

## Overview: full scale experience of the SHARON® process for treatment of rejection water of digested sludge dewatering

R. van Kempen\*, J.W. Mulder\*\*, C.A. Uijterlinde\*\*\* and M.C.M. Loosdrecht\*\*\*\*

\* Grontmij Water & Waste Management, P.O. Box 14, 3730 AA, De Bilt, The Netherlands

\*\* Water Authority Hollandse Eilanden & Waarden, P.O. Box 469, 3300 AL Dordrecht, The Netherlands

\*\*\* Water Authority De Stichtse Rijnlanden, P.O. Box, 550 3990 GJ Houten, The Netherlands

\*\*\*\* Department of Biochemical Engineering, Delft University of Technology, Julianalaan 67, 2628 BC Delft, The Netherlands

**Abstract** A SHARON® system has been constructed at the Utrecht WWTP and at the Rotterdam Dokhaven WWTP. In the SHARON® process rejection water from dewatering of digested sludge is treated for N-removal. It concerns a high active process operating without sludge retention. Due to differences in growth rate nitrite oxidisers can be washed out of the system while ammonia oxidisers are maintained, resulting in N-removal over nitrite. The SHARON® process was selected in competition with several other techniques.

The feed of a SHARON® system is concentrated, with ammonia concentrations ranging from 0.5 to 1.5 g N/l. The results show that conversion rates of 90% are well possible with N-removal mainly via the nitrite route. The process was shown to be stable. Due to the high ammonium influent concentrations pH control is of great importance, preventing process inhibitions. The acidifying effect of nitrification can be compensated completely by CO<sub>2</sub> stripping during aeration and by denitrification. Heat production by biological conversions is significant, due to the high inlet concentrations, and contributes to the optimal operating temperature of 30-40°C.

**Keywords** SHARON®; nitrification; denitrification; nitrite; rejection water; N-removal

### Introduction

New legislation for nitrogen removal requires optimisation of existing WWTPs. The Utrecht WWTP (400,000 pe) and the Dokhaven WWTP in Rotterdam (470,000 pe) are both two-stage processes (Figure 1). A two-stage process is well suited for BOD removal as well as nitrification. However denitrification in the second stage is poor due to BOD shortage and a high sludge loading rate of around 0.10–0.15 g BOD/(g MLSS\*d). A conventional extension of the Utrecht WWTP was only possible at relative high investment costs and additionally demolition of a large part of the existing WWTP was necessary. The aeration tanks and the clarifiers of the Rotterdam Dokhaven WWTP have been constructed underground in the city centre, and could not be extended. At both WWTPs a SHARON® process has been constructed, to improve the overall N-removal.

A study of the nitrogen balance of the Rotterdam Dokhaven WWTP (Figure 2) shows that a significant fraction of the nitrogen is recirculated from the sludge digestion (so-called rejection water) towards the activated sludge tanks. This amounts to 15% of the total nitrogen loading of the treatment plant. Removing this load will directly result in an equivalent decrease of the total nitrogen load in the effluent.

Several available techniques for treatment of the rejection water from sludge dewatering were evaluated, including laboratory and pilot scale tests at three large WWTPs. This research was initiated by the Dutch foundation for Applied Water Research, STOWA. The following techniques were evaluated in this project: air stripping of ammonia; steam stripping of ammonia; Magnesium-Ammonia-Phosphate precipitation (MAP/CAFR process); Membrane Bioreactor (MBR); biofilm airlift suspension reactor. An overview of

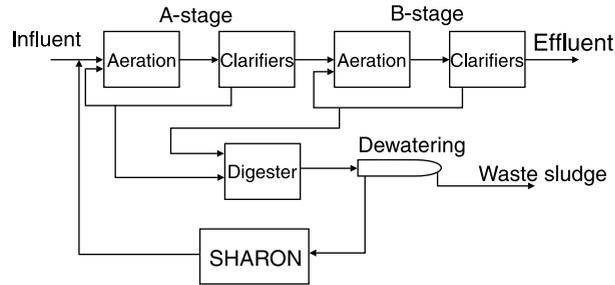


Figure 1 Flow scheme of a two-stage WWTP

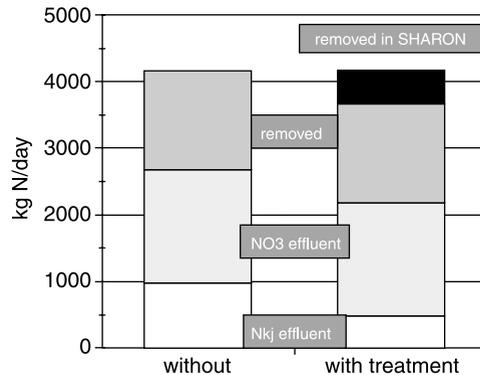


Figure 2 N-balances with and without SHARON<sup>®</sup>

this research project is presented by STOWA (1995b) and by Janus and van der Roest (1997). At the same time a new process was developed at the Delft University of Technology (Hellinga *et al.*, 1998; STOWA 1996). In this so-called SHARON<sup>®</sup> process ammonium is nitrified/denitrified with nitrite as intermediate, without the need of sludge retention. In the past before the SHARON<sup>®</sup> process was developed, a broad range of process factors such as: pH, DO, temperature,  $\text{NH}_4$ ,  $\text{HNO}_2$  and other inhibitors have been tested to achieve nitrification/ denitrification with nitrite as intermediate. Most of them initiated the formation of nitrite but could not prevent the formation of nitrate after longer periods. It seemed likely that all these process factors were not successful for full-scale application (STOWA, 1995a). The SHARON<sup>®</sup> process is the first successful technique by which nitrification/ denitrification with nitrite as intermediate under stable process conditions was achieved.

The SHARON<sup>®</sup> process proved to be the most cost-effective technique, especially due to the absence of chemical sludge production, a low biological sludge production, the advantage of N-removal over nitrite and the simplicity of the process. Table 1 gives a general overview of the different investigated techniques. Studies in Germany (Liebig, 1999) and Switzerland (Siegrist, 1996) gave similar results.

### Description of the SHARON<sup>®</sup> process

The SHARON<sup>®</sup> process (Single reactor system for High activity Ammonia Removal Over Nitrite) has been described in detail by Hellinga *et al.* (1998). This process (patented) distinguishes itself from other biological wastewater treatment processes by a complete absence of sludge retention. Growth and washout of sludge are in equilibrium. The process has the following characteristics.

- Developed for biological nitrogen removal over nitrite in concentrated wastewater.
- Due to high temperatures (30-40°C) fast growing micro-organisms (nitrifiers/ denitrifiers) will develop in the reactor. The aerobic retention time may be limited to 1 day.

**Table 1** General comparison of different techniques for N-removal from rejection water

	Production chemical sludge	Production biological sludge	Dosage chemicals	Energy requirements	Operation	Cost estimate* Euro/kg N
Air stripping	yes	no	yes	average	average	6.0
Steam stripping	yes	no	yes	high	complex	8.0
MAP/CAFR process	yes	no	yes	low	complex	6.0
Membrane bioreactor	no	yes	yes	high	average	2.8
Biofilm airlift reactor	no	low	yes	average	average	5.7
SHARON® process	no	low	yes	average	simple	1.5

\* Cost estimate based on STOWA (1996) for WWTP capacity of 500,000 pe.

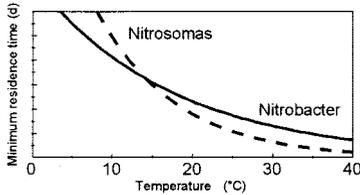
- Micro-organisms show high activity, however the  $K_s$  value is rather high. As a result effluent concentrations at an aerobic retention time of 1 day will be several tens of milligrams. The effluent concentration is independent of the influent concentration, the removal efficiency increases with higher inlet concentrations. The influent concentration varies per WWTP and is mainly dependent on the sludge concentration in the anaerobic digesters.  $\text{NH}_4\text{-N}$  concentration of rejection water can vary between 0.5 and 1.5 g/l.
- Nitrite oxidation can be prevented since at higher temperatures the  $\text{NO}_2$ -oxidizing bacteria grow slower than the  $\text{NH}_4$ -oxidisers (Figure 3) (Hunik, 1993). In a system without biomass retention (SRT=HRT) it is simple to limit the SRT in such way that ammonium will be oxidised and nitrite will not be oxidised. Ammonia removal over  $\text{NO}_2$  instead of  $\text{NO}_3$  has the following advantages:
  - oxidation to  $\text{NO}_2$  requires only 75% of the aeration energy;
  - denitrification starting with  $\text{NO}_2$  requires only 60% of the BOD addition.
- pH control is very important, due to high concentrations and high reaction rates. The bicarbonate in the anaerobic effluent and the denitrification process compensate the acidifying effect of the nitrification. Both take 50% of the alkalinity requirement. In the process however  $\text{CO}_2$  stripping must be sufficient to allow full use of the bicarbonate.
- Heat production is significant due to the high inlet concentrations. This has to be considered in the process design.
- As the process functions without sludge retention there is no influence of the presence of suspended solids in the rejection water, for example due to temporary malfunction of the sludge dewatering.
- A simple single reactor (CSTR) system can be applied.

Since the SHARON® effluent is recycled to the first stage of a two-stage process, denitrification in the SHARON® process is primarily needed for pH control. The  $\text{NO}_x$  mass can be returned to the inlet of the WWTP. The extremely high loaded first stage can easily denitrify this load. Use of methanol to produce alkalinity by denitrification appeared to be cheaper compared to dosing of caustic directly. Any  $\text{NO}_x$  that is left after denitrification for pH control, will be denitrified in the first-stage.

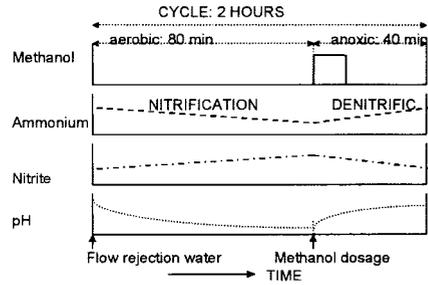
Both nitrification and denitrification can take place in a single reactor system using intermittent aeration. The aerobic retention time is controlled by the total duration of the aeration periods. The length of one aerated period depends on e.g. inlet flow and pH set points. During aerobic periods the pH will decrease, and during anoxic periods the pH will increase. A typical cycle pattern is illustrated in Figure 4.

### Implementation and design parameters

The SHARON® process has been developed and tested at laboratory scale (1.5 l) at the Delft University (Hellinga *et al.*, 1998). General scale-up was done at the TU-Delft by model based procedures (Hellinga *et al.*, 1999). The company Grontmij Water & Waste Management in



**Figure 3** Minimum HRT for  $\text{NH}_4$  and  $\text{NO}_2$  oxidisers as function of the temperature



**Figure 4** Transient medium conditions due to intermittent aeration

co-operation with the Water Authorities HDSR (Utrecht) and ZHEW (Rotterdam) performed the detailed full-scale design of the two SHARON<sup>®</sup> systems. The SHARON<sup>®</sup> system at the Utrecht WWTP was built after a pilot test (1 m<sup>3</sup>) period of one year. The system at the Rotterdam Dokhaven WWTP was constructed without performing an intermediate pilot test. Table 2 gives an overview of the design parameters of the two SHARON<sup>®</sup> systems.

At the Utrecht WWTP the average influent concentration is relatively low (< 0.6 g  $\text{NH}_4\text{-N/l}$ ) and at the same time a nitrification efficiency of over 95% was required. This can only be achieved at an aerobic retention time of more than 1 day and results therefore in only partial N-removal by nitrite.

At the Rotterdam Dokhaven WWTP there was no area available for extension, therefore a post-thickener was taken out of operation and converted into a SHARON<sup>®</sup> reactor. The volume is 1,800 m<sup>3</sup>, exceeding the process design requirements (1,150 m<sup>3</sup>). The most important process factor, the aerobic retention time, can be controlled by the duration of the aerated periods. The remaining part of the cycle time will not be aerated. Laboratory tests at the Delft University showed no negative influence of variable anoxic periods. The extended volume of 1,800 m<sup>3</sup> provides the flexibility to modify process conditions, for example during the start-up phase and ensures spare capacity when needed.

### SHARON<sup>®</sup> experience at the Utrecht WWTP

#### Start-up

The SHARON<sup>®</sup> system in Utrecht has been in operation since 1997. In Figure 5 the results of the first 6 months are presented. The nitrification process started immediately and after 3 weeks the nitrification efficiency was over 95%. Next the dosing of methanol was started (replacing the addition of caustic) in order to start the denitrification process. The dosage of methanol was slowly raised until sufficient denitrification capacity for correction of the pH was achieved.

#### General

In Figure 6 and Figure 7 the results of one complete year are presented. The average nitrogen

**Table 2** Design parameters full-scale SHARON<sup>®</sup> systems

		Utrecht	Rotterdam
Tank volume	m <sup>3</sup>	4,500	1,800
Design flow	m <sup>3</sup> /h	35	31.5
Maximum flow	m <sup>3</sup> /h	62.5	50
Design N-load	kg/day	420	540
Maximum N-load	kg/day	900	830
Influent $\text{NH}_4$ concentration	g N/l	0.5–0.7	1–1.5
Aerobic retention time	day	2.5	1
Anoxic retention time	day	1.25	0.5–1.4

load was 408 kg N/day. The inlet ammonia concentration varied between 400 and 750 mg N/l. The feed to the SHARON<sup>®</sup> system was not constant and the flow varied between 0 and 1.375 m<sup>3</sup>/day. The average effluent ammonia concentration was less than 5 mg N/l.

In Figure 8 the variation of the TSS influent concentration due to temporary malfunction of the sludge dewatering is illustrated. The TSS influent concentration varied between <0.1 and 5 g/l and did not disturb the process.

The average ratio COD:N-denitrified had a value of 3.3 g COD/g N indicating, as expected, denitrification mainly via nitrate (see also ratio COD:N-denitrified SHARON<sup>®</sup> system Rotterdam Dokhaven WWTP). The choice of the waterboard was to remove a maximal amount rather than to optimise the methanol requirement.

#### WWTP effluent

After introduction of SHARON<sup>®</sup> the total nitrogen load of the effluent decreased by approximately 30%. During the first half year of 1998 the average total nitrogen concentration dropped from 16 to 11 mg N/l, indicating a positive effect of the SHARON<sup>®</sup> system on the WWTP effluent results.

### SHARON<sup>®</sup> experience at the Rotterdam Dokhaven WWTP

#### Start-up

The reactor was filled with river water, warmed up to approximately 30°C and waste activated sludge was used as seeding material. During the first period of the start-up the flow to SHARON<sup>®</sup> was limited. In this manner an overload was prevented, potentially resulting in pH increase due to CO<sub>2</sub> stripping, and resulting in an increase of the ammonia concentration. A combination of high ammonia concentrations (>200 mg/l) and pH above 8 is supposed to be toxic for nitrifiers in this process (Antonissen *et al.*, 1976). Initially the pH was controlled by addition of caustic, however after starting up the denitrification process the pH was controlled by methanol addition. Starting with a limited load to SHARON<sup>®</sup> the flow was increased periodically. The entire production of rejection water was treated from week 7 onward.

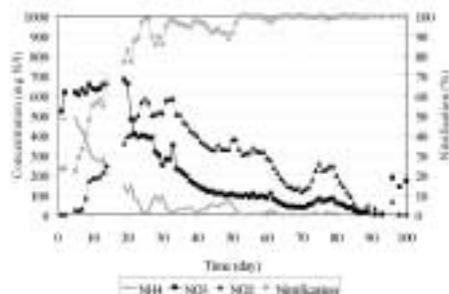


Figure 5 NH<sub>4</sub>, NO<sub>x</sub> concentrations during start-up

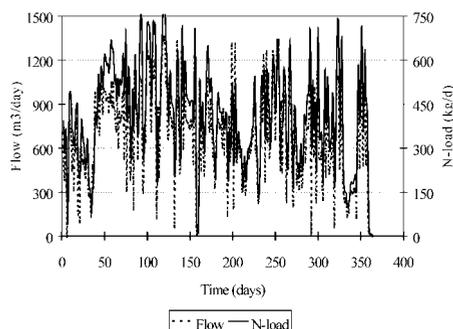


Figure 6 Fluctuations of flow and N-load

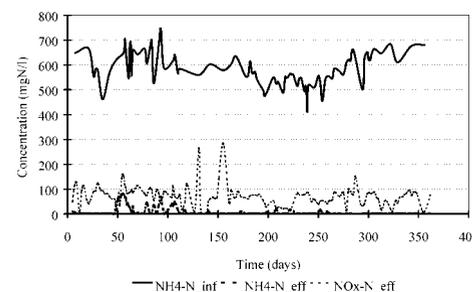


Figure 7 Daily NH<sub>4</sub> and NO<sub>x</sub> concentrations

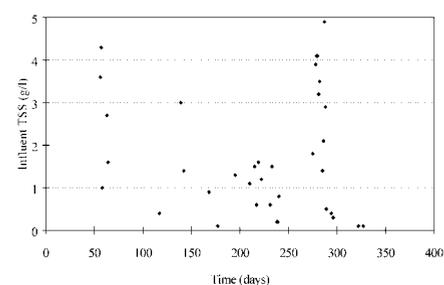


Figure 8 Fluctuations of influent TSS

## General

In Figure 9 the conversion during the first 5 months is presented and the weekly removal efficiencies are shown in Figure 10. The average nitrogen load in the rejection water was 520 kg N/day. The load to SHARON<sup>®</sup> was limited during the first 1½ month with a steady increase. The feed to the SHARON<sup>®</sup> tank was not constant. Sludge dewatering in the decanters was dependent on sludge production and sludge storage in sludge buffers. The flow to the SHARON<sup>®</sup> varied between 0 and 980 m<sup>3</sup>/day. The inlet ammonia concentration was on average 1,230 mg N/l, with a maximum of 1,530 mg N/l. The design for the influent concentration was 1,000 mg N/l.

## Nitrite route

Ammonia was initially converted to nitrite as well as to nitrate. This was due to the seeding material as well to an aerobic retention time higher than 1 day allowing growth of nitrite oxidisers. Nitrite and nitrate were denitrified partially. Because nitrite and nitrate were produced as well as consumed, the exact contribution of the nitrite route is unknown. Weekly averaged concentrations are presented in Figure 11. The nitrite route however can be estimated with the assumption that nitrite/nitrate consumption takes place in the same ratio as nitrite/nitrate production. The calculated contribution of the nitrite route is estimated at 70% of the total conversion. Considering an aerobic retention time of 3 days to 1.5 days this value is already higher than expected (Figure 12). A conversion over nitrite of >90% is expected after reaching an aerobic retention time of 1 day.

## Denitrification

For denitrification, methanol was used as carbon source. In theory the minimal stoichiometric demand would amount to 1.9 g/g NO<sup>3</sup>-N or 1.14 g/g NO<sup>2</sup>-N denitrified. Considering the biomass yield, the demand is expected to be 3.5 and 2.2 g/g N denitrified (Hellinga *et al.*, 1999). Figure 13 illustrates the methanol addition in relation to the denitrification. During the first months the ratio was high, up to 6 g COD/g N. This was due to an overdosing of methanol related to short anoxic retention times and a suboptimal process control. As a result methanol was partly oxidised with oxygen.

After the cycle times were properly controlled, the ratio decreased to 2.4, indicating an efficient use of methanol for denitrification, and indicating denitrification mainly via nitrite. After the successful start-up period this ratio was maintained up to the present date.

## Heat balances

In Figure 14 the temperature during the start-up period is illustrated. During the first months the temperature was lower than the desired value of 35°C due to the relatively long HRT and the low winter-air temperatures. At the end of the period the temperature reached, according to the process design, 35°C and finally external heating was no longer needed. In the winter of 1999/2000 no heating needed to be applied. In Figure 15 the contribution of different heat sources on the reactor temperature effects is illustrated. The possibility for

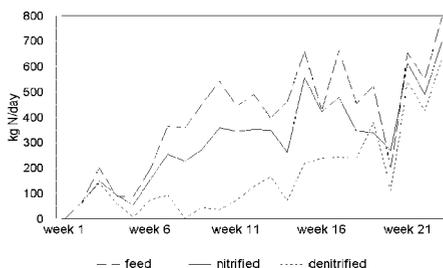


Figure 9 Weekly averaged nitrogen loads

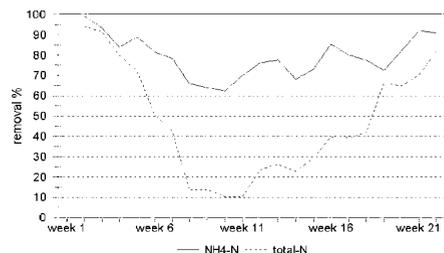


Figure 10 Weekly averaged removal efficiencies

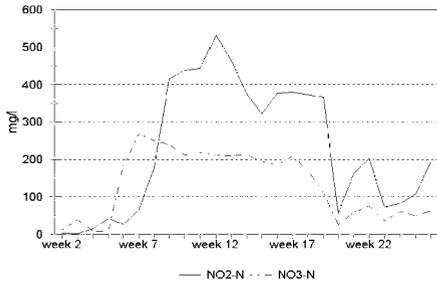


Figure 11 Weekly averaged  $\text{NO}_x$  concentrations

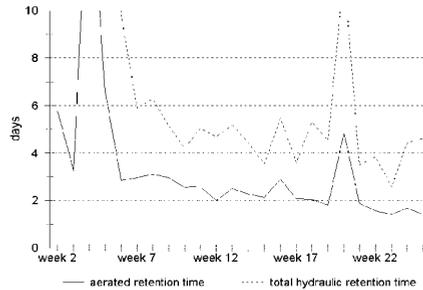


Figure 12 Hydraulic and aerated retention times

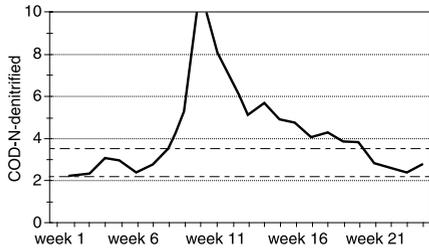


Figure 13 Methanol addition and denitrification

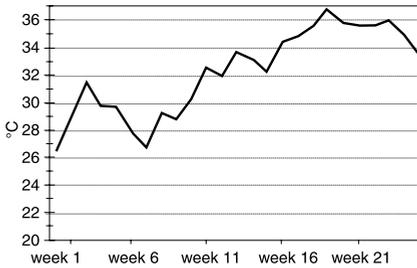


Figure 14 Reactor temperatures

external temperature control was added for safety, because the process was directly scaled up from laboratory experiments. Future experience will show how sensitive the process is towards temperature fluctuations.

#### WWTP effluent

Figure 16 illustrates the positive effect of SHARON<sup>®</sup> on the  $\text{NH}_4$  and TKN effluent concentration of the WWTP. After implementation of the SHARON<sup>®</sup> system the TKN effluent concentration dropped from 6.1 to 2.1 mg N/l.

#### Discussion

In general the start-up of a SHARON<sup>®</sup> system proved to be simple. Scaling up the process from laboratory scale (1.5 l) to full scale has been no problem. It proved to be possible to achieve nitrification without sludge retention. Depending on the aerobic retention time, ammonia effluent concentration ranging from <5 to around 100 mg N/l can be achieved. The aerobic retention time can be controlled by the duration of the aerated periods. Thus a fixed aerobic retention time can be maintained independent of the inlet flow. Process stability is insensitive to variations of the load or other disturbances, such as high SS in the influent.

The initial conversion over nitrate could be gradually replaced by a stable conversion

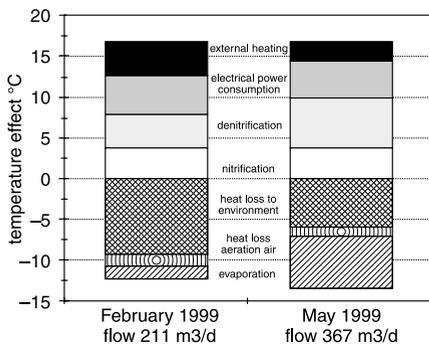


Figure 15 Factors of influence on temperature

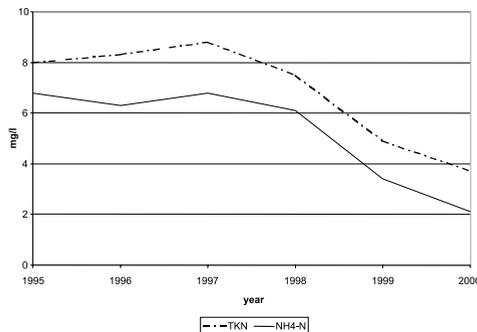


Figure 16 WWTP effluent results

over nitrite. As the retention time decreases nitrite oxidisers were no longer maintained in the system. The low observed COD/N ratio for the denitrification process also indicates this.

The temperature can rise due to biochemical conversion to more than 35°C. The biochemical heat production is a significant contribution to the heat balance.

The pH appears to be a very important process factor. When the pH drops below 6.5 the ammonia conversion decreases to 50%. There is no indication of a long-term negative effect on the biomass. At pH values over 8.0, nitrification also decreases. In this case there are indications that high pH values (>8), especially in combination with high ammonia concentrations, can be harmful for the nitrifying population.

An extra advantage of the process was that the staff of the treatment plant could easily learn to operate the plant (large similarities to conventional wastewater treatment). Moreover the time needed to operate the system once started up was approximately 5 hours per week.

## Conclusions

The following conclusions can be drawn.

- The SHARON<sup>®</sup> process scaled up successfully from laboratory scale to full-scale.
- The SHARON<sup>®</sup> process has been stable, despite load variations and some process disturbances. The process can be easily controlled by adjustment of the aerated periods. The SHARON<sup>®</sup> process is a highly dynamic process and therefore the process control (especially for pH) needs to respond rapidly too.
- Heat production is significant, due to high inlet concentrations and high conversion rates.
- The process is insensitive to high TSS influent concentrations.
- The nitrite route can be maintained by washing out the nitrite oxidisers.
- Methanol was dosed as a carbon source in a minimum ratio of 2.4 kg COD/kg N<sub>removed</sub>, indicating N-removal over nitrite.
- The pH of the SHARON<sup>®</sup> system can be controlled by the alkalinity production of the denitrification process.
- A N-removal efficiency of 90% can be achieved.
- The expected decrease of ammonium effluent of the main treatment plant was achieved

## References

- Antonissen, A.C., Loerhr, R.C., Prakasam, T.B.S. and Srinath, E.G. (1976). Inhibition of nitrification by ammonia and nitrous acid. *Journal of Water Pollution Control Federation*, **48**(5), pp. 835.
- Hellinga, C., Schellen, A.A.J.C., Mulder, J.W., van Loosdrecht, M.C.M. and Heijnen, J.J. (1998). The SHARON-process; an innovative method for nitrogen removal from ammonium rich waste water. *Wat. Sci. Tech.* **37**(9), 135–142.
- Hellinga, C., van Loosdrecht, M.C.M. and Heijnen, J.J. (1999). Model based design of a novel process for nitrogen removal from concentrated flows. *Math. Comp. Modell. Dyn. Sys.* **5**, 1–13.
- Hunik, J.H. (1993). Engineering aspects of nitrification with immobilised cells. PhD thesis, Wageningen Agricultural University.
- Janus, H.M. and van der Roest, H.F. (1997). Don't reject the idea of treating reject water. *Wat. Sci. Tech.* **35**(10), 27–34.
- Liebig (1999). Halbtechnische Untersuchungen zum Vergleich von Verfahrensvarianten der biologischen Stickstoffelimination aus Prozebwässern. Fachbeitrag Nr. 14 in "Stickstoffrückbelastung – Stand der Technik 1999", Hrsg.: M. Grömping, ATEMIS 1999.
- Siegrist, H. (1996). Nitrogen removal from digester supernatant – comparison of chemical and biological methods. *Wat. Sci. Tech.*, **34**,(1–2), 399–406.
- STOWA (1995a). Treatment of nitrogen-rich return flows of sewage treatment plants. Evaluation of Dutch pilot plant research projects (in Dutch). STOWA report 95-08.
- STOWA (1995b). Treatment of nitrogen-rich return flows of sewage treatment plants. MBR pilot plant research of nitrification/denitrification over nitrite for sludge treatment plant Sluisjesdijk (in Dutch). STOWA report 95-15.
- STOWA (1996). Treatment of nitrogen-rich return flows of sewage treatment plants. Single reactor system for removal of ammonium over nitrite (in Dutch). STOWA report 96-01.