SBR systems followed by wetland treatment:
Long-term observations of two plants in Sweden treating low temperature wastewater

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Sammanfattning

Två olika reningsanläggningar, bägge utformade med ett biologiskt reningssteg baserat på SBR-teknik och med en våtmarksanläggning som ett poleringssteg, presenteras. De två anläggningarna, Nynäshamns kommunala avloppsverk och reningsanläggningen för lakvatten Isätra avfallsanläggning har i så motto en liknande uppbyggnad, men behandlar mycket olika typer av avloppsvatten. I bägge fallen är de låga vattentemperaturerna vintertid en av avgörande faktorer för reningsresultaten. Förhållande lång driftstid vid bägge anläggningarna möjliggör en god redovisning av driftsförhållanden och reningsresultat. Resultaten pekar på att kombinationen "intensiv-biologisk" rening och våtmark som efterföljande poleringssteg kan vara ett mycket intressant sätt att behandla avloppsvatten, då höga krav ställs på utgående vatten.

Abstract

Two biological wastewater treatment plants are presented in this paper: one at Nynäshamn treating municipal wastewater and septic sludge and the second at Isätra treating leachate and discharge from a compost plant, but both using a combination of SBR (Sequencing Batch Reactor) units and an artificially constructed wetland/ root zone system. In both cases the plants have to treat low temperature wastewater in winter, yet still carry out biological nitrogen removal. The results for both plants over an operating span of eight and five years respectively are given below. Special attention is given to nutrient removal

under low temperature conditions. The combi-nation of an SBR system with a refining stage based on "natural" extensive treatment is shown to be a sustainable way of keeping discharge levels low. Particular attention is given to phosphorus removal during the leachate treatment.

Background

Current biological wastewater treatment may, very simply, be classified according to two different strategies. One is based on "advanced" or compact technology, such as different types of enhanced microbiological models, either attached growth or suspended sludge systems i.e. activated sludge of different types. The second may be summarised as simple "green" solutions, based on extensive systems such as multi-stage oxidation ponds, infiltration systems, wetlands and root zone technologies. Sometimes the two strategies are presented as "competitors" and arguments are put forward for one as superior to the other. This paper will propose an alternative view: that the two can complement rather than exclude each other in order to obtain high quality effluent. Two examples are given from Sweden.

One of the dominant factors in biological wastewater treatment is the variation in water temperature throughout the year, particularly with very low water temperatures in wintertime. A typical temperature range in Sweden is 2 – 18°C. Two different plants are presented here; one is a municipal treatment facility, called Nynäshamn, and the second is a plant treating leachate and effluent from a compost facility at a waste site some 150 km north west of Stockholm. This is referred to as "Isätra". The observations from both plants have been taken over a period of at least six years. Comparisons are given with published reports from the US and United Kingdom; see US EPA guidelines (1988). Middlebrooks (2006), Questa Engineering Corporation (2005), Bicudo and others (2004) and Barr and Robinson (1999).

Objectives of the study

The objective of this study is to present and analyse two plants using a treatment system including SBR technology at the main biological treatment stage and wetland at a downstream refining stage. In both cases winter conditions necessitate operating at low to very low water temperatures. The aim is to show how performance is influenced by temperature variation.

Materials and methods

For both plants long-term operational data are included. For the Nynäshamn WWTP (WasteWater Treatment Plant), data taken from 2000 up to and including the two first quarters of 2008 are used. In the case of the Isätra leachate treatment facility, the data cover the years 2002-06.

In both cases the following sources of information have been used:

- Design data for the plants from the original planning stage
- Annual environmental reports on the plants obligatory under

Swedish law

- For Nynäshamn a special study conducted as part of an MSc thesis, see Berg and Biderheim (2004)
- Operational data taken from the day-to-day operation of the plants
- Oral information given by the plant operators

All sampling at the plant is based on flow proportional 24 hour samples, with the exception of the discharge point from the wetland. The discharge quality is deemed stable over an extended period. This is why grab samples are deemed adequate in this case.

The analysis methods used are the following:

- For BOD7 SS-EN 872, including nitrification inhibitor, accuracy in analysis result +/- 30 %
- For Total P SS 028127-2, accuracy in analysis result +/- 10 %
- For total Nitrogen SS-EN ISO 13395, accuracy in analysis result +/- 20 %
- For NH_4 SS-EN ISO 11732, accuracy in analysis result +/-10 %

Description of the Nynäshamn wastewater treatment plant

Nynäshamn is located about 60 km south of Stockholm city along the coastline of the Baltic Sea. The adjoining aquatic environment forms the southern part of the large Stockholm archipelago. The population numbers roughly 20,000.

The plant has been extended and modernized on several occasions since it was first built in the 1970s. In the mid 1990s the community of Nynäshamn decided to construct a wetland with the principal aim of reducing nitrogen discharges from the community. The treatment objectives - set as BOD_7 < 15 mg/l; total P < 0.5 mg/l and total N < 15 mg/l - were maintained throughout the year, with the clear exception of nitrogen removal.

In 2001 the community resolved to modernize the handling of septic sludge "produced" in the suburban area south of Stockholm. It stated officially that nitrogen removal in the area was insufficient. An assessment of the amounts of septic sludge showed a short term annual amount of 15,000 – 20,000 m^3/year. A number of alternatives were considered, and finally it was decided to extend the main WWTP serving Nynäshamn to meet these demands. The adopted technical solution was to build a four-unit SBR facility. This treatment stage would receive the septic sludge directly after sieving and equalization. This solution was based on the favourable results experienced at a nearby SBR plant already in existence; see Morling (2001).

The upgraded Nynäshamn treatment plant now has the following treatment process:

- Pre-treatment with fine grade screens and sand trap
- Two parallel primary sedimentation tanks
- Four SBR units, each of 1150 m^3. Each unit is typically operated at 9 to 10 cycles/d
- Chemical precipitation, flocculation and final sedimentation
- An artificially constructed

wetland, with a total area of 320 000 m^2

Description of the Isätra plant for treatment of leachate and compost wastewater treatment plant

The treatment plant for leachate and wastewater from the compost plant at the Isätra solid waste treatment site has the following:

- An equalization basin of > 3 500 m^3
- A pumping station with two pumps each of 20 m^3/h
- An SBR unit of 250 m^3, with a hydraulic capacity of about 100 m^3/d and a design capacity for nitrogen = 11 kg total N/d. The unit is typically operated at 2 to 3 cycles/d. Addition of methanol is done to secure sufficient denitrification
- A three-stage root zone polishing facility with an inlet zone of 380 m^2; a spray area of 860 m^2; followed by a final treatment zone of 860 m^2

The plant has been in operation since 2001, achieving performance stability in 2002. In 2005 the wastewater entering the plant changed when a new composting plant was commissioned. This caused a change in the composition of the wastewater.

Results

Nynäshamn

After a few years' operation of the wetland it was found that the treatment objectives with respect to BOD_7 and total P had been satisfactorily met at the plant. On the other hand it was evident that the demands for nitrogen removal, specified as a maximum effluent concentration of 15 mg/l as annual mean value, and a minimum percentage removal of 50 % were seldom met. These results are illustrated in Table 1. The results are taken from the total discharge from the plant, including about 30 % of the flow that bypassed the wetland and was only treated with chemical precipitation.

Year/Parameter	2000	2001	2002	Consent levels	
BOD_7					
Discharge conc.	14	15	11	< 15	mg/l
Removal	90	91	93	(> 90)	%
Total P					
Discharge conc.	0.24	0.23	0.19	< 0.5	mg/l
Removal	96	96	97	(> 90)	%
Total N					
Discharge conc.	17	21	17	< 15	mg/l
Removal	47	46	51	> 50	%

Table 1. Performance figures for the Nynäshamn WWTP years 2000-02, related to current effluent standards

It is possible to carry out a closer study of the wetland performance in line with the performance of nitrogen removal. Middlebrooks (2006) reports results from a number of wetland plants in the US and Canada on both N (nitrogen) and P (phosphorus) removal. The given figures on ammonia nitrogen discharge in particular from these plants may be compared. Eight different plants show ammonia discharge concentrations ranging from 2 to 13 mg N/l, as an average. A more comprehensive study from Iowa presents annual variation from six different plants, all but one showing clearly that the ammonia discharge augments in wintertime. These results may be compared with the 2001 operation in Nynäshamn, as shown in Figure 1.

The Nynäshamn community has carefully recorded the performance of the plant, especially the wetland performance. In total more than 200 observations have been made that in turn allow a detailed analysis of the wetland performance. An important factor when studying the results is the nominal hydraulic retention time which appears very long for the wetland. Some circumstances, however, must be borne in mind:

- The discharge of treated water from the wetland takes place 35 to 70 days later than the influent of the same volume of water
- This fact will influence the performance figures especially when the wetland has been out of operation. After 70 days standstill – when no water enters the wetland at all – the discharge of water takes place 100 to 120 days after its influx. During such a long period most of the environmental conditions in the wetland will change more or less dramatically
- The extended retention time has resulted in the false impression that the wetland performs "best" during the first months after the winter freeze. In reality, the very low load during this extended period in conjunction with dilution due to precipitation and snowmelt will be the two main reasons for the very low discharge concentrations found during the first two months' operation in the spring. This leads to the conclusion that only by studying the figures for a full year can a reliable picture be drawn

After the inclusion of the SBR facility the plant performance has improved steadily since the end of 2003. It has stabilized at new low effluent concentrations, as may be seen in Table 2, showing the discharge figures from early 2004. Another way to illustrate the effect of the new SBR facility is shown in Figure 2. The effect on ammonia removal over the wetland has been improved substantially in comparison with the previous operation, see Figure 1. The SBR units operate at an MLSS concentration of about 2.5 kg/m^3. It is also interesting to observe that the need for a chemical precipitant (alum salt) has decreased by half since the introduction of the SBR facility.

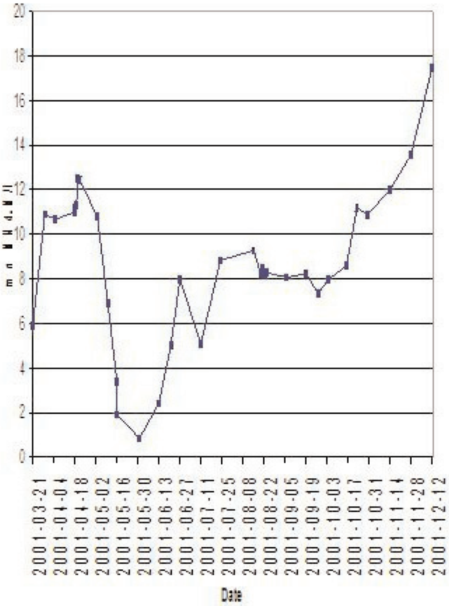

Figure 1. NH4-N (in mg/l) discharge from Nynäshamn wetland in 2001 (34 observations)

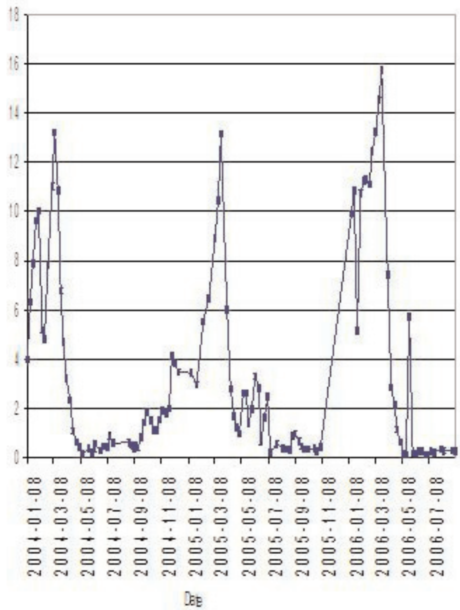

Figure 2. Discharge from Nynäshamn WWTP, after upgrading, 2004-06 (115 observations)

Year/Parameter	**2004**	**2005**	**2006**	**2008 (2 quarters)**	
Flow into wetland	1,877,026	1,896,521	2,018,050	1,059,763	m^3/year
- part of total flow	93.4	93.5	92	97.4	%
BOD_7 out	< 3	3.6	3.5	3.2	mg/l
Total P out	0.08	0.08	0.07	0.06	mg/l
Total N out	8.8	6.6	6.8	7.5	mg/l
NH_4-N out	4.0	3.2	3.5	3.2	mg/l

Table 2. Discharge figures from Nynäshamn WWTP, after upgrading, 2004-06, (> 30 observations per year, and more than 24 observations for 2008), values given in mg/l

Isätra

The Isätra plant operates under conditions that differ radically from Nynäshamn, but some similarities are apparent.

The dominating performance factor is the variation in water temperature according to the season. This fact is clearly illustrated in Figures 3 and 4, showing the discharge of total N and NH_4-N during the years 2002 and 2005. The performance figures for the years 2003 and 2004 show virtually the same pattern: a clear decrease in performance during the first quarter, remaining evident for about two months, when the temperature influence on the nitrification impacts fully on the SBR unit. The nitrification recovery will start again some weeks before the full effect is found in the root zone effluent. The SBR unit operates at an MLSS concentration of about 5.6 kg/m^3. Another way to illustrate this statement is to study the actual specific nitrification rate in the SBR unit during year 2002, as shown in Figure 5. This shows a tendency for the nitrification rate to be substantially higher in summer time. With respect to the prevailing low temperature during the winter season this pattern is expected.

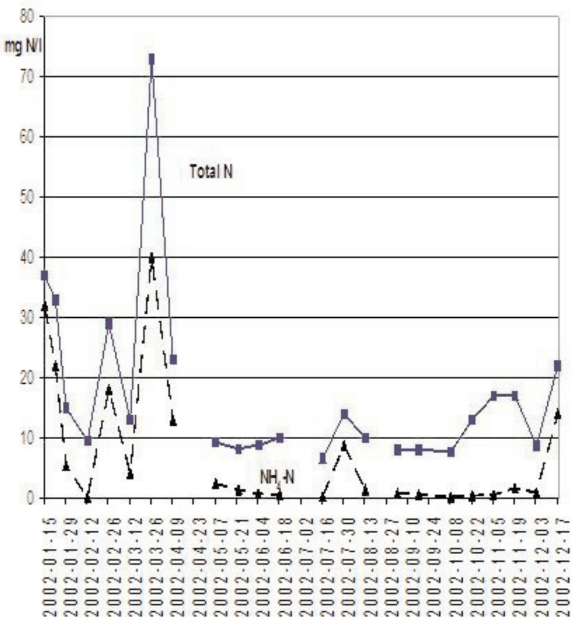

Figure 3. Total N and NH4-N discharge from root zone 2002

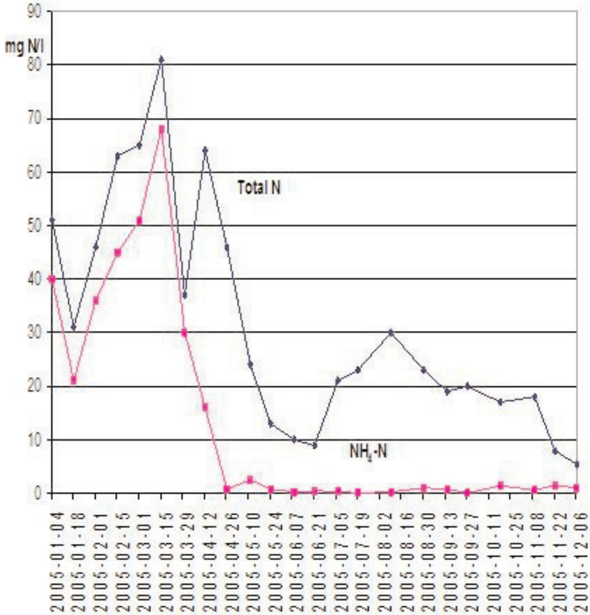

Figure 4. Total N and NH_4-N discharge from root zone 2005

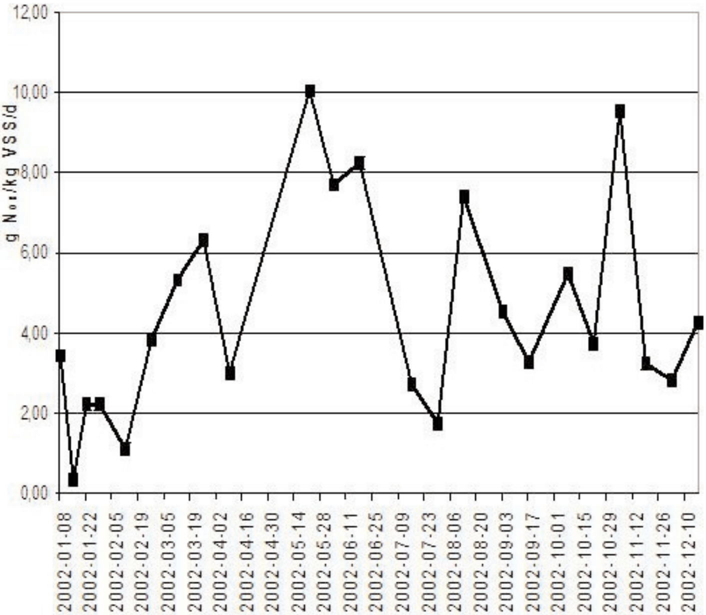

Figure 5. Specific nitrogen removal rate in g N/kg VSS/d in year 2002

The removal of phosphorus shows a quite different pattern, with a long-term change in the effluent concentration. The effluent concentration increased steadily during the period 2002-06. Table 3 shows the P balances over the plant for 2002 and 2006.

Conclusions

Experiences from the Nynäshamn plant facility may be concluded as follows:

- The capability of running the wetland throughout the year was established with the introduction of the SBR system. This fact has contributed to the improved results.

Year	2002 In SBR	2002 Out SBR	2002 Out root zone	2006 In SBR	2006 Out SBR	2006 Out root zone
Nos of observ.	24	26	23	18	23	25
Max value	5	12	1	8.3	4.5	2.6
Mean	2.47	1.60	0.38	2.69	1.92	1.11
Min value	0.99	0.00	0.10	0.49	0.23	0.41
Standard dev.	1.17	2.28	0.27	0.85	0.79	1.37

Table 3. Total P performances over the plant, 2002 and 2006, values given in mg/l

- From many aspects the wetland performed well after the upgrading of the plant, providing effluent concentrations of BOD_7 and a total P of very high quality. BOD removal was most likely due to an oxidation of organic matters into CO_2 and H_2O. This may be explained by a substantially lower organic load on the wetland; the BOD inlet concentration has gone down from about 30 mg/l to 10 mg/l, and the discharge of BOD is consistently about 3 mg/l.
- By combining the SBR in sequence with the wetland it has been possible to operate the SBR using a very short cycle time of about 2.5 hours. "Normal" cycle times for SBR systems last between 4-6 hours. The SBR system continues to be operated at a low F/M rate, about 0.065 kg BOD/kg SS/d; see also Berg and Biderheim (2004).
- A fourth point to bear in mind is that it is not possible to assess with any accuracy the "mass balance" over the wetland as long as the water balance is not known – the precipitation and evaporation figures over the year have yet to be ascertained.
- The amount of wastewater entering the wetland has increased. Previously only 60-70 % of the wastewater was treated in the wetlands; since the change about 92 % of the total flow is now treated.
- The wetland has performed well in the nitrification and denitrification processes.

- The total P concentration has been decreased by about 44 %; from about 0.12 to 0.07 mg P/l (annual average). The P removal in a wetland is normally a function of precipitation and absorption into solids. The long-term accumulation of P may become a problem, as the wetland will ultimately become "saturated" with respect to P. Other wetland operations have demonstrated that when saturation level is reached, the discharge of P increases; see the comments below on the Isätra performance.
- The problem previously observed of odour from the inlet part of the wetland has vanished. The need for a chemical precipitant (alum salt) has been reduced by up to 50 % as compared with previous operations.

Experiences from Isätra may be concluded as follows:

- This plant facility is operated under a different scheme compared with the Nynäshamn plant. The main nitrogen removal is consistently performed in the SBR unit, and the root zone is used as a final refinement, providing stability in summer time.
- The effect of low temperature in the leachate water is clearly demonstrated, with a moderate effect on ammonia oxidation in the first quarter of the year, while the oxidation is virtually complete during summer.
- The effect of an increased total P concentration in the effluent from 2002 through 2006 can most likely be attributed to the fact that the root zone has become saturated with phosphorus over time. Observations at the Nynäshamn wetland indicate that the inlet P level to a wetland (or a root zone) should not exceed about 0.5 mg/l P, in order to avoid an excessive accumulation. Another factor that may contribute to the increased P levels may be a secondary release of phosphates due to a very high SRT – often found to be greater than 100 days; see also Morling (2001).

Nevertheless, the wetland and root zone may play an important role in wastewater treatment as long as the constraints and the main virtues of these extensive models are respected.

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