HIGH RATE TREATMENT WITH THE SHARON® PROCESS OF WASTEWATER FROM SOLID WASTE DIGESTION

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Abstract
The SHARON® process is a proven technology for the treatment of rejection water from sludge dewatering at WWTP's. Several full scale plants are in operation or are in preparation in the Netherlands. The application of the SHARON® process for the treatment of highly loaded wastewater with a low C/N ratio from digestion processes is demonstrated in several tests. The results of pilot plant tests on wastewater from digestate dewatering are presented. It shows a very high ammonia conversion rate of 1.0 to 1.4 g N/l.day in case of wastewater from a mixture of manure and organic waste digestion up to 4.0 g N/l.day in case of the treatment of wastewater from pig manure treatment. In normal activated sludge systems a maximum conversion rate of 0.3 g N/l.day is possible. The ammonia removal is over 90% at an aerobic hydraulic retention time of only one day. As a result small volumes can be applied and low operational costs for aeration and chemicals are feasible. The presented pilot plant test of the SHARON® process combined with post treatment in a conventional activated sludge system results in a high overall ammonia conversion rate and low effluent values.
Keywords
Digestion, Wastewater, Low C/N ratio, High rate treatment, SHARON®,Nitrification, Denitrification; Nitrite.

INTRODUCTION

The treatment of organic waste streams from agricultural source as a result of the recent food safety issues in the European Union (BSE, dioxin, foot and mouth disease and food chain responsibility) becomes an important topic in the discharge of residues from the agricultural industry. In the European Union landfilling of organic waste is in several countries no longer allowed or will be banned soon (Directive 1999/31/EC). Processing of organic wastes in solid waste incinerators is very often technically not possible or very expensive. The digestion of organic waste streams or the combined digestion with other organic streams as sludge or manure (co-digestion) has become attractive. Also the encouragement of the production of "green energy" and other measurements to reduce CO_2 emissions act as a stimulation of digestion technologies. This has resulted in the erection of several solid waste digestion plants in Europe lately.

The digested material (digestate) can be utilised for agricultural benefit or has to be pre-treated before utilisation or disposal. Especially treatment of wet organic slurries and sludge dewatering and / or drying results in wastewater production. As a result of the anaerobic digestion processes nitrogen from organic substances will be converted to ammonia. This kind of wastewater is typical highly loaded with ammonia, has a low C/N ratio, a high suspended solid concentration, a high buffer capacity and with elevated temperature ranges. In case of disposal, discharge costs are very high because of the high oxygen demand or disposal is no longer allowed because of strict nitrogen discharge standards. Conventional biological treatment based on nitrification / denitrification is a good treatment option but rather expensive. The plants have a big foot print because of high nitrogen levels and oxygen demand and often require extra COD addition. Nitrogen removal over nitrite and higher conversion rates should improve the application of biological treatment for this type of wastewater. The SHARON® process is typically applying these advantages and is very robust for the treatment of this kind of wastewater.

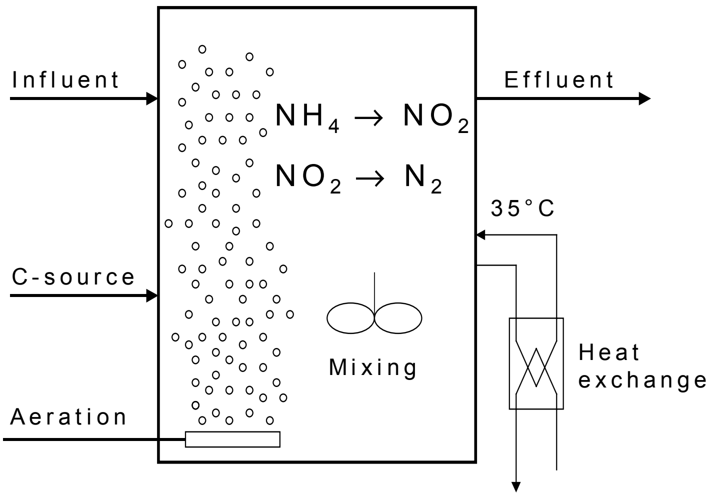
Grontmij Water & Waste Management is applying this technology already for several years for the treatment of rejection water of digested sludge dewatering at WWTP (van Kempen *et al.*, 2001). During the last few years several pilot plant tests have been performed for the treatment of high ammonia concentrated digestion effluents such as wastewater from pig manure treatment and landfill leachate. At a digestion plant for the treatment of a combination of manure and organic slurries, pilot plant tests are performed. The result of tests with the SHARON® process and supplementary after treatment of wastewater from the dewatering and drying of digestate is reported in this article.

THE SHARON® PROCESS

Description

The patented SHARON® process (Single reactor system for High activity Ammonia Removal Over Nitrite) has been described in detail by Hellinga (Hellinga *et al.*, 1998). This process is the first successful commercial technique by which nitrification/denitrification with nitrite as intermediate under stable process conditions was achieved. The Dutch foundation for Applied Water Research, STOWA initiated a research of techniques for treatment of the rejection water from sludge dewatering, inspired by new legislation for nitrogen removal at WWTP's. About 15% of the total nitrogen loading of a treatment plant is generated by recirculating water from the sludge digestion towards the activated sludge tanks. The SHARON® process proved to be the most cost-effective technique for the treatment of rejection water, 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 low investment costs (STOWA, 1996). Studies in Switzerland (Siegrist, 1996) and Germany (Liebig, 1999) gave similar results.

Figure 1. Schematic representation SHARON®



At the specific operation circumstances growth and washout of sludge are in steady state. The hydraulic retention time (HRT) is equal to the sludge retention time (SRT) and no sludge retention is maintained in the reactor (Figure 1). Due to differences in growth rate nitrite oxidisers can be washed out of the system while ammonia oxidisers are maintained, resulting in a stable N-removal over nitrite. This saves 25% on aeration energy and 40% on BOD addition in comparison with conventional systems as illustrated below.

Nitrification:

$NH_4^+ \quad + \quad \mathit{1.5}\ O_2 \quad \rightarrow \quad NO_2^- \quad + \quad H_2O \quad + \quad 2\ H^+$ (SHARON)

$NH_4^+ \quad + \quad \mathit{2}\ O_2 \quad \rightarrow \quad NO_3^- \quad + \quad H_2O \quad + \quad 2\ H^+$ (Conventional)

↑ 25% reduction

Denitrification:

$$6\,NO_2^- + 3\,CH_3OH + 3\,CO_2 \rightarrow 3\,N_2 + 6\,HCO_3^- + 3\,H_2O \text{ (SHARON)}$$

$$6\,NO_3^- + 5\,CH_3OH + CO_2 \rightarrow 3\,N_2 + 6\,HCO_3^- + 7\,H_2O \text{ (Conventional)}$$

↑ 40% reduction

The SHARON® process is further characterised by the following:

- 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;
- Micro-organisms show high activity, however the Ks 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 so the removal efficiency increases with higher inlet concentrations (>90% when influent-N> 500 mg/l);
- Nitrite oxidation can be prevented since at higher temperatures the NO_2-oxidizing bacteria grow slower than the NH_4-oxidisers (Figure 2) (Hunik et al., 1993). In a system without biomass retention (SRT=HRT) it is easy to limit the SRT in such way that only ammonium is oxidised and nitrite is not. This results in power and BOD savings;
- As the process functions without sludge retention there is no influence of the presence of suspended solids in the wastewater.
- Biological heat production is significant due to the high inlet concentrations;

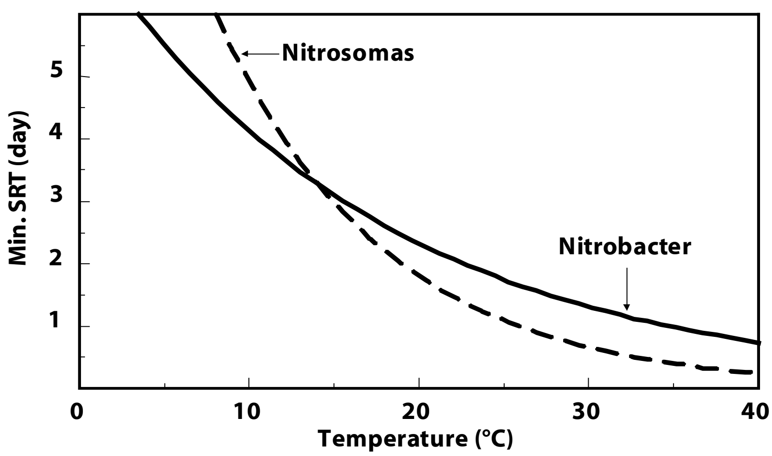


Figure 2. Minimum HRT for NH_4 and NO_2 oxidisers as function of the temperature

Denitrification in the SHARON® process is primary needed for pH control and can be partial when required. Use of methanol to produce alkalinity by denitrification appeared to be cheaper compared to dosing of caustic directly. In case of organic slurry digestion, the use of the original input for the digester can be used as a carbon source as suspended solids do not influence the process. Any NO_x that is left after denitrification for pH control will be denitrified in the conventional post treatment. Both nitrification and denitrification can be applied in a single reactor system using intermittent aeration or in separate reactor compartments depending on the specific application and starting points.

Full scale SHARON® plants at municipal WWTP's

Two full-scale SHARON® plants (Utrecht, Rotterdam) are in operation in the Netherlands. The third (Zwolle) and the fourth (Beverwijk) plant will be operational in 2003. Table 1 gives the design parameters of the four different SHARON® systems. The already operating systems run stable and according to the specifications. N-removal efficiency of ≥ 90% can be achieved. As a result the nitrogen load of WWTP effluent has dropped as expected.

Table 1. Design parameters full-scale SHARON® systems for treatment of rejection water

		Utrecht	Rotterdam	Zwolle	Beverwijk
Design flow	m^3/d	840	760	600	900
Maximum flow	m^3/d	1,500	1,200	720	1,200
Design N-load	kg/day	420	540	420	900
Maximum N-load	kg/day	900	830	510	1,200
Influent NH_4 concentration	g N/l	0.5 – 0.7	1 – 1.5	0.7 – 1.3	1 - 1.3

Pilot test for large-scale pig manure treatment

New ways for application and treatment of pig manure are studied. Centralised large-scale treatment is one of the possibilities. A proposed process was the separation of the solid fraction, incineration and power production. The pig manure was centrifuged to separate the solids. The centrate contains high levels of N-Kj, COD and suspended solids and has to be treated (table 2).

Table 2. Average characteristics pig manure centrate

Parameter	Dimension	Value	Parameter	Dimension	Value
N total	mg/l	5,000	Sulphate	mg/l	250
NH_4-N	mg/l	3,750	Sodium	mg/l	2,000
COD total	mg/l	30,000	Potassium	mg/l	5,000
BOD	mg/l	8,000	SS	mg/l	2,500
Chloride	mg/l	2,000	pH	-	8,0

The feasibility of the SHARON® process for treatment of the centrate was successfully tested during a period of 9 months. Despite the high NH_4 inlet concentrations, salt levels and metal concentrations, the SHARON® process proved to be stable. The test showed that an overall N-removal efficiency of 90-95% could be achieved. Due to extreme high nitrification activity of up to 4 g NH_4-N/l/d, adequate process control is needed.

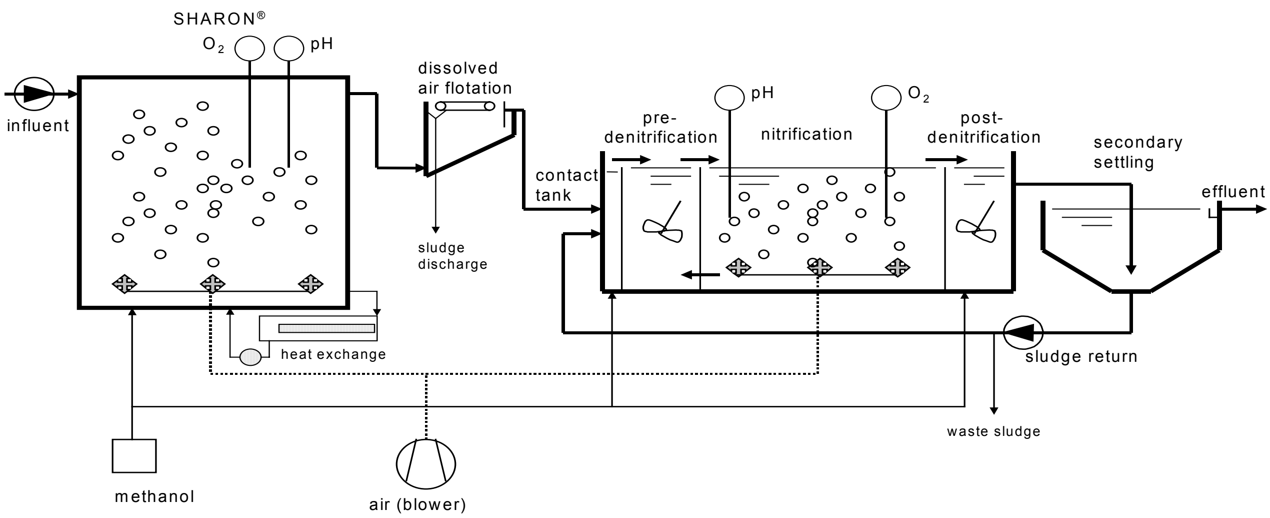
PILOT TESTS AT MANURE AND WASTE DIGESTION PLANT

The SHARON® process was tested on wastewater from the dewatering and drying of digestate from a combined manure and organic slurry digestion plant (MAV, Ghent Belgium). This 50 m^3/h wastewater flow contains high levels of ammonia and suspended solids. Prior to the test a feasibility study showed that a biological treatment system was most suitable to treat this type of wastewater. It was determined that the SHARON® process combined with a post treatment stage based on conventional aerobic treatment was preferable to fully conventional aerobic treatment or treatment in a membrane bioreactor (MBR). In the favoured process configuration the SHARON® process removes the bulk of the nitrogen load of the wastewater and the conventional aerobic post treatment stage polishes the SHARON® effluent before discharge. This process configuration was technologically less complex, more flexible and investment and operational costs were lower than fully conventional treatment or treatment by a MBR. In pilot scale tests the technical performance, the attainable effluent quality and the operational costs were researched over a period of five months.

Methods

The pilot plant consisted of a continuously stirred 850 l SHARON® reactor, which was alternately operated as a nitrification and denitrification reactor by intermittent aeration. The SHARON® reactor was continuously fed with 21 l/h, corresponding an aerobic hydraulic retention time of one day. During pilot plant circumstances methanol was dosed during the first ten minutes of every denitrification period because of a lack of biological available COD. Oxygen concentration and pH in the reactor were measured and registered. The reactor content was during the pilot plant situation continuously heated or cooled depending on the circumstances. Sludge in the SHARON® effluent was separated by a flotation unit before the wastewater entered the post treatment stage. Post treatment existed of a pre-denitrification tank, a nitrification tank, including pH and oxygen control, a post-denitrification tank and a secondary-settling tank. Return sludge was mixed with the flotation effluent in a contact tank before re-entering the post treatment stage. During the research Ferro(III)chloride was dosed alternately to the SHARON® reactor and to the post treatment to enhance phosphate removal. Also polyelectrolyte was added to the SHARON® effluent to promote sludge separation by dissolved air flotation. A flow diagram of the pilot plant is given schematically in figure 3.

Figure 3. Pilot plant



The test was divided in two main periods. In the first period a mixture of centrifugate (from dewatering of digestate) and condensate (from digestate drying) was treated. In the second period only centrifugate was treated. The average characteristics of both types of wastewater are given below in table 3. The distinction between the two periods is based upon a difference in wastewater characteristics and treatment behaviour. As can be seen in table 3 centrifugate is higher loaded with COD and nitrogen, it contains higher concentrations of suspended solids and is better naturally buffered. The alkalinity is of great importance due to the high rate in which the buffering capacity is used up as a result of the high volumetric nitrification rate in the SHARON® reactor.

Table 3. Characteristics of centrifugate/condensate mixture and centrifugate

Parameter	Unit	Centrifugate/condensate	Centrifugate
Period		1	2
COD-tot	mg/l	2,500 ± 500	3,300 ± 1,200
COD-sol	mg/l	1,300 ± 300	1,900 ± 500
COD-sol/COD-tot	-	0.5	0.6
BOD_5	mg/l	1,000 ± 200	950 ± 200
N-tot	mg/l	1,150 ± 200	1,600 ± 300
N-Kj	mg/l	1,150 ± 200	1,600 ± 300
NH_4-N	mg/l	900 ± 200	1,350 ± 300
P-tot	mg/l	40 ± 15	68 ± 20
SS	mg/l	1,000 ± 700	1,800 ± 1,000
Alkalinity	mg HCO_3^-/l	5,200 ± 2,500	8,700 ± 1,000
pH	-	8.5 ± 0.2	8.6 ± 0.3

The influent and effluent from the SHARON® reactor and the final effluent from the post treatment were regularly sampled and analysed. The use of chemicals was measured and registered.

Results and discussion

The results of period 2 are presented in more detail. This period is subdivided in shorter stages with different process conditions. The different stages are explained in table 2.

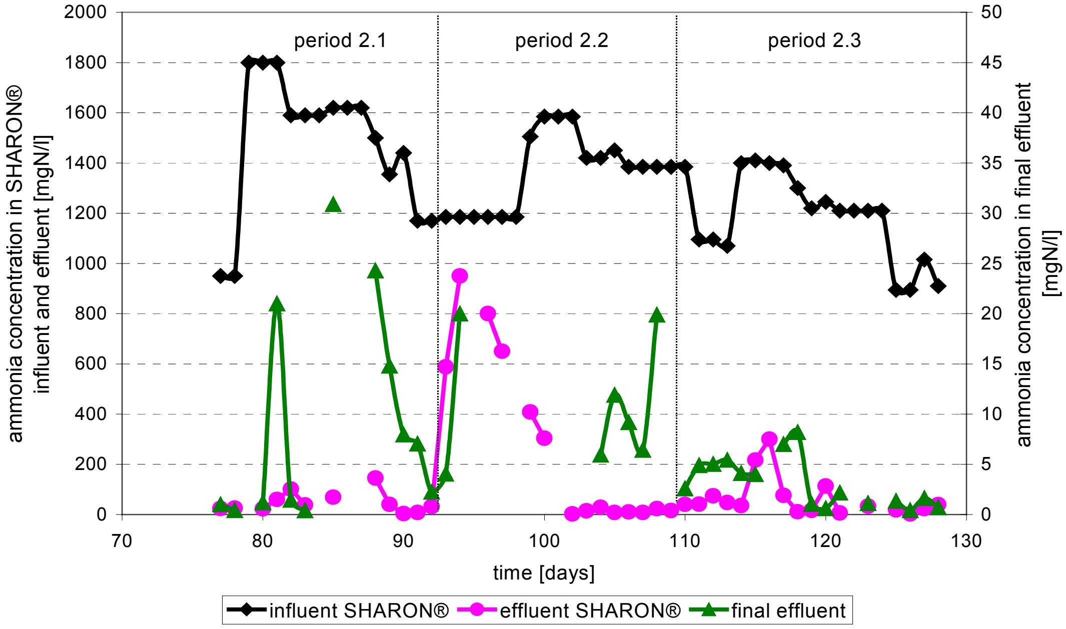
Table 4. Stages during pilot testing of centrifugate wastewater

Period / Stage	Explanation
	Treatment of centrifugate
2.1	transition period: adaptation to different type of wastewater
2.2	inhibition period: accumulation of ammonia in SHARON® reactor due to technical malfunction, turn off of feed until nitrification rate was restored without any inoculation.
2.3	stable operation with P and SS removal: $FeCl_3$ dosing to SHARON® and PE dosing to SHARON® and post treatment

N-removal. After an adaptation and start-up period the oxidation of ammonia in the SHARON® reactor proceeded over nitrite at both types of wastewater as could be observed by the low methanol demand. For denitrification during treatment of centrifugate (period 2) 2.4g COD/l was required. Together with the BOD of the wastewater the necessary C/N-ratio for the removal of nitrogen in the SHARON® reactor was ≤3.

Ammonia levels are given in figure 4. As can be seen the centrifugate is highly loaded with ammonia. Even though during stable operation the overall performance of the treatment system is equal for both types of wastewater. High levels of nitrite (50 – 150 mg/l) and low levels of nitrate (0 – 30 mg/l) were detected in the SHARON® effluent. Ammonia in the SHARON® effluent was 80 – 100 mg/l during centrifugate treatment, with exception of stage 2.2 where ammonia inhibition took place because of the malfunctioning of the pH measurement during some days. The ammonia removal efficiency of the SHARON® reactor was 80 – 99%.

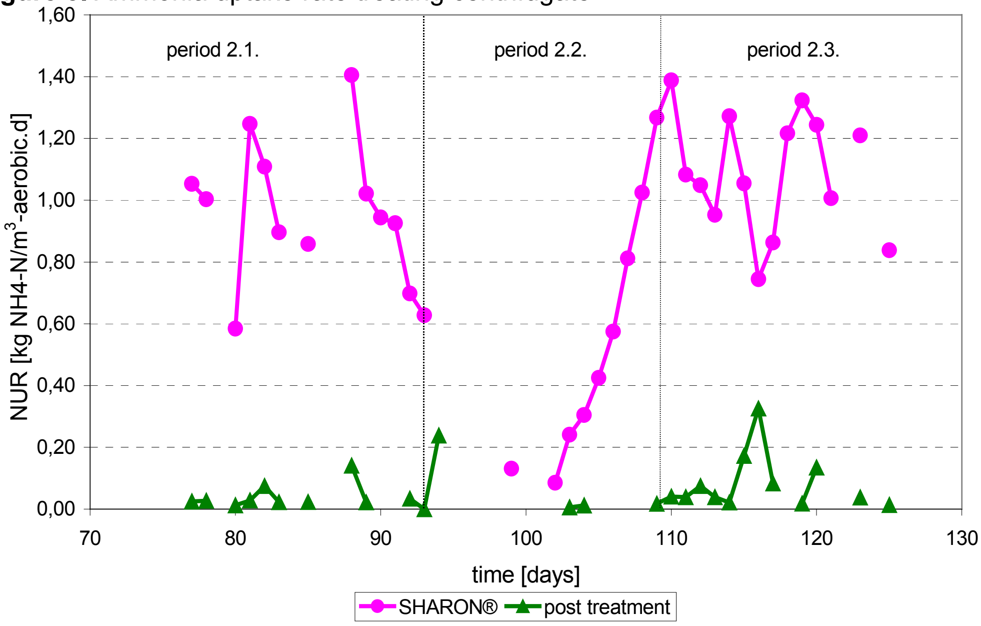
Figure 4. Ammonia concentrations during the treatment of centrifugate



The overall ammonia removal efficiency is 97% - >99.5%. The high levels of suspended solids in the influent did not influence the nitrification in the SHARON® reactor and were removed in the sludge separation stage before the post treatment. The maximum ammonia uptake rate by the nitrifiers in the SHARON® reactor on a mixture of centrifugate and condensate was 1.0 - 1.2 g NH_4-N/l.d. This is 6 - 7 times higher than the maximum ammonia uptake rate in the conventional aerobic treatment system. The maximum ammonia uptake rate in the SHARON® reactor on centrifugate was 1.0 - 1.4 g NH_4-N/l.d aerated volume (see figure 5). This is even 6 - 8 times higher than the maximum ammonia uptake rate in the conventional aerobic treatment system.

As can be seen in period 2.2 of figures 4 and 5 the ammonia uptake rate in the SHARON® reactor quickly recovers to its maximum rate after the ammonia concentration has dropped below inhibiting levels.

Figure 5. Ammonia uptake rate treating centrifugate



The overall nitrogen removal efficiency for both types of wastewater was 99 –100% for ammonia and other biologically available nitrogen. During stable process conditions nitrate in the final effluent was 0 – 10 mg/l, ammonia and nitrite in the final effluent were nearly zero. The total nitrogen concentration in the final effluent was 20- 35 mg/l (>97% removal efficiency) for treatment of the mixture of centrifugate and condensate and 60 – 75 mg/l (>95% removal efficiency) for treatment of centrifugate only. This rest concentration mainly exists of non-degradable nitrogen compounds as present in natural organic matter like humic acids. Flocculation and sedimentation tests with $FeCl_3$ and PE on the final effluent showed an additional total nitrogen, SS and COD removal.

COD-removal. Total COD-removal in the SHARON® reactor is limited because of the low COD content of the influent, and low BOD/COD ratio. Dissolved COD is used for denitrification and converted from soluble to suspended COD in the form of sludge, which can easily be removed by dissolved air flotation. The remainder of the biodegradable COD is removed in the post treatment stage. The overall COD-removal efficiency is 70 – 75%. Rest COD is mainly present as natural organic matter (humic acids) probably as a result of the digestion of manure. BOD removal efficiency in the SHARON® is nearly 100%

Effluent quality. After biological treatment the wastewater contained still a relatively high amount of COD and N-Kj as a result of colloids and humic acids in the wastewater. Physical-chemical tests on the final effluent were performed with $FeCl_3$ and PE dosing on laboratory scale. Biological treatment and additional tertiary physical-chemical treatment could reach the effluent qualities given in table 5.

Table 5. Attainable effluent quality

Parameter	Unit	Period 1 Final effluent	Period 1 Physical-chemical treatment	Period 2 Final effluent	Period 2 Physical-chemical treatment
COD-tot	mg/l	500 – 900	120 – 360	1,150 – 1,800	450 – 600
BOD_5	mg/l	< 5 – 25	< 5	< 5-50	< 5
N-Kj	mg/l	15 – 25	12 – 25	60 – 75	20 – 45
NO_3-N	mg/l	5 –10	3 – 7	< 5 – 10	3 – 7
N-tot	mg/l	20 – 35	15 – 32	70 – 85	25 – 55
P-tot.	mg/l	3-5	<2	4-6	<2
SS	mg/l	70 – 300	< 60	100 – 300	< 60
pH	mg/l	6.5 – 8.5	6.5 – 9	7.5 – 8.5	6.5 – 7.5

Conclusion

SHARON® technology proved to be a very suitable treatment system to remove the bulk of nitrogen from different types of wastewater released by the digestion of organic waste streams and manure. Because of the high ammonia uptake rate and efficient N-removal over nitrite investment and operational costs are very attractive in comparison to other biological treatment options. Biological heat production is significant which makes integration with mesofilic or thermofilic digestion from energy point of view attractive.

In combination with a conventional post treatment system for polishing low effluent concentrations can be reached very efficiently. The aerobic nitrogen uptake rate of the tested combination of treatment systems is very high (0.8 – 0.9 kg NH_4-N/m^3.d) compared with fully conventional treatment system (maximum 0.3 kg NH_4-N/m^3.d). This results in a more compact, flexibel and cheaper plant for the treatment of wastewater from digestion processes.

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