FULL-SCALE EXPERIENCE WITH THE SHARON PROCESS THROUGH THE EYES OF THE OPERATORS

J.W. Mulder*, J.O.J. Duin, J. Goverde, W.G. Poiesz, H.M. van Veldhuizen, R. van Kempen, P. Roeleveld

*'Hollandse Delta' Water Board
P.O. Box 469
3300 AL Dordrecht, the Netherlands

ABSTRACT

This paper summarizes different operating aspects and experiences of several SHARON plants. The SHARON process is suitable for treatment of high strength ammonia wastewaters such as reject water from dewatering of digested sewage sludge and wastewater from sludge drying or incineration plants. The aerated retention time and nitrite concentration are the two most important process parameters to control the ammonia outlet concentration. Ammonia removal efficiencies can be over 95%, are variable and can be targeted according to the required needs of the main WWTP and/or to minimize overall nitrogen removal costs. The process is compact and simple to operate. Depending on site specific circumstances there are different system configurations possible. Nine years of operating experience prove that the SHARON process is sustainable and highly competitive. Compared to conventional techniques there are significant savings of energy and consumables. Application of fine bubble aeration has further decreased aeration costs. Recently the use of by-products of the biofuel industry as COD source for denitrification has further increased the cost effectiveness. SHARON is successfully applied to significantly improve the main WWTP nitrogen effluent quality. It proves to be a cost effective alternative for conventional extension of the WWTP.

KEYWORDS

SHARON, Nitrogen removal, nitrification, denitrification, nitrite, rejection water, side stream

INTRODUCTION

The SHARON process was developed in the 90's of the last century at the Delft University of Technology (Hellinga *et al.*, 1998; Hellinga *et al.*, 1999; STOWA, 1996). SHARON refers to Stable and High activity Ammonia Removal Over Nitrite. The process is especially suitable for high strength ammonia wastewaters. Typical applications are treatment of reject water from dewatering of digested sewage sludge (Mulder *et al.*, 2001; Kempen *et al.*, 2001) and wastewater from sludge drying or incineration plants. By treating reject water which is only 1% of the hydraulic load of a WWTP, the nitrogen load to a WWTP is reduced by 10 to 30%. With side stream treatment the overall nitrogen removal efficiency of the WWTP can be significantly improved. Other applications are treatment of landfill leachate and wastewater from digestion of organic waste and manure (Notenboom *et al.*, 2002).

The SHARON process makes advantage of the difference in growth rate of ammonia oxidizers and nitrite oxidizers which is illustrated in Figure 1. At higher temperatures, the ammonia oxidizers have a significant higher growth rate. By controlling the aerated retention time to approximately 1 day, the nitrite oxidizers will be washed out of the tank, and nitrification will be limited to nitrite formation. The SHARON process is operated in completely mixed reactors without sludge retention. Therefore the hydraulic retention time (HRT) is equal to the sludge retention time (SRT). A system without sludge retention behaves like a chemostat. Typically the outlet concentration of a chemostat is independent of the inlet concentration. A chemostat is therefore especially suited for treatment of high strength wastewaters. Furthermore the absence of sludge retention makes the SHARON process insensitive to suspended solids levels that may vary in reject water of sludge dewatering.

Figure 1 – Different growth rate of ammonia and nitrite oxidizers

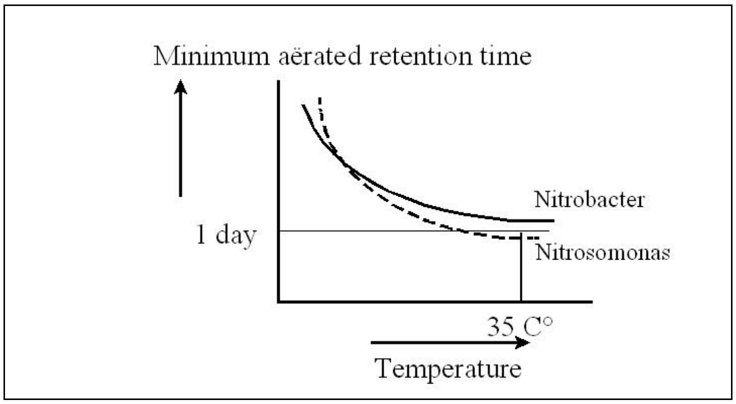
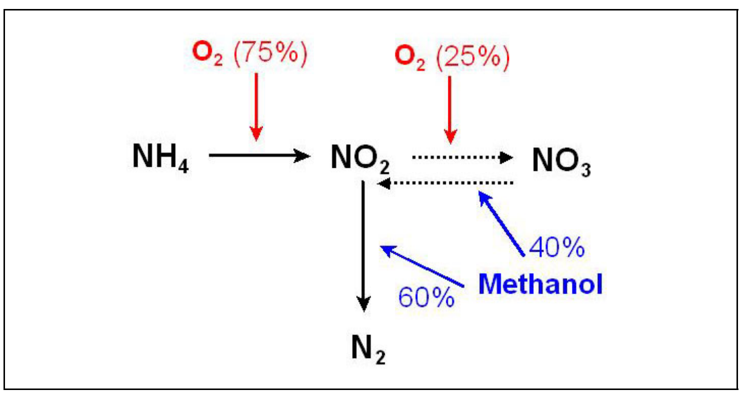


Figure 2 – The nitrite route



As a result of N-removal by nitrite instead of nitrate energy and COD are saved. Nitrification limited to nitrite saves 25% of aeration energy. Denitrification of nitrite saves 40% of COD, as is indicated in Figure 2. More than 80% of the energy demand related to the treatment of high strength ammonia wastewaters is contributed to aeration energy. Therefore a 25% reduction of the aeration energy is a significant decrease of the overall energy consumption. In addition 30% less surplus sludge is produced and overall 20% less CO_2 is emitted.

The advantage of a high conversion rate and the savings on consumables demand makes the SHARON process a compact and sustainable method for nitrogen removal.

This paper presents from an operational perspective an overview of the different SHARON plants.

OVERVIEW OF SHARON PLANTS

The first full scale SHARON plant came in 1997 in operation. At present six systems are implemented. In Table 1 an overview of the SHARON systems in the Netherlands is presented and Figure 3 contains a photograph of each plant. Most plants are applied for treatment of reject water from sludge dewatering. The first large scale SHARON system outside the Netherlands will be built at the WWTP New York Wards Island (Carrio, 2003). This plant will have a capacity of 5.000 kg nitrogen per day and will be operational in 2007.

Figure 3 – From left to right and from top to bottom: SHARON plant: Rotterdam-Sluisjesdijk, Utrecht, Zwolle, Beverwijk, The Haque-Houtrust and Groningen-Garmerwolde

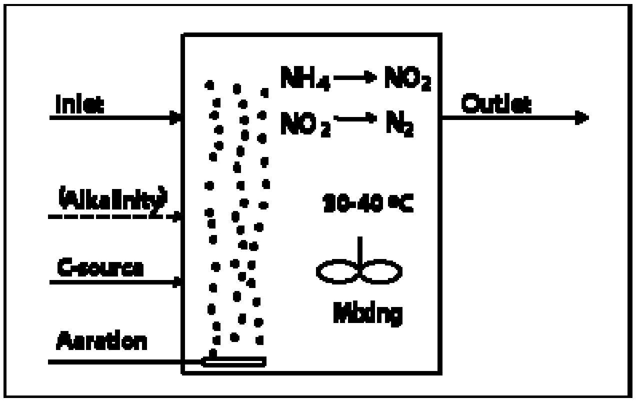
Table 1 - Full scale SHARON plants Netherlands

SHARON	In operation since	Load (kg N/day)	Wastewater application
Utrecht	1997	900	sludge dewatering
Rotterdam-Dokhaven	1999	850	sludge dewatering
Zwolle	2003	410	sludge dewatering
Beverwijk	2003	1,200	sludge dewatering/drying
The Hague-Houtrust	2005	1,300	dewatering
Groningen-Garmerwolde	2005	2,400	sludge dewatering/drying

SYSTEM CONFIGURATION

The basic configuration of SHARON process consists of a single, completely mixed tank. The tank is aerated intermittently to accommodate nitrification and denitrification (Figure 4). An alternative configuration consists of two separate tanks, one for nitrification and one for denitrification. Water is recirculated between the two compartments. An advantage of this configuration is a lower installed aeration capacity because the aeration system can operate continuously at design treatment capacity. A disadvantage however is the need for a recirculation flow which restricts the maximum denitrification efficiency and requires an extra pump. Depending on the site specific circumstances such as space restrictions, wastewater characteristics, existing available tank volume and minimum overall costs an optimum system configuration is selected. Table 2 presents the configuration and volume of the different full scale plants.

Figure 4 – Schematic representation of a single tank SHARON system



Heating or cooling may be required to maintain a process temperature between 30° Celsius and 40° Celsius (86 -104 F).

Usually an external COD source such as methanol is needed because the BOD concentration of reject water is low. Caustic can be used for additional pH control. In practice most SHARON plants operate without the use of caustic and caustic is only used as back-up facility.

Jet aerators or fine bubble diffusers are used for aeration. The first SHARON plants were equipped with jet aerators. For more recent SHARONs, material developments made application of fine bubble diffusers in warm media possible, achieving higher oxygen transfer efficiencies. The denitrification process requires mixing.

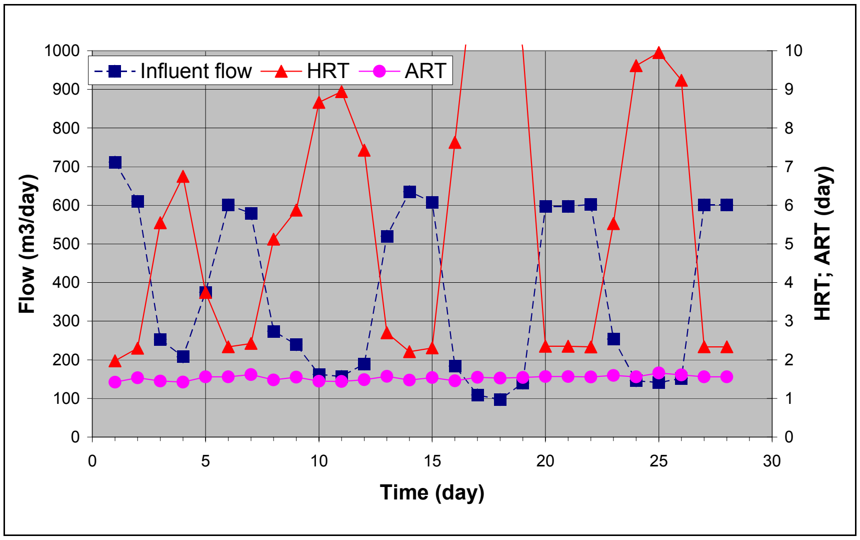
Table 2 – System configuration SHARON plants

SHARON	Tanks	Volume (m3)	Volume (US Gallon)
Utrecht	Two	3,000/1,500	792,600/396,300
Rotterdam-Dokhaven	Single	1,800	475,560
Zwolle	Two	900/450	237,780/118,890
Beverwijk	Two	1,500/750	396,300/198,150
The Haque-Houtrust	Single	2,000	528,400
Groningen-Garmerwolde	Two	4,900/2,450	1,294,580/647,290

AERATED RETENTION TIME CONTROL

The nitrification is limited to nitrite formation. A key feature to obtain stable nitrite production is control of the Aerated Retention Time (ART). At a temperature of around 35°C an ART of 1-2 day is required to predominately (>98%) produce nitrite. The aeration is operated discontinuously and according to the inlet flow the length of an aeration period is adjusted accurately. A typical trend of the ART control is illustrated in Figure 5.

Figure 5 – Typical trend ART control SHARON Zwolle

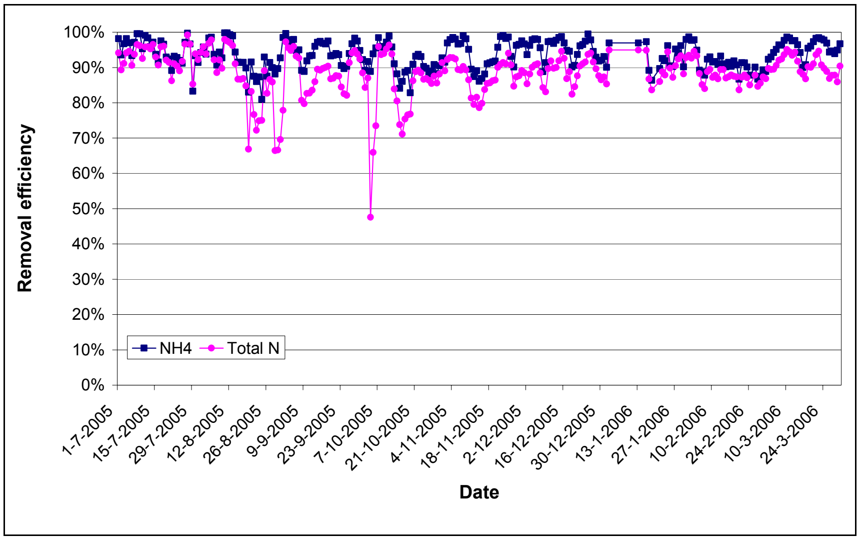


AMMONIA REMOVAL EFFICIENCY

An advantage of the process is a high conversion rate at temperatures above 30° C and therefore a short ART (1-2 days) is sufficient for the nitrification process. On the other hand the Ks value (Monod kinetics) for ammonia increases with increasing growth rates. As a consequence the ammonia outlet concentration increases with shorter ARTs. As rule of thumb the ammonia outlet concentration increases from less than 5 NH4-N/l at an ART of 2 days to approximately 100 mg NH4-N/l at an ART of 1 day. At an ART of 1.5 days an ammonia outlet concentration of approximately 20 mg NH4-N/l can be achieved. In addition the ammonia outlet concentration depends on the nitrite outlet concentration. Originally denitrification was applied for pH control only. The SHARON Rotterdam-Sluisjesdijk plant was run with nitrite concentrations as high as 200-300 mg NO_2-N/l. During a period with complete denitrification low outlet ammonia concentrations (< 20 mg/l) were achieved. High nitrite levels do significantly reduce the activity of ammonia oxidizers.
Besides the ART and nitrite outlet concentration the process parameters pH, temperature and oxygen concentration do influence the actual outlet ammonia concentration. Increased temperatures, pH values and oxygen levels do in general increase the ammonia removal efficiency. The ammonia outlet concentration is thus variable and depends on the actual settings of the process operating parameters. Based on full scale experience the ammonia outlet concentration can be targeted according to a required ammonia removal demand and/or to minimize overall nitrogen removal costs.

Figure 6 presents the nitrogen removal efficiency of SHARON Beverwijk. The average ammonia removal efficiency is 94%. Incidentally there is a shortage of COD source (sludge dryer condensate) that lowers the denitrification efficiency. Even so the average total nitrogen removal efficiency is 88%.

Figure 6 – Removal efficiencies SHARON Beverwijk



In Table 3 the average ammonia removal results of several SHARON plants are presented.

Table 3 - Average results of different SHARON plants

Location	ART (day)	Inlet concentration (mg NH4-N/l)	NH4-N removal efficiency (%)
Utrecht[1]	3 – 6	600 – 900	90 – 95
Rotterdam	1.3 – 1.8	1,000 – 1,500	85 – 98
Zwolle	1.3 – 1.8	400 – 600	85 – 95
Beverwijk	1.3 – 1.8	700 – 900	85 – 95
Houtrust	1.5 – 1.8	900 – 1,200	85 – 98
Garmerwolde[2]	1.4 – 1.5	700 – 800	≥ 95

[1] Due to the ART above 2 days nitrogen is removed partly by nitrate
[2] Expected results after start pre-thickening surplus sludge

PH CONTROL

Nitrification results in a pH decrease. Because of the high inlet concentrations the pH effect will be strong, and without pH correction nitrification will be inhibited. Three mechanisms can be responsible for pH adjustment.

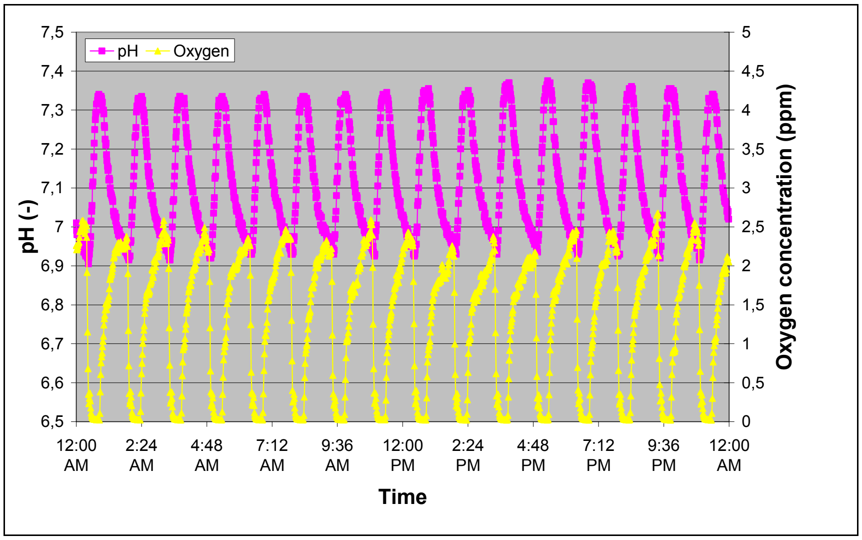
The first mechanism is stripping of CO_2. Wastewater originating from sludge digestion will contain high concentrations of CO_2. In these wastewaters the stripping effect will be responsible for neutralizing about 50% of the pH decrease. The process of CO_2 stripping cannot be controlled.

The second mechanism is denitrification. A maximum of 50% of the pH effect can be neutralized by denitrification. For denitrification both external and internal COD sources are applied. Dependant on the requirements of the main WWTP full or partial denitrification can be targeted. For pH control only partial denitrification is often sufficient. In addition any outlet nitrite will be denitrified in the part(s) (head of works, primary sedimentation, first aeration etc.) of the main WWTP.

The third mechanism is dosage of caustic which is the most direct way of pH control. However dosage of caustic is more expensive in comparison with denitrification with external C-sources. In practice dosage of caustic can be needed in situations where due to addition of specific chemicals such as iron chloride for dewatering, the CO_2 content of the wastewater is decreased. In these cases the CO_2 stripping effect will be less than 50% and depending on targeted nitrification efficiencies addition of caustic may be needed. Two of the six full scale SHARON plants in operation do require additional caustic dosage due to the use of ferric chloride at the dewatering. Other SHARON plants have caustic dosing systems as a backup provision. The SHARON The Haque-Houtrust plant has no caustic dosing system at all.

In all situations pH measurement and control is very important for process stability. In case of a single tank system the aeration is discontinuous and the pH will vary during a cycle. The difference between the maximum and minimum pH value during a cycle can be 0.5 pH unit. A typical pH trend of single tank system is illustrated in Figure 7.

Figure 7 – Typical pH trend SHARON The Haque-Houtrust



COD SOURCES FOR DENINITRIFICATION

The BOD concentration of most ammonia rich wastewaters is very limited, e.g. wastewater from dewatering of digested sludge. In this situation an external COD source has to be dosed.
The ratio of COD:N for denitrification has a stoichometric value of 2.86 in case of denitrification of nitrate and 1.71 in case of nitrite. Including sludge production the COD consumption is expected to be about 4 g COD/g NO_3-N and 2.4 g COD/g NO_2-N. The actual COD consumption is the best indicator for nitrification/denitrification by the nitrite route. Nitrate and nitrite effluent concentrations are of little importance because the actual ratio between production and conversion of nitrate and nitrite are unknown.

Different types of COD sources are used for denitrification as is presented in Table 4.

Table 4 – Different COD sources used for denitrification

Location	COD source
Utrecht	by-product from biofuel production
Rotterdam-Sluisjesdijk	methanol[1]
Zwolle	by-product from biofuel production
Beverwijk	condensate sludge drying
Houtrust	methanol
Groningen-Garmerwolde	condensate sludge drying; industrial waste product; methanol

[1] Use of methanol is stopped due to start-up of Anammox

Traditionally methanol is applied as a cost effective external COD source. Methanol is not part of the natural citric acid cycle breakdown pathway and therefore denitrifying bacteria need some adaptation time. In full scale practice the observed adaptation time is short and amounts to less than several days. The use of methanol requires safety measures for storage and dosing, due to fire and explosive risks. Plants that use methanol do investigate the feasibility of using alternative COD sources.

Alternative COD sources such as industrial waste products can be used as well. Issues for use of industrial waste products are residuals such as heavy metals, continuity of delivery and COD concentration. A high COD concentration is important in order to avoid significant decrease of the hydraulic retention time due to dilution. The application of industrial waste products is not very common yet.
Recently byproducts from the rapid growing biofuel production industry have become widely available as external COD source. These products can be 2-4 times more cost effective than high grade methanol and may require less stringent storage measures. Usually existing storage and dosing facilities for methanol can be used.

Some SHARON plants treat a mixture of wastewater from dewatering of digested sludge and wastewater (condensate) from sludge drying. Wastewater from sludge drying is COD rich and therefore no or less external COD source is needed.

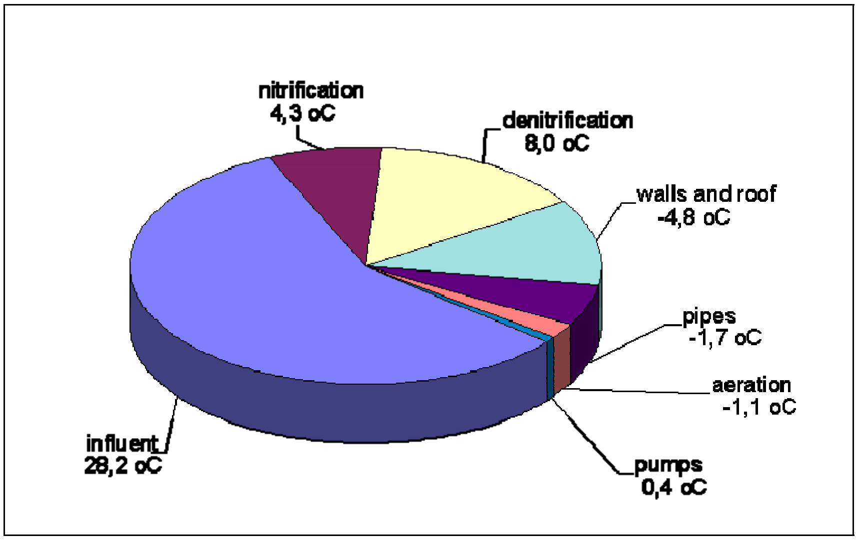
In practice the SHARON plants have a COD:N ratio below 2.4 gram COD per gram nitrite removed. SHARON Utrecht has a COD:N ratio of 3.0. The ART of this plant is above 2 days and therefore partially nitrate besides nitrite is produced by nitrification

Finally by combining the SHARON process with the Anammox process, nitrogen can be removed without a COD source (Dongen *et al.*, 2001) which has been successfully achieved at SHARON Rotterdam-Sluisjesdijk (Abma, 2006)

TEMPERATURE CONTROL

Biological processes produce heat. As a consequence the heat production of the high strength wastewaters is significant. As rule of thumb nitrogen removal (nitrification/denitrification) by nitrite produces 10° C temperature increase per 1 gram ammonia per liter. A temperature of 35° Celsius (95 F) is used as design temperature. In practice the process functions well within a range of 30° to 40° Celsius (86 - 104 F). In full scale practice even maximum temperatures of 42° Celsius (108 F) were reached. Temperature control is therefore not a very critical factor. For each plant a detailed heat balance is made. Most dominant factors are wastewater temperature, inlet ammonia concentration and tank insulation. Figure 8 illustrates a heat balance of the SHARON Rotterdam-Sluisjesdijk plant.

Figure 8 – Heat balance SHARON Rotterdam-Sluisjesdijk

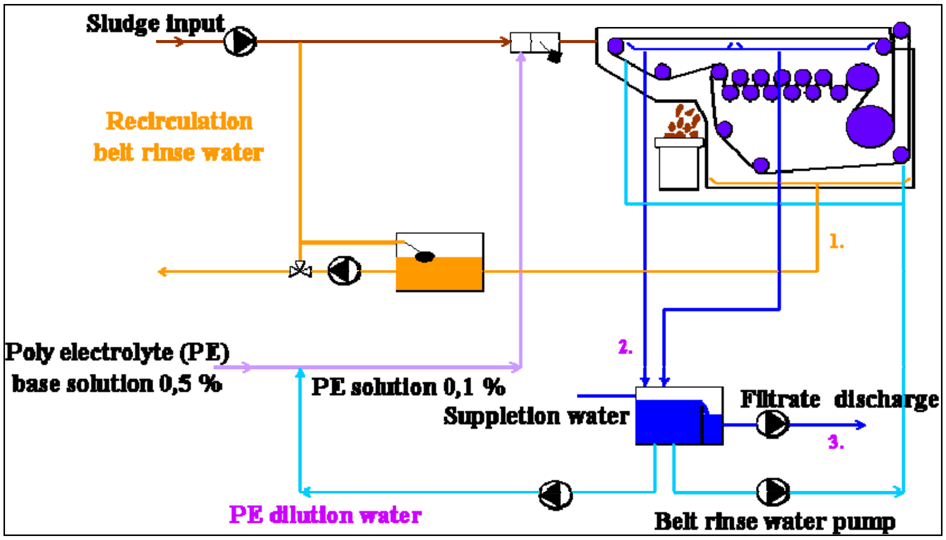


A system without cooling/heating equipment is preferable because of its simplicity. The SHARON plant The Haque-Houtrust has no heating or cooling system. Here the system temperature varies over season between 34° and 42° Celsius (93 – 108 F).
On other locations depending on site specific circumstances cooling or heating can be required. At sites with sludge drying, the condensate can have temperatures up to 70° Celsius (158 F) and thus cooling is necessary. Locations with relatively low wastewater temperatures (below ≈ 25° Celsius (77 F)) and low inlet concentrations (below ≈ 700 mg NH4-N/l) may require additional heating. In many occasions excess heat and/or biogas are available for additional heating.

SLUDGE DEWATERING

Sludge dewatering operation can have a significant effect on both inlet temperatures and inlet concentrations. For example in case of a belt filter press the belt press water (filtrate) should preferably be collected separately from the belt pres rinse water as is illustrated in Figure 9. The filtrate can be reused as belt rinse water. Additionally the used belt press rinse water can be added to the sludge input to remove suspended solids. In case fresh water is used as belt pres rinse water the filtrate is unnecessarily cooled and diluted. Also filtrate can be used to dilute the Poly Electrolyte (PE) base solution and can be subject of optimization. Optimum sludge thickening prior to digestion is another factor of importance to reach high inlet concentrations and does improve the effectiveness of digestion and side stream treatment in general. Large uncovered digested sludge storage tanks should be avoided to prevent unnecessary cooling. Finally the use of specific anti-foam agents prior to the SHARON process can have a negative effect on oxygen transfer efficiency of the aeration. In case an anti-foam agent is needed, a suitable product should be carefully selected depending on site specific wastewater characteristics and circumstances. In general the SHARON processes are operated without the additional use of anti-foam agents.

Figure 9 – Reuse of belt press water (filtrate) as belt rinse water



PROCESS STABILITY AND CONTROL

The definition of process stability depends on the required ammonia outlet concentration. For example the ammonia outlet concentration of SHARON Rotterdam-Sluisjesdijk may amount to about 100 mg/l. Here this outlet concentration is sufficiently low for the main WWTP. Other SHARON plants do reach lower ammonia outlet concentrations, even as low as 20 mg/l. To continuously achieve low ammonia outlet concentrations advanced process control is needed. These systems are therefore not only equipped with an oxygen, pH and temperature sensor but also with an online ammonia sensor and online nitrite sensor to enable a more advanced process control program.

In full scale practice the supply of reject water can be interrupted due to a discontinuous operation of the dewatering facility during for example weekends or maintenance periods. During these periods, that may last several days or longer, the actual ammonia removal capacity is preserved. This is achieved by restriction of the aeration. Without the availability of oxygen the activity of the nitrite oxidizers is preserved and full capacity remains standby. The high process temperature and thus the high growth rate of the ammonia oxidizers, contributes to the high process stability of the SHARON process. In addition the high process temperature enables during start-up a capacity increase of up to 50% per day.

All SHARON plants operate automatically. In full scale practices normal operation activities are restricted to less than 1 hour per day.

OPERATIONAL COSTS

The main operational costs are for energy and COD source. Costs for the COD source are strongly influenced by the type of COD source used. COD from condensate from sludge drying is available for free. Application of industrial waste streams as COD source can even be a source of income. The use of byproducts from the production of biofuel can be up to four times more cost effective than the use of a high grade methanol. Expressed per kg nitrogen removed the

SHARON process is highly competitive with other techniques for removal of high strength wastewaters.

IMPROVED WWTP EFFLUENT QUALITY

The effect of SHARON on the main WWTP nitrogen effluent quality was previously described (Kempen *et al.*, 2005). For two large WWTPs (Utrecht and Rotterdam-Dokhaven) the nitrogen balance was studied. The balances show the external and internal nitrogen loads before and after side stream treatment implementation. In both cases, implementation of SHARON significantly improved the overall WWTP nitrogen removal efficiency and nitrogen effluent quality.
Three situations can be distinguished where SHARON is effective; (i) a limited aeration capacity, (ii) a limited denitrification capacity and (iii) a limited aerobic sludge age.
It was shown that SHARON is successfully applied in the first and second situation. Based on model study and supported by full scale practice it was shown that in case SHARON is combined with enhanced suspended solids removal, the aerobic sludge age can be extended to maintain nitrification at lower temperatures. In the example the critical temperature for nitrification could be lowered with several degrees Celsius. In Table 5 an overview of the model results of the effect of SHARON on the WWTP nitrogen effluent quality is presented.

Table 5 – Model results effect of SHARON on WWTP nitrogen removal efficiency

Nitrogen balance	Activated sludge process (AS) without SHARON			AS with SHARON
	Limited aeration capacity	Limited denitrification capacity	Limited aerobic sludge age	
TN load				
Raw influent	100	100	100	100
Rejection water	20	20	20	1
N removal AS				
Nitri/Deni	72	72	0	72
Surplus sludge	4	4	4	4
SHARON	-	-	-	19
Total	76	76	4	95
Effluent load				
TKN	21	2	96	2
NO_3-N	3	22	0	3
TN	24	24	96	5

In full scale practice the following improvements were achieved. At WWTP Rotterdam-Dokhaven, aeration capacity of the activated sludge system was limiting. By implementation of SHARON the effluent ammonia load was decreased by approximately 50%. At WWTP Utrecht the denitrification capacity was the limiting factor. After implementation of SHARON the overall TN removal efficiency increased from 65% to over 75%.
In both situations the improved overall nitrogen removal results were achieved even with a 6% increase of the WWWP influent nitrogen load. At both locations SHARON did improve the

WWTP effluent quality and made compliance with nitrogen removal requirements possible. SHARON proved to be a cost effective alternative for conventional extension of the WWTP.

CONCLUSIONS

Nine years of operating experience prove that SHARON is an economic and sustainable process for nitrogen removal of high strength wastewaters. Compared to conventional techniques there is a significant saving of energy and consumables. The process is compact and simple to operate. Depending on site specific circumstances, different system configurations are possible.

The process can be operated very stable. The aerated retention time and nitrite concentration are the two most important process parameters to control the ammonia outlet concentration. The process temperature is less critical and may vary between 30° and 40°C. Ammonia removal efficiencies can be over 95%, are variable and can be targeted according to the required needs of the main WWTP and/or to minimize overall nitrogen removal costs.

The SHARON process is highly competitive with other techniques for removal of high strength wastewaters. Application of fine bubble aeration has further decreased aeration costs. Recently the use of by-products of the biofuel production industry as COD source for denitrification, has further increased the cost effectiveness.

SHARON is successfully applied to improve the main WWTP nitrogen effluent quality. It proves to be a cost effective alternative for conventional extension of the WWTP.

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END NOTES

J.O.J. Duin is employee of the ‘De Stichtse Rijnlanden’ Water Board, J. Goverde is employee of the ‘Hollands Noorderkwartier’ Water Board, W.G. Poiesz is employee of the ‘Noorderzijlvest’ Water Board, H.M. van Veldhuizen is employee of the ‘Groot Salland’ Water board, and R. van Kempen and P. Roeleveld are employees of the ‘Grontmij Nederland’ Consulting Engineering Company.

Mixing and Mass transfer Technologies INC, Lotepro Environmental Systems and Services is the licensee from Grontmij of the SHARON process in North America. Please address all communications regarding SHARON to Alphonse Warakomski by e-mail at: awarakomski@m2ttech.com

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