containing soluble and colloidal substances by paper filtration (black ribbon, Schleicher & Schuell). Polysaccharide (PS) concentration in the filtrate and in plant permeate was measured according to the photometric method proposed by Dubois et al. (1956) which yields results in glucose equivalents.

4 Operation of the pilot plant with irregular sludge wastage

On the 9.7.2004 the pilot plant was seeded with recycle sludge from the WWTP Wassmannsdorf which operates with EBPR and pre-denitrification. Afterwards the plant was operated continuously. A relatively stable operation was reached after 6 weeks. Table 4-1 summarizes major events during the first 6 months of operation.

Date	Event
9.7.04	Start of operation (no constant inflow)
from 26.7.04	Constant inflow of 13L/h
31.8.04	1. membrane cleaning
from 13.9.04	Rahnsdorf influent profile
from 23.9.04	Grünau C influent profile
29.9.04	2. membrane cleaning
28.10.04	3. membrane cleaning

Table 4-1 Major events

4.1 Start up problems

During the start up phase two major operational problems occurred. The first one concerned the influent pump P1. The pump must draw the waste water against 7m water column. On peristaltic pumps the suction performance depends strongly on the ability of the flexible tube to reopen. The firstly used Pharmed tubes with a wall of 1.6 mm could only provide enough flow for three days hence the plant was not correctly fed in the first weeks. Since these were not suitable operational conditions a replacement rotor was implemented to use Norprene tubes with 2.4mm wall thickness, which enabled a stable and sufficient flow for several weeks. A constant inflow into the plant of 13L/h was provided from the 26.7.04.

The second major problem was level control. The first used pressure indicator was faultily from the start on and failed completely after one month. The second sensor showed an intolerable temperature dependency and was replaced with a better temperature compensated sensor on the 12.10.2004. Afterwards the level in the reactor was reliably controlled. Especially in the first month, level control problems led to a lot of overflow events and uncontrolled sludge loss occurred.

On a few days the controlling computer failed. Since one of these events led to sludge loss, a non computer based level switch was installed.

4.2 Evolution of biomass concentration, loading rates and sludge yield

Biomass evolution. The pilot plant was operated with irregular sludge removal. At the beginning of the operation it was decided to withdraw the sludge at least every two weeks in order not to disturb the EBPR process by a too high P content in the sludge. Figure 4-1 shows that the P-content in the sludge was relatively stable around 3-4% and raised just slightly towards the end of one sludge removal cycle. After two months of operation it was revealed that even with longer cycles the EBPR process could work reliably. Afterwards the measured oxygen concentration in the aerobic zones, dependent mainly from sludge concentration and temperature, was the indicating parameter for a necessary sludge wastage. When it dropped below 2 mg/L 50% of the sludge in the plant was withdrawn.

Due to the irregular sludge wastage the TS concentration varied between 3 and 13 g/L in the aerobic zone. In the start up phase, when a lot of unscheduled sludge losses took place, TS concentration was on a lower level. With a more stable operation from September and no unwanted sludge losses, the TS concentration was kept between 6 and 13 g/L. The reduction of biomass on the 4.10.04 was not due to a sludge wastage but may result from a massive foam sludge build up. Since that date a 2 to 3 cm high stable foam sludge layer was observed on both anoxic zones. Figure 4-2 shows that VS concentration of the foam sludge was stable around 80% while TS varied on a high level between 40 and 70 g/L. In the foam sludge a lot of oligochets (*Aeolosoma*, small red worms) could be observed. These organisms are typically encountered under unstable conditions and peak loading of WWTP (BLW, 1999)

On the 26.11.04 a serious failure led to nearly complete sludge loss. Considering the 3.5 gTS/L measured on 29.11.04 a concentration of approximately 2 gTS/L is assumed for the 27th.

The VS concentration rose from 50% at the start and stabilized around 76%. This increase can be explained by the different waste water reaching the WWTP Wassmannsdorf. Furthermore the WWTP Wassmannsdorf is operated sometimes with co-precipitation which leads to an increase of the inorganic fraction in the sludge.

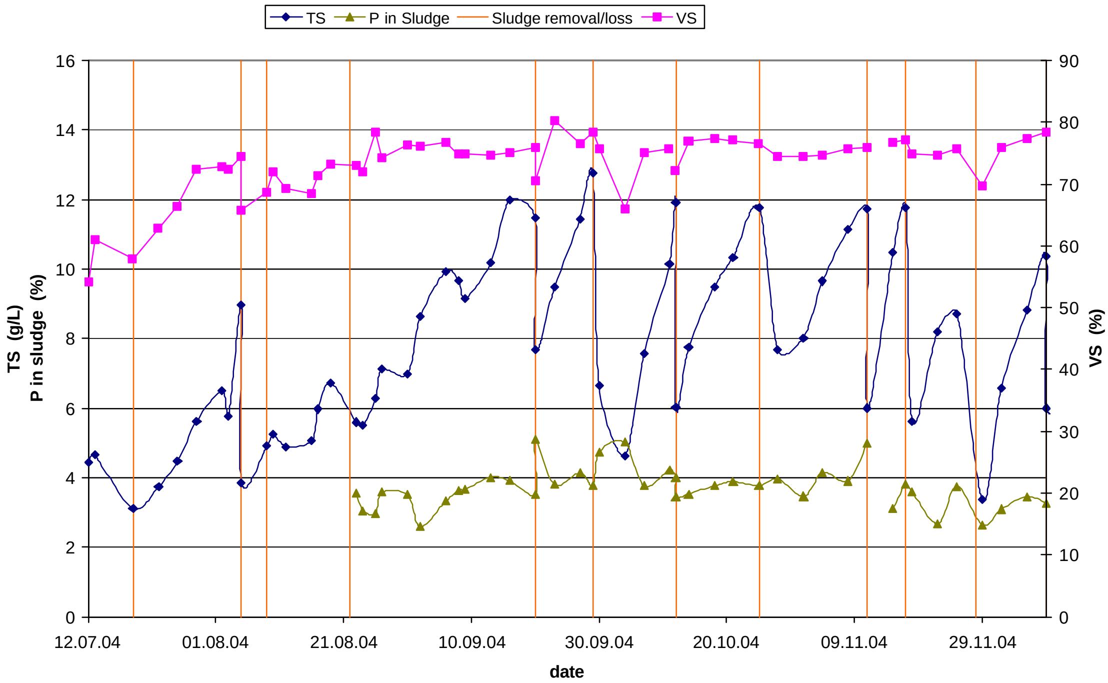

Figure 4-1 TS, VS and P content evolution

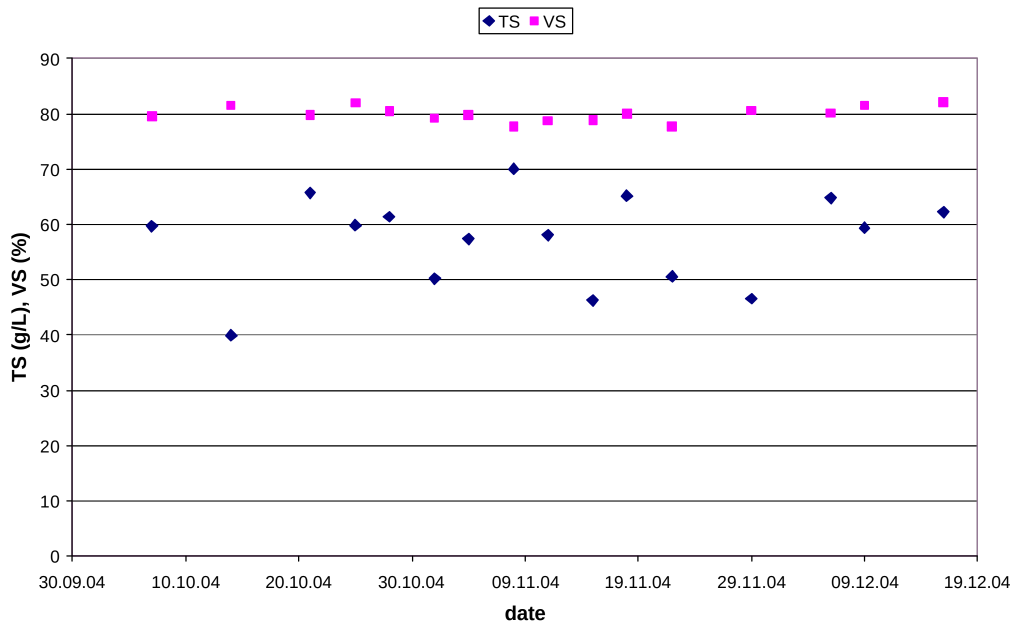

Figure 4-2 Foam sludge TS and VS concentration

Loading rates. The pilot unit was operated under varying COD- and TN-loads, as a result of varying pollutants concentrations in the waste water and varying biomass concentrations in the process. The evolution of the F/M ratio for COD and nitrogen are given in Figure 4-3. COD loading was between 0.2 and 0.4 kgCOD/kgTSS d at the beginning of the trials but raised up to 1 kgCOD/kgTSS d from October onwards. The higher COD loading occurred with more solids in the influent and caused a faster growth rate and shorter sludge removal cycles. Nitrogen loading was high for a domestic wastewater, and between 0.024 and 0.09 kgN/kgTSS d.

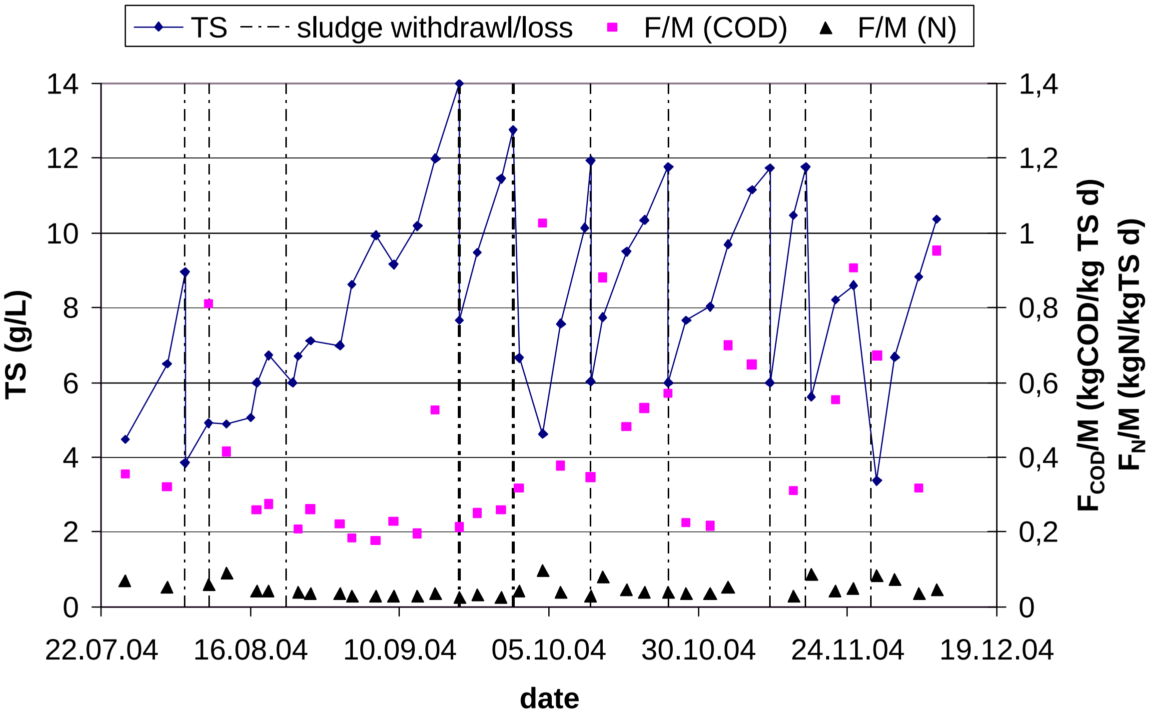

Figure 4-3 Evolution of TS concentration and COD and nitrogen loadings

To verify that all zones are sufficiently mixed and no sludge settlement occurs and no short circuits exist in the plant three TS profiles were measured in the plant. Figure 4-4 shows the measurement of 14.10.04. It becomes apparent that the measured data matched well the theoretical values from the mass balance due to the sludge recirculation pattern. Deviation was in the range of the measurement accuracy, hence well mixed zones were assumed.

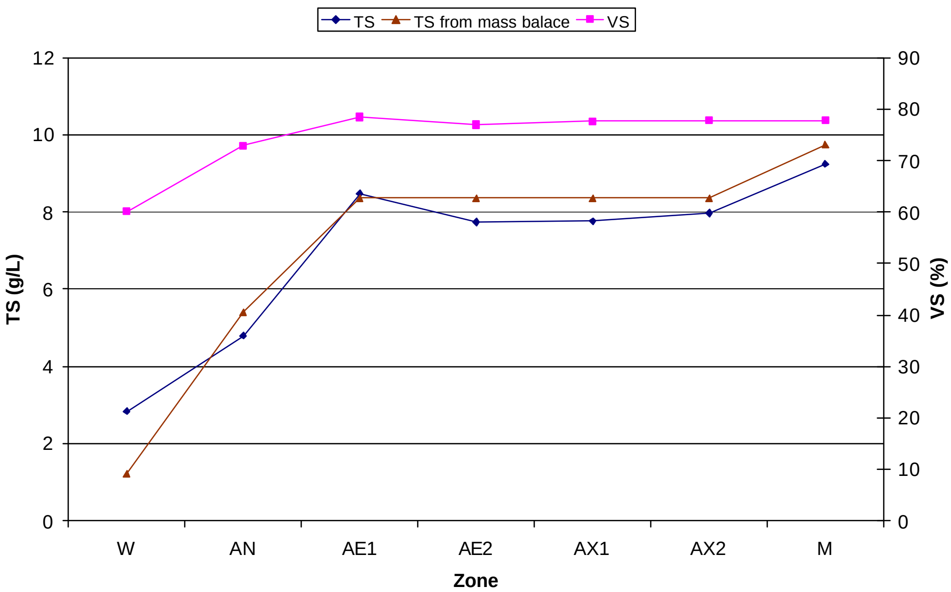

Figure 4-4 TS Profile in the plant on 14.10.04

The sludge yield was calculated based on COD reduction measured in the profile measurements twice a week. Table 4-2 shows the average yield for each sludge cycle. It is apparent that the yield scatters a lot and is relatively low. The overall average yield was 0.21 gTS/gCOD. Assuming a COD/BOD relation of 1.8 this would lead to 0.38 gTS/gBOD which matches the ATV values for a solid retention time of 25-30d, considering the amount of sludge produced by biochemical phosphorus removal.

Sludge Cycle	y (gTS/gCOD)	avg. COD removal (mg/L)
19.7.-5.8.	0.43	667.25
5.8.-19.8.	0.10	854.53
19.8.-.20.9.	0.14	873.92
20.9.-29.9.	0.25	959.40
29.9.-12.10.	0.14	1290.23
12.10.-25.10.	0.08	2226.10
25.10.-11.11.	0.05	2964.52
11.11.-17.11.	0.34	1198.40
17.11.-25.11.	0.06	2883.33
25.11.-9.12.	0.12	2469.48
9.12.-16.12.	0.06	1984.20
16.12.-10.1.	0.19	851.80

Table 4-2 Sludge yield and average COD removal for each sludge cycle

4.3 COD elimination

Figure 4-5 shows the evolution of COD elimination during the first 5 months of operation. Right from the start up, COD degradation was never a problem and elimination rates were always above 90%. COD effluent concentrations ranged between 35 and 60 mg/L despite the very high influent values. The COD influent concentration was around 1000 mg/L until October 2004. Afterwards higher values were measured with a maximum of 4300mg/L. These very high concentrations always came along with higher solids concentrations, hence the COD concentration was raised by more solid organics. The effect of a bigger solid fraction in winter months is also known from other plants (Gnirss 2004), but no satisfying explanation could be found so far.

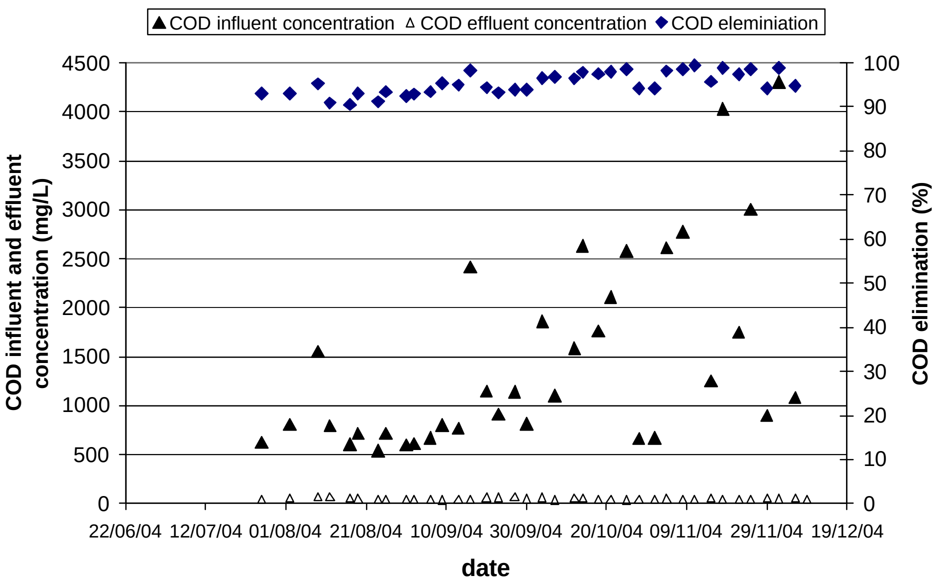

Figure 4-5 evolution of COD elimination and influent and effluent concentration

4.4 Phosphorus elimination

The Phosphorus elimination was rather poor in the start up phase, see Figure 4-6. But after four weeks of operation the elimination rate was always above 95% and TP effluent concentrations were between 0.1 and 0.3 mg/L without addition of any precipitant. Parallel to the evolution of the COD influent concentration, an important increase of the organic P fraction was revealed since October 2004.

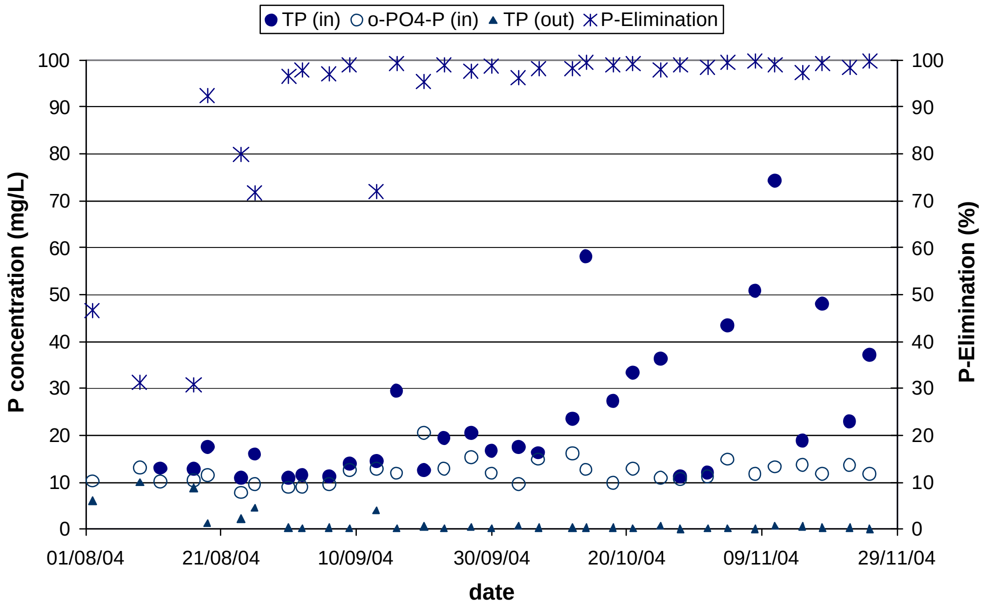

Figure 4-6 Evolution of P influent concentration and P elimination

In the profile (Figure 4-7) a high P-release in the anaerobic zone to 75 mgP/L was observed. This was very typical and also measured in batch tests. Such a high P-release was not observed in previous studies (e.g. Adam 2004). Possible reasons are the higher P-content (4% instead of 2.5%) inside the microorganisms and the higher P-and VFA influent concentration. The plant profile clearly showed good P uptakes in the aerobic and anoxic zones. Batch tests proved, that P uptake rates were up to 10 mgP/gVS h under aerobic conditions (Figure 4-8). A batch test to determine P-uptake under anoxic conditions showed a slightly lower P-uptake rate than under aerobic conditions and P-uptake ended on a level of 10 mgP/L (data not show).

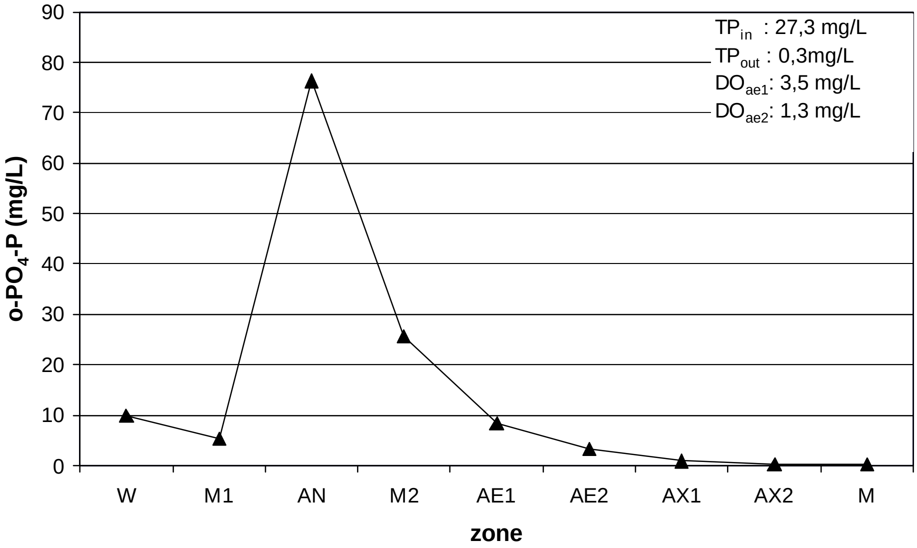

Figure 4-7 Phosphate profile in the plant on 18.10.04 from 8:30AM to 11:00AM.

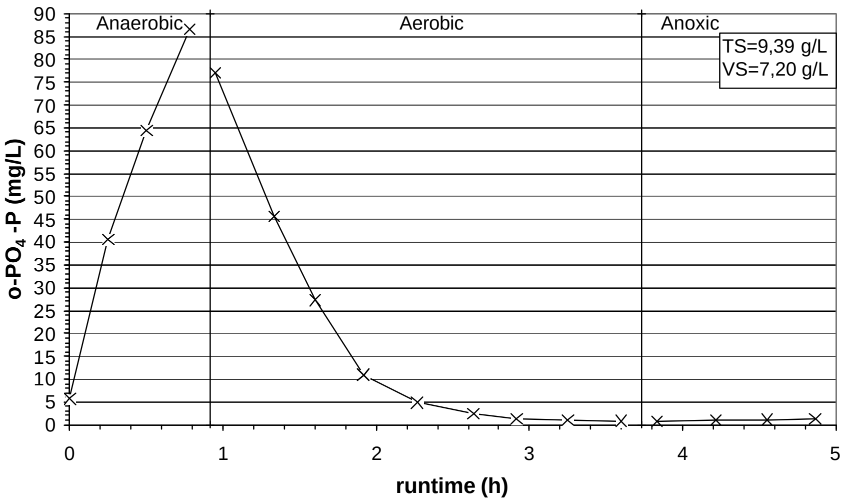

Figure 4-8 Batch test for determination of phosphate release and uptake on 18.10.04.

4.5 Nitrogen elimination

The nitrogen elimination was more problematic than COD and P elimination. Designed for an NH_4-N influent of 70 to 80 mg/L the plant had to deal with 90 to 110 mg/L and a TN up to 380 mg/L (Figure 4-9). Therefore even with elimination rates of 90% and more, observed from September 2004, TN effluent concentrations were between 10 and 30 mg/L. This is clearly above the targetted 5mgTN/L. From the profile (Figure 4-10) it is apparent, that the nitrification was not completed within the aerobic zones. Even with a good nitrification rate (here 2.8 mgN/gVS h at 15 °C) ammonia entered the anoxic zones. In most cases, the remaining NH_4 was finally nitrified in the membrane chamber. When lower nitrification rates or lower TS concentrations occurred, effluent NH_4-N concentrations up to 20mg/L were measured. Nitrification rates were changing a lot during the first month (see Figure 4-12). No clear correlation to e.g. time since last sludge removal or oxygen concentration could be found. Still, a minimum oxygen concentration was needed to achieve nitrification. On 25.10.04 the oxygen concentration was near zero in both aerated chambers and no nitrification was observed. Afterwards it was tried to keep O_2 above 1.5 mg/L in both zones and nitrification rate was mostly above 1.5 mgN/gVS h and increased towards the end of November. This trend was also observed in batch experiments (Stumpf 2005). In the plant and also in the batch tests (Figure 4-11) an accumulation of nitrite was observed during nitrification. This may be due to the high ammonium concentrations in the aerated zones (up to 30 mg/L). *Nitrobacter* (turning NO_2 into NO_3) can be inhibited by ammonium concentrations higher than 7 mgNH_4-N/L at a pH of 7.5.

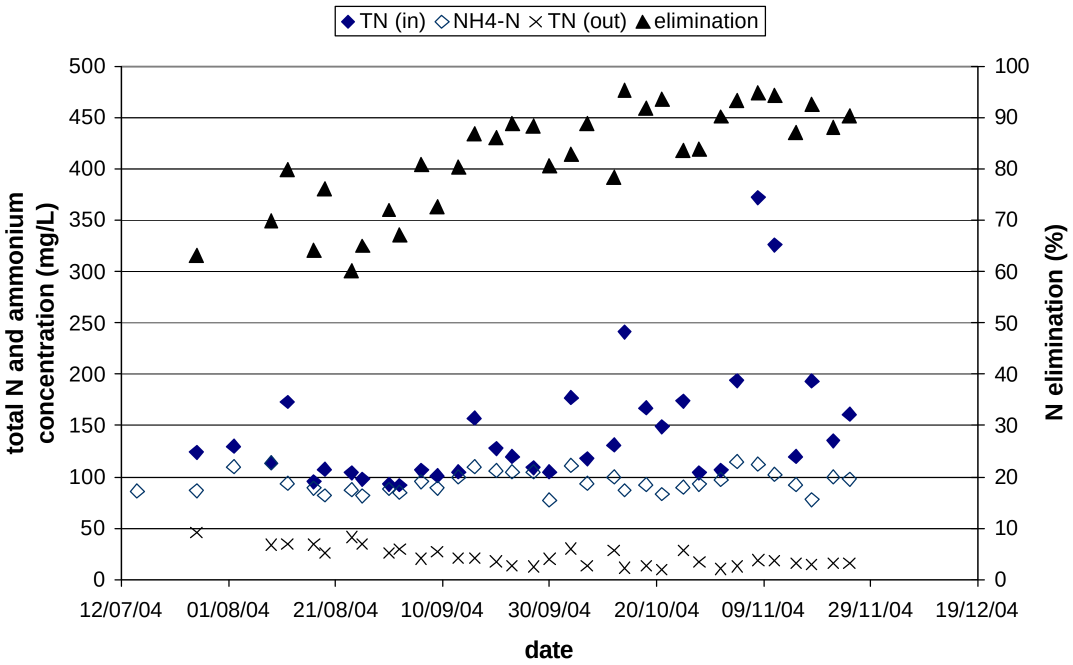

Figure 4-9: Evolution of nitrogen influent concentration and N-elimination

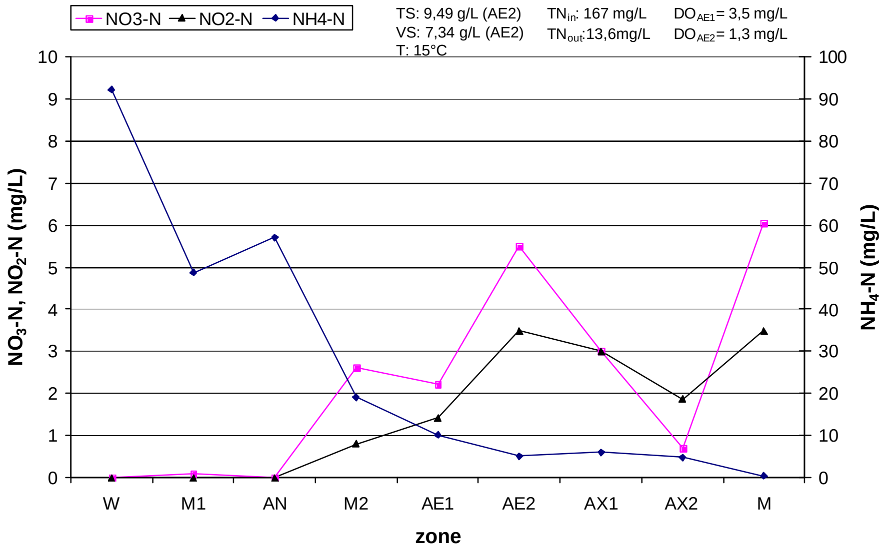

Figure 4-10 Nitrogen fraction profile in the plant on 18.10.04 from 8:30AM to 11:00AM.

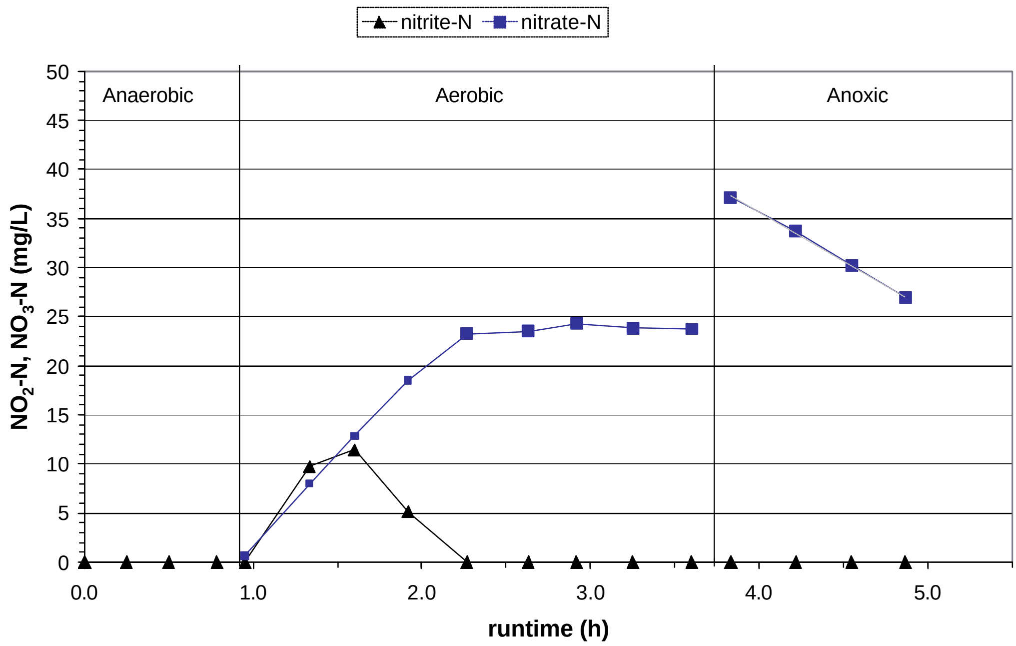

Figure 4-11: Batch test at 20°C with ammonium and nitrate spiking. NR= 2.4 $mgNO_3$-N/h gVS; DNR: 1.4 $mgNO_3$-N/h gVSS, 18.10.04

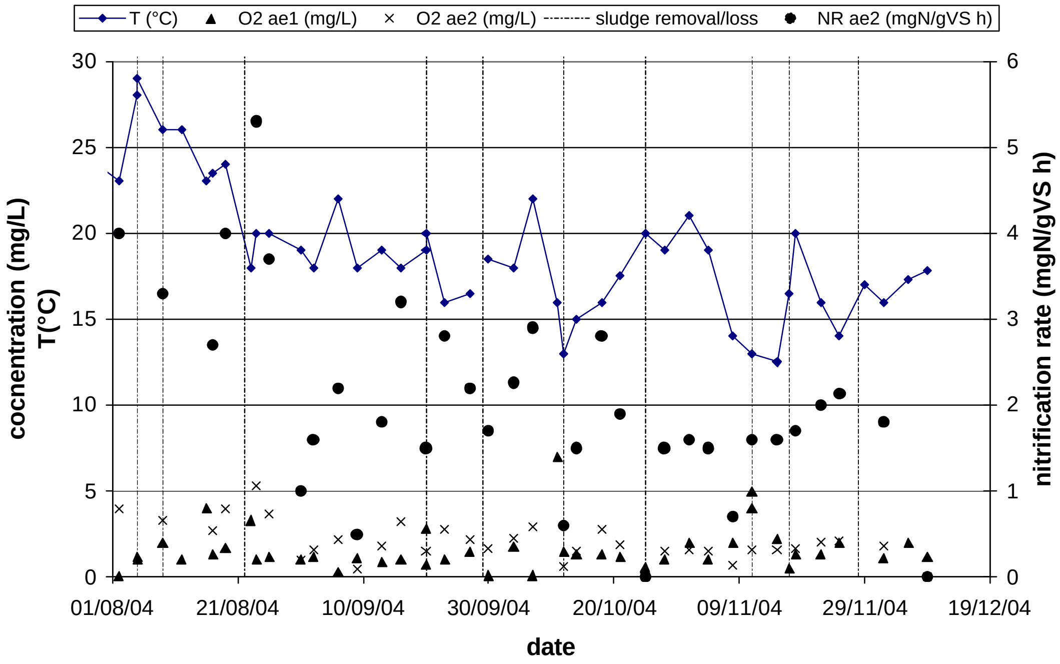

Figure 4-12 Nitrification rate in AE2 at the measured temperature, calculated with the NH_4-N reduction in AE2 and the contact time of AE2

During the whole testing phase, denitrification showed always good rates. It was higher during the start up at 4 mgN/h gVS but stabilized at 1.5 mg mgN/h gVS at 20°C. These rates are clearly above endogenous rates. In Batch experiments endogenous DNRs of 0 to 0.6 mgN/gVS h were measured after 24h of aeration.

Denitrification also showed a dependency on VS concentration. Lower VS values after sludge withdrawal events led to higher DNRs (Figure 4-13). The presented DNRs are measured in 29 batch tests where temperature was 20°C (Stumpf, 2005).

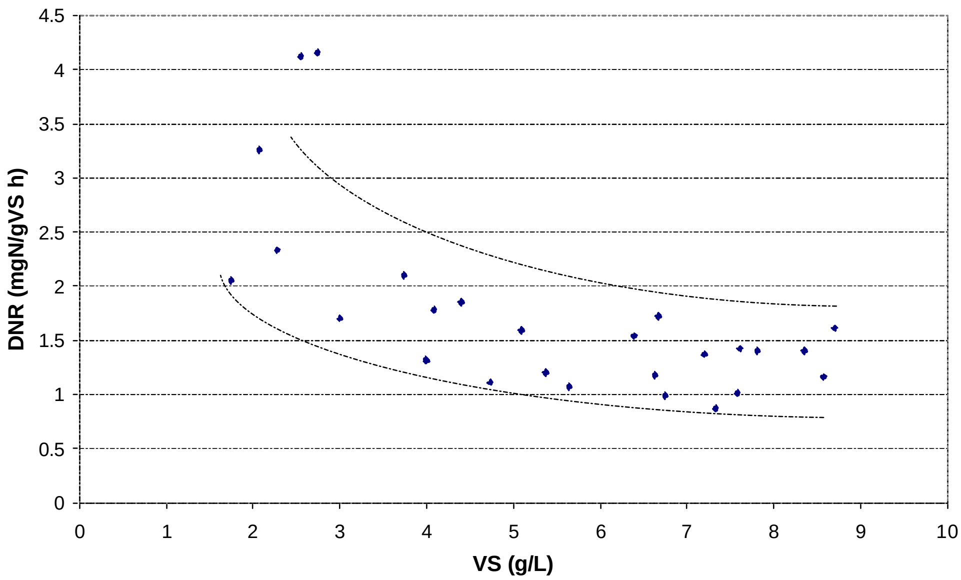

Figure 4-13 DNR dependency on VS concentration, measured in batch tests at 20°C

4.6 EPS measurements and membrane module performance

The concentration of polysaccharides (PS) in the sludge water phase showed two dependencies: TS concentration and oxygen concentration. From Figure 4-14 it is apparent that PS concentrations were on a higher level directly after a sludge withdrawal than after a period of sludge growth. But it could be also often observed that directly before a sludge withdrawal, when oxygen concentrations were low, the PS concentration raised quickly. Particularly striking are the 12.10 and 25.10., where oxygen was below 1mg/L in both aerobic zones and PS concentration was higher before the sludge removal than afterwards.

PS influent measurements showed PS concentrations between 20 and 30 mg glucose/L. It is therefore assumed, that with low TS concentration no PS are degraded while with higher TS concentrations PS are degraded. Under oxygen paucity conditions the biomass seems to produce more extracellular polymeric substances (EPS) as a stress reaction. (More data in Iversen, 2005)

Measured PS concentration in the plant but also in the influent were higher than in previous projects. If the higher concentrations in the plant resulted from the irregular sludge wastage should be confirmed with test phase 2, where regular excess sludge wastage will be implemented.

For the fouling of the membrane two major outcomes were revealed. Higher PS concentrations caused a faster fouling. The fouling was not reversible without chemical cleaning, since the transmembrane pressure was not declining significantly when PS concentrations went down.

Secondly it can be stated that older membranes foul faster. The Module was equipped with new membrane cushions at the start of operation. After the third cleaning the TMP was rising faster than in the previous weeks.

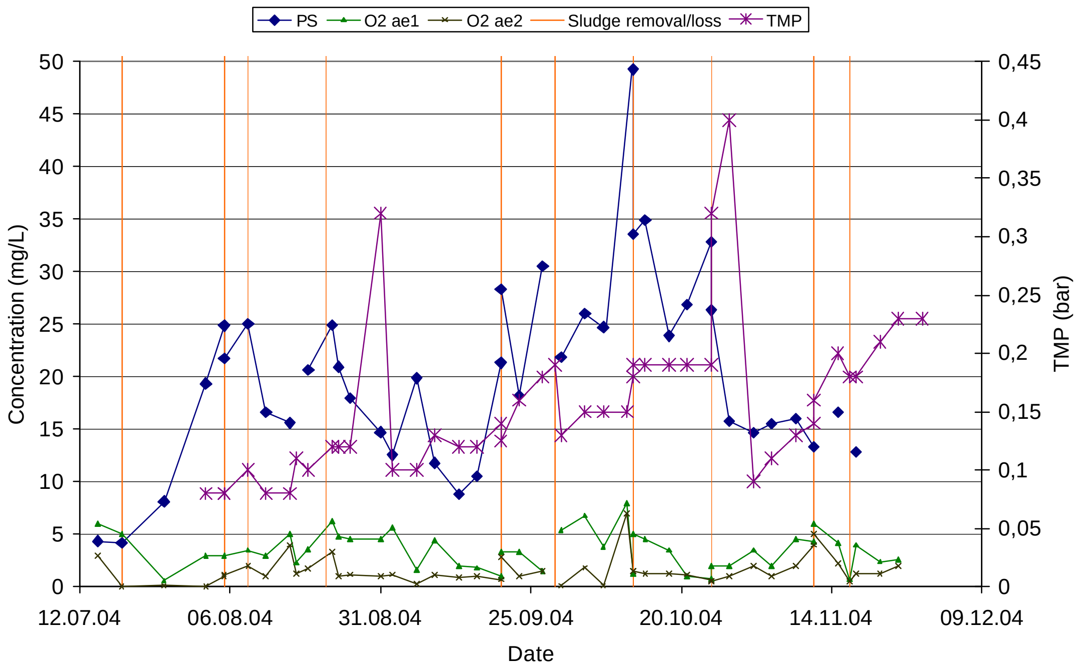

Figure 4-14 PS concentration in the plant and TMP

5 Conclusions and Outlook

After 6 moths operating a pilot plant in a decentralized area with irregular sludge removal a recommendation for the operation and design of the Margaretenhöhe demonstration plant can be given.

The plant should be designed for very high influent concentrations, especially NH_4-N concentrations of 90 to 100mg/L must be considered. Since the influent flow and influent concentration varied a lot during the day, a buffer tank with at least 12 h HRT should be installed, in order to minimize hydraulic and concentration load variations. Total nitrogen effluent concentrations were 10 to 30mg/L under stable operation and NH_4-N effluent concentrations were 0 to 20mg/L. The nitrification rates (app. 2mgN/gVS h) and denitrification rates (app. 1.5 mgN/gVS h) were in the expected range, hence more biomass is needed to produce constantly TN effluent concentrations at the initially targeted 5 mg/L. In contrast to the nitrogen elimination P- and COD elimination were satisfying. Total P effluent concentration was 0.1 to 0.3 mg/L under stable operation. This elimination was reached only by biological removal. The irregular sludge removal did not impact the EBPR process.

The extracellular polymeric substances (EPS) concentration showed higher values after each sludge wastage, when TS concentration was low. Low oxygen concentration led also to higher Polysaccharides (PS) concentrations. Fouling rates were higher with high PS concentrations. The impact of sludge withdrawal strategy on PS concentrations will be further assessed in the second phase of the trials with daily sludge removal.

The oxygen concentration should be kept above 2mg/L to ensure both sufficient nitrification and lower fouling. Since also high TS concentrations are needed to ensure complete nutrients removal the TS range is relatively small and it must be concluded that the irregular sludge wastage strategy was not beneficial in this case and the demonstration plant should be run with regular sludge removal.

The pilot plant will be operated with regular sludge removal from January 2005 onwards. Additionally further tests for the influence of oxygen concentration on PS production will be conducted. Batch tests to monitor kinetics will also be continued.

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