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PERFORMANCE OF AN SBR PLANT IN ÖLMANÄS SWEDEN

Driftresultat från en SBR-process vid Ölmanäs reningsverk

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Abstract

The waste water treatment plant in Ölmanäs, Kungsbacka, Sweden has been enlarged by means of two SBR basins in order to meet more stringent effluent standards with respect to total nitrogen. The plant has been designed for an equivalent capacity of 11 000 inhabitants. The rebuilt plant has been operation since the fall of 1993.

The plant performance is presented in this paper and some aspects on biological nutrient removal are discussed.

The performance figures during 1995 are as follows (mean values):

BOD_7	<3	mg/l
tot N	4.5	mg/l
tot P	0.35	mg/l

Key words – Sequencing Batch Reactor, Biological nitrogen removal, Biological phosphorous removal.

Sammanfattning

Ölmanäs avloppsreningsverk, Kungsbacka kommun, har byggts ut för kvävereduktion, varvid SBR-teknik kommit till användning. Anläggningen har varit i drift sedan hösten 1993.

Anläggningens kapacitet är ca 750 kg BOD_7/d (motsvarande ca 11.000 pe).

Den biologiska kvävereduktionen har varit hög och stabil. Biologisk fosforreduktion har under en kortare tid använts i SBR-steget. Denna har inte varit tillräcklig för att upprätthålla utsläppsnivån <0,5 mg P/l, utan kompletterande kemisk fällning måste ske.

Utsläppsnivåerna under 1995 har varit följande (medelvärden):

BOD_7	<3	mg/l
tot N	4,5	mg/l
tot P	0.35	mg/l

Background

The latest review of the effluent standards in Sweden for the discharge of municipal waste water includes permit levels also for nitrogen, adding to the previous normal requirements for limits on BOD and phosphorus. The nitrogen requirements have been exercised mainly for discharges into salt or brackish water bodies. The "normal" effluent standards for larger coastal plants in Sweden is expressed as follows:

BOD_7 10–15 mg/l
Total P < 0.3–0.5 mg/l
Total N < 8–15 mg/l.

The Community of Kungsbacka, on the Swedish West coast, has been operating separate waste water treatment plants for the towns of Åsa, Frillesås and Ölmanäs from the beginning of the 1970-ies until the end of 1993 . These plants were deemed not suitable to meet the revised effluent standards, without major retrofit actions, causing a considerable reinvestment level for the Community.

A feasibility study regarding the future treatment localisation and treatment level showed that a new plant located at Ölmanäs would be the best solution. Additonal studies included the process selection for nitrogen removal to be incorporated in the future plant.

Based on these studies the community of Kungsbacka concluded, that the plant at Ölmanäs would be extended by means of two units of Sequencing Batch Reactors (SBR). The reasons for the selection was based on the following motives:

The SBR technology has proven good "built in" possibilities to control and change the process conditions;
The SBR proved in this case to be cost competitive compared to other biological nitrogen removal systems.

For the Ölmanäs plant, which is sized for about 11 000 inhabitants, the "less" stringent effluent standards are valid, or as follows:

BOD_7 < 15 mg/l
Total P < 0.5 mg/l
Total N < 15 mg/l.

The plant was taken into operation in the fall of 1993.

Plant configuration

The plant has been based on the existing facilities, but the SBR part is entirely new. This has enabled the Community to build the reactors and adjacent buildings with very limited operational stops of the existing plant. Once the SBR facilities were in operation the old plant was retrofitted. The plant contains today the following parts:

Pre-treatment facilities

* The raw water is pumped by means of four submersible pumps into a screening channel.

* The screening is performed by means of a fine grade screen with free openings of 3 mm. The peak hydraulic capacity for the screen is 900 m^3/h. The separation of coarse matters is improved by the creation of a "sieving carpet" on the upstream side of the screen. The refuse is collected directly into a refuse press that dewaters the refuse to about 30 % dry solids content.

* The screened water passes into an aerated grit chamber, where sand and grit are separated and pumped by means of three air lifts into a sand classifier.

* The refuse and removed sand are collected in a container and transported to a sanitary land fill.

Biological treatment

* The pre-treated water enters the old aeration basin, that is converted into an equalisation basin. The basin is equipped with two submersible pumps, each of 225 m^3/h at 7.5 m total head, feeding the SBR units as a part of a predetermined sequential cycle. The equalisation basin enables the operator to chose the feeding time for each reactor within certain limits. This is especially true when the plant is low loaded.

* The two SBR units are equally sized, each with a maximum volume of 2 990 m^3 and a surface area of 530 m^2. The net volume in each reactor is about 1 900 m^3. They are supplied with aeration by means of submerged disc aerators of rubber membrane. The aeration capacity at standard conditions, tap water is 200 kg O_2/h for in each reactor. The needed air is supplied by two dual speed rotary blowers, each of 30 kW. The blowers have been renovated and has now been in operation at the plant for more than 20 years. The necessary mixing in the reactors is performed by means of direct drive floating mixers, each of 15 kW. The mixers are sized not only to maintain an efficient mixing in the reactors, but also to re-suspend the activated sludge that has settled on the bottom during the sedimentation phase. This is a unique design criteria for the mixers in a SBR process as compared to mixing in a continuos flow system.

The treated water is decanted by means of a floating decanter in each reactor, with a flow capacity ranging from 300 to 1 100 m^3/h.

The SBR process at the plant is operated at a five hours total cycle time, which means that a little less than 10 cycles/d are performed at the plant.

The process is controlled by means of time, water level and the free oxygen level during the aeration period.

The wasting of activated sludge is performed by gravity. An automatic valve for each reactor controls the discharge of the sludge to a sludge holding tank located in the older part of the plant.

* The two SBR units are operated in the classical batch way, performing the following scheme:

FILL+MIX	Waste water is fed into a reactor by means of pumping, the mixer is running.
FILL+REACT	Waste water is fed into a reactor by means of pumping, the mixer is running, the aeration is put on.
MIX/REACT	Waste water feed into the reactor is stopped, the mixer is running. The aeration is running or stopped at high free oxygen level in the reactor.
SETTLE	All process actions in the reactor are stopped, no feed, no mixing, no aeration is running. The reactor is turned into an "ideal" settling basin.
DECANT	The treated water is discharged from the reactor by means of opening the decanter.

* The biologically treated water passes into two parallel sedimentation tanks. A chemical dose is added upstream the sedimentation in order to keep the phosphorus level below 0.5 mg/l.

Sludge treatment

* The waste activated sludge is discharged during the reaction phase in the reactors, thus providing a very simple way to control the Solids Retention Time (SRT) in the system. A gravity thickening brings the dry solids content of the sludge to about 1 %. The final thickening is provided by means of a rotary drum screen and brings the dry solids content to about 5 %. The sludge is transported to the central plant in Kungsbacka for final dewatering and lime treatment.

Performance during 1994 and 1995

The plant has been operated for almost two years with far better removal levels with respect to BOD, COD and total nitrogen as compared to the effluent standards levels. Only phosphorus is kept just below the given level, 0.5 mg/l. The results throughout these two years will be presented in the following, and some conclusions

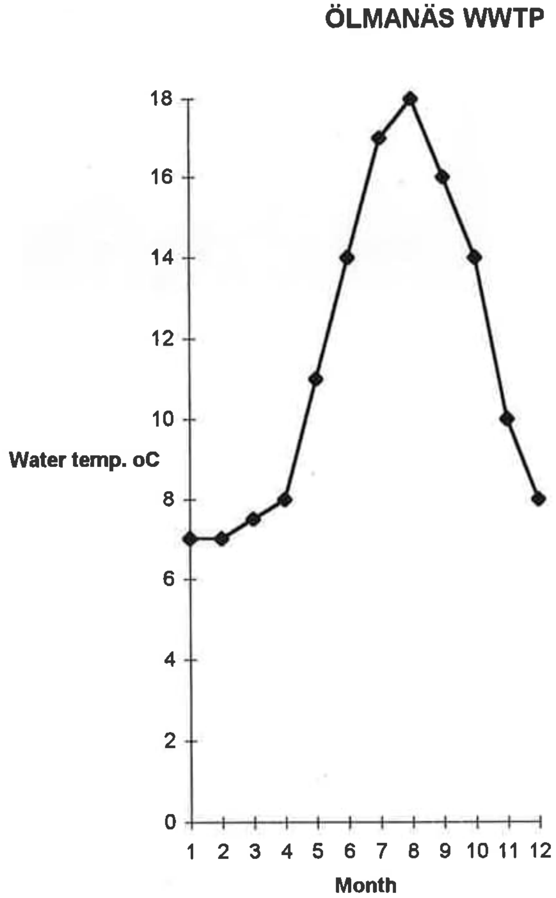

Figure 1. *Waste water temperature variation throughout a year at the Ölmanäs WWTP.*

with respect to the plant capacity with respect to nitrification/denitrification and biological phosphorus removal are presented.

Water temperature

The waste water temperature varies substantially during the year. During winter and springtime the temperature is in the range 6–8°C, to successively increase until July–August, when the temperature becomes 1–19°C. The lowest water temperature in the SBR reactors recorded so far is about 4°C during the winter 1994. The temperature falls then again to a minimum level in January. A typical temperature pattern is shown in Figure 1.

The variation shows a typical pattern for the waste water temperature at a moderate sized Swedish plant. The low water temperature during wintertime is caused by cooling of a part of the waste water, that is pumped in a 6.5 km long pipe from Frillesås and Åsa to the plant. The pressure pipe is located on the bay bottom at a length of about 4 km.

Current loads on the plant

The plant is currently run at an average daily waste water flow of 2 500 m^3, with a minimum flow of about 1 000 m^3/d and a peak flow of about 6 500 m^3/d.

The organic load on the plant, expressed as BOD7, has so far varied from about 120 kg/d as the lowest to about 550 kg/d as the peak load level. The corresponding nitrogen load has varied from about 30 kg total N/d to about 130 kg/d during these two years of operation.

Solids Residence Time (SRT)

The Solids Residence Time has been kept in the range of 30 to 35 days, thanks to the rather low load on the plant. As the concept SRT is not an obvious design criteria for an SBR plant it is useful to address the "aerated" SRT. As the process cycle is split into aerated and non aerated conditions in a more or less systematic way, the "aerated" SRT may represent a more adequate variable. In this case, with an aeration part of about 40 % of the total cycle, the aerated SRT is found to be 12 to 14 days. The excess sludge leaving the reactors is considered as odour free.

F/M ratio and sludge quality in the reactors

The plant is at present run at a low load, with an F/M ratio of about 0.045 kg BOD_7/kg VSS/d. Occasionally the F/M ratio has been in the vicinity of 0.1, i. e. during the Summer 1994. The MLSS concentration has been rather stable, around 3.0 kg SS/m^3, as defined as the concentration at low level and completely mixed conditions in the reactor. The sludge volume index (SVI) has normally been 100 ml/g with a maximum level of about 150 and low levels at about 75. No problems related to excessive filamentous growth has been reported from the operation so far.

BOD removal

The plant has performed extremely well with respect to the BOD removal. This is true not only when looking

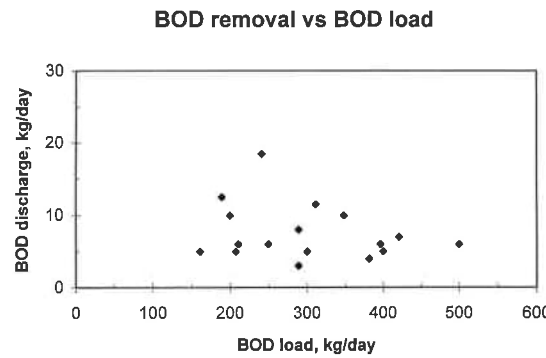

Figure 2. *BOD_7 discharge as function of the BOD_7 load during 1994.*

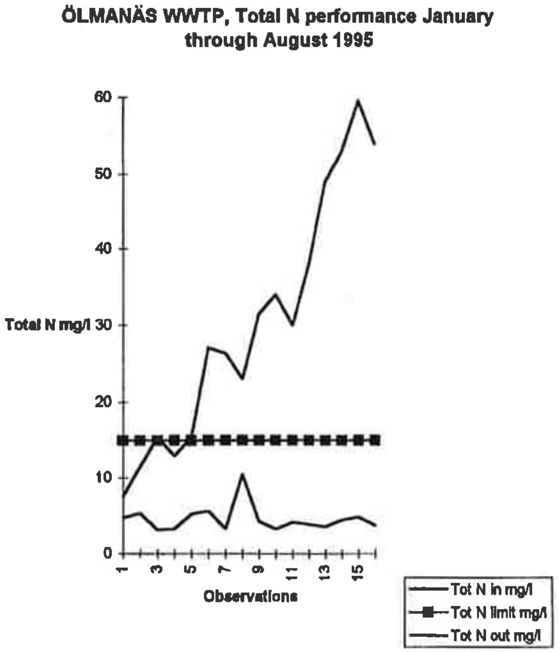

Figure 3. *Total Nitrogen removal performance at the Ölmanäs WWTP during 1995.*

into the discharge levels but also with respect to the process stability. The inlet BOD amount versus the discharge amounts during the first half of 1994 (the first year of operation) is demonstrated in Figure no 2. Apart form one observation it may be stated, that regardless of the daily load variation on the plant, the discharge level is kept almost constant in terms of kg BOD_7/d, or about 10–15 kg as a daily discharge.

During 1995 the process stability has been maintained. The discharge BOD_7 concentration has only exceeded 5 mg/l at two occasions out of 16. Normally the discharge level is below the level of accuracy in the analysis method, < 3 mg O_2/l.

COD loads during 1995

The COD load on the plant during 1995 varies from 558 to 1592 kg COD/d, with an average value of 812 kg COD/d. The discharge COD concentration is often below the accuracy level for the analysis method, or < 30 mg/l. The ratio COD: BOD in the raw waste water is about 2.5: 1, a very typical value for domestic waste waters in Sweden.

Nitrogen removal

The development of the nitrogen removal at Ölmanäs plant shows a rather typical pattern. When comparing the two years 1994 and 1995 it is found that the average discharge level has been improved by about 1 mg/l, from 5.5–6 to 4.5 mg total N/l. The nitrate level in the dis-

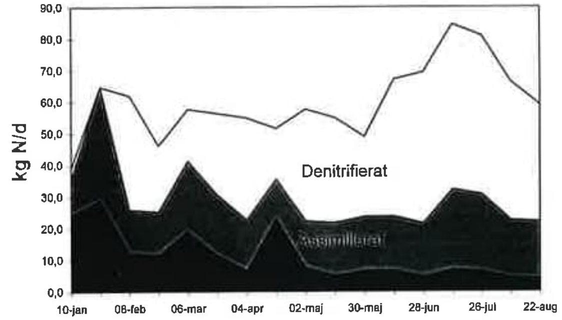

Figure 4. *Nitrogen removal at Ölmanäs WWTP.* Distribution between assimilative and dentrification N removal.

charge is about 2.5 mg N–N O_3/l, and the organic nitrogen + the remaining ammonia nitrogen is about 2.0 mg N/l, whereof about the organic nitrogen is about 1.5 mg N/l.

The amount of nitrogen that is removed by means of assimilation to the biomass is calculated as follows:

N(ass) = (COD(in)–30) * Q * 0.025 * 10(–3),

where

N(ass) is the amount of nitrogen that is removed by assimilation, in kg N/d;
COD(in) is the COD concentration in the raw waste water, in g/m^3;
30 is assumed to be the inert component of the COD, that does not contribute to the microbiological activity in the reactor, in g/m^3;
Q is the daily wastewater flow in m^3/d;
0.025 is the assimilation factor COD:N;

When applying this formula to the performance data at Ölmanäs WWTP the following denitrification is found, see Figure 4.

Phosphorus removal

The phosphorus removal is performed in four ways at the plant:

* As "normal" assimilative uptake by the mixed liqueur;
* As enhanced biological phosphorus removal, referred as "Bio-P";
* By means of simultaneous precipitation in the SBR system, using ferric chloride, $FeCI_3$;
* By means of post precipitation by means of a polishing addition of alum in the decanted water from the SBR system.

These models are normally not all operated at the same time. As the plant has been operating with biological phosphorus removal in the system from time to time, and the performance has been followed by means of analysis and sampling, it is possible to present the results from the first half of 1995.

The assimilation of phosphorus into the sludge is calculated as follows:

P(ass) = (COD(in)–30) * Q * 0.005 * 10(–3),

where

P(ass) is the amount of nitrogen that is removed by assimilation, in kg N/d;
COD(in) is the COD concentration in the raw waste water, in g/m^3;
30 is assumed to be the inert component of the COD, that does not contribute to the microbiological activity in the reactor, in g/m^3;
Q is the daily wastewater flow in m^3/d;
0.005 is the assimilation factor COD: P.

The total phosphorus removal in the SBR system has been about 9 kg P/d, or 79 % of the incoming amounts. The assimilation level is calculated to about 3.7 kg P/d, leaving about 5.3 kg P/d for "Bio-P" removal and simultaneous precipitation.

The enhanced biological removal of phosphorus is related to the presence of Volatile Fatty Acids (VFA) in the waste water, see (1).

The need for VFA in relation to the "Bio-P" removal may be expressed as follows:

COD(VFA) = P(removed) – P(assimilated) * 15,

where

COD(VFA) is the need for Volatile Fatty Acids for the "Bio – P" removal, in mg COD/l;
P(removed) is the total removal of phosphorus in mg P/l;
P(assimilated) is the amount of phosphorus removed by assimilation to the sludge, in mg P/l;
15 is the specific need for COD(VFA) to remove 1 mg P/l by means of "Bio-P" removal.

The normal relation between COD(VFA) and total COD in a raw waste water is about 1: 8, or 11 to 13 %.

When using these relations for the Ölmanäs plant figures, it is found that the need for VFA is about 11 % of the incoming COD, if it assumed that all the phosphorus in the reactor is removed by means of either assimilation or through "Bio-P" removal. This means that theoretically, the 79 % P removal in the SBR system would be possible without any addition of precipitation agent. In reality however it has not been possible to operate the plant in this way. The simultaneous precipitation has been exercised up to the 20 of January and was reassumed on the 21 of May. During the intermediate period the SBR system has been operating with a P removal based largely on assimilation "Bio-P". During this period the total P discharge level from the SBR system has varied between 0.3 and 2.8 mg, with a successive rise of the P concentration as from the second half of April through the middle of May. The removal has varied

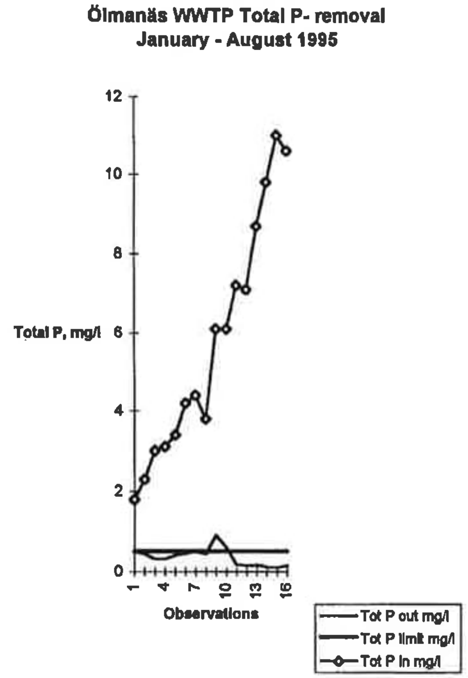

Figure 5. *Total Phosphorus removal performance at the Ölmanäs WWTP during 1995.*

between 54 and 91 % during the same period. When applying simultaneous precipitation again the discharge level is stabilised at about 0.8 mg P/l from the SBR basins into the post precipitation stage.

The overall removal of phosphorus at the plant has been about 94 %, with an average discharge level of 0.35 mg P/l.

Conclusions

The Ölmanäs WWTP has demonstrated a stable performance record throughout its operation as a SBR nutrient removing plant. The organic removal, both expressed as BOD and COD, has been very satisfying since the conversion ofthe plant in the Winter 1993–94.

The nitrogen removal has averaged at 80–90 % efficiency, and with a few exceptions the discharge level has been kept in the range 3–6 mg total N/l.

The variation in loads on the plant either it is expressed as low temperature conditions, rapid variation in flows or organic or nutrient amounts have not caused any deterioration of the performance. Especially interesting is to observe that the plant is operated during a long period at low water temperature, without any significant affect on the nitrogen removal.

The phosphorus removal is maintained by means of four different modes. It has not been possible to obtain a phosphorus level of < 0.5 mg/l by means of simultaneous precipitation in the SBR system only. It should also be pointed out that the period from end of January to mid May would not be a "true" biological phosphorus removal performance, as remains of the precipitant agent possibly will be active during a certain operation period, at least during a period equal to one SRT, or 30 to 35 days after the stop ofthe dosing.

The polishing by means of post precipitation has shown necessary to exercise. At low water temperature it seems reasonable to assume that the Bio-P" removal in the SBR system is affected both by the decreased reaction rate and a slower use of the nitrate oxygen in the process. The temperature effect on the Bio-P" removal has been studied elsewhere, see (2).

The apparently low load on the system has contributed to the stable performance. The apparently good sludge characteristics without any tendency of uncontrolled filamentous growth, nor formation of "pin point" flocs, has been a paradigm for the SBR operation so far.

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