Wastewater Technology Fact Sheet

Side Stream Nutrient Removal

United States Environmental Protection Agency

INTRODUCTION

A significant nutrient load can be generated internally by publicly owned treatment works (POTWs). These nutrients can be found in the reject water, also known as side streams, of many municipal wastewater and sewage sludge treatment processes. These side streams include the reject stream from membranes, supernatant liquid from sludge digesters, and the centrate/filtrate return stream from sewage sludge dewatering processes, among others. Most of these side streams are conventionally returned to the headworks of the POTW, where they are combined with the normal influent. Estimates of the nitrogen load from this side stream return are between 15 and 30 percent of the total nitrogen load on the process (Solley, D. 2000).

Recently, there has been research into the separate treatment of these high-nutrient side streams. It is reported to be more efficient and cost effective than the conventional method of returning these side streams untreated to the headworks of the plant. The use of side stream treatment is intended to decrease the loading on the main nutrient removal process, resulting in lower effluent nutrient concentrations (Vandaele et al. 2000).

Several relatively new processes have been developed to remove nitrogen in high-concentration side streams from biosolids processing—SHARON®, ANAMMOX®, and InNitri® (Warakomski et al. 2006), and BABE® (STOWA 2006). Each procedure has unique characteristics that remove nitrogen more cost effectively. SHARON® incorporates a different metabolic pathway than is usually implemented in wastewater treatment. InNitri® and BABE® use bioaugmentation (the seeding of specific strains of organisms to achieve desirable results) in a new way, and ANAMMOX® uses an entirely new group of bacteria to oxidize ammonia anaerobically.

SHARON PROCESS

1. Description and working principle

The SHARON (Single reactor for High activity Ammonia Removal Over Nitrite) process takes place in a completely mixed reactor without biomass retention. It has been developed to treat high strength ammonia side streams from sludge digestion. The conventional means of converting ammonia to nitrogen gas is by utilizing the nitrification/denitrification process. In the SHARON® process, ammonia is converted directly to nitrite (as opposed to nitrate in conventional methods), and then directly to nitrogen gas (Solley, D. 2000). The conversion from ammonium to nitrite is described by the following formula:

$$NH_4^+ + 1.5\ O_2 \Rightarrow NO_2^- + H_2O + 2\ H^+$$

(STOWA 2006)

The ammonia oxidation is stopped at the nitrite step by operating the SHARON® process at an elevated temperature. At higher temperatures, the ammonia oxidizers grow significantly faster than the nitrite-oxidizing bacteria. In this process the hydraulic retention time (HRT) is equal to solids retention time (SRT). Therefore the slow-growing nitrite oxidizers are washed out of the system and the ammonia oxidization is stopped at nitrite.

This is an exothermic process which operates at process temperatures between 30 and 40 degrees Celcius (°C) (86 to 104 degrees Fahrenheit (°F). Depending on the ammonia concentrations in the side stream being treated and final effluent limitations, hydraulic retention times may be in the range of 1 to 2 days (Solley, D. 2000).

Temperatures of side stream water from digesters can be expected to be generally around 25 to 30 °C. The exothermic microbiological activity in the SHARON® reactor produces a temperature rise of approximately 5 to 8 °C. Depending on the local climate, additional heating might be required only in wintertime.

2. Design guidelines/Technical data

Two wastewater treatment plants (WWTPs) in the Netherlands utilizing the SHARON® process have been studied to determine their performance and costs. The SHARON® process takes place in a single reactor, therefore, the amount of land required can be much less than expanding conventional nitrification/ denitrification systems. The design specifications for the SHARON® process at the two Dutch WWTPs (Utrecht and Dokhaven) is presented below.

Table 1.
Process design specifications

Parameter	Units	WWTP Utrecht	WWTP Dokhaven
Tank volume	m^3	4.500	1.800
Design flow	m^3/h	35	31.5
Maximum flow	m^3/h	62.5	50
Design N-load	kg/d	420	540
Maximum N-load	kg/d	900	830
Influent NH_4 conc.	g N/l	0.5–0.7	1–1.5
Aerobic retention time	d	2.5	1
Anoxic retention time	d	1.25	0.5–1.4

The Dokhaven WWTP operates in an aerobic/anoxic cycle. The Utrecht WWTP utilizes a two reactor continuous system (Solley, D. 2006). For the Utrecht facility, the length of one aerated period can be dependent on inlet flow and pH set points. During aerobic periods, the pH will decrease; during anoxic periods, the pH will increase. This results in a discernible pattern. The fluctuations in pH can be addressed with process controls.

3. Performance

Performance at WWTP Dokhaven (Rotterdam, The Netherlands).

The SHARON® process was first introduced at the Dokhaven WWTP in 1997. As shown below, the ammonium concentration in the effluent from has continued to decrease (STOWA 2006).

Table 2.
Average Ammonium effluent concentration – Dokhaven WWTP

Year	Average NH_4^+ effluent. conc. [mg/l]
1997–1998	9.6
1999	6.2
2000	5.2

Removal efficiencies of ammonia during this time period have averaged in the 70 to 90 percent range, with the process becoming more efficient in more recent years.

SHARON®/ANAMMOX® PROCESS

1. Description and working principle

The ANaerobic AMMonium Oxidation (ANAMMOX®) process is a variation on the SHARON® process described previously. In the ANAMMOX® process, ammonium is converted to dinitrogen gas (N_2). The combination of the SHARON® process with the ANAMMOX® provides an efficient and cost effective means to treat nutrient rich side streams (STOWA 2006).

Treatment step 1: SHARON® process.

The SHARON® process is used to produce an ammonium-nitrite mixture. For the SHARON®/ ANAMMOX® process however, the goal is to convert only 50 percent of the ammonium to nitrite so the difference in the SHARON® portion of this process is the conversion of only 50 percent of the ammonium. To ensure that only 50 percent of the ammonium is converted to nitrite, the oxygen supply is limited.

Treatment step 2: ANAMMOX® process.

In this treatment step, the ammonium-nitrite mixture produced in the SHARON® reactor is converted to nitrogen gas. Ammonium is used as an electron donor under anoxic conditions. The conversion of ammonium and nitrite to nitrogen gas is described by the following formula (STOWA 2006):

$NO_2^- + NH_4 \Rightarrow N_2 + 2\ H_20$

The bacteria involved in the reaction are autotrophic do not need the addition of an external carbon source.

Since the ANAMMOX® bacteria have a slow growth rate (doubling in 10 days at 30°C) (STOWA 2006), sufficient volume must be available to prevent wash out of the bacteria. Sequential batch reactors have been used for this purpose in pilot tests (STOWA 2006).

The treatment sequence of the combined SHARON®/ANAMMOX® process is depicted in Figure1.

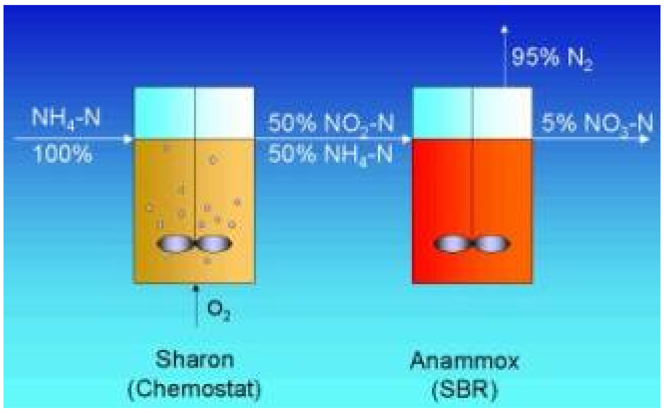

Figure 1. SHARON/ANAMMOX process

2. Design and Application

When sludge thickening and dewatering occur before digestion, higher ammonia concentration and lower overflow rates result.

WWTP Dokhaven (Rotterdam, The Netherlands): In 2002, the Dokhaven WWTP's SHARON® reactor was combined with an ANAMMOX® system. The installation began operating in June 2002 (STOWA 2006).

3. Performance

It is estimated that the combined SHARON®/ ANAMMOX® process can achieve an overall nitrogen removal rate of 90 to 95 percent. Since the process does not need an external organic source and operates under low oxygen concentrations, cost savings can be realized over the traditional nitrification/denitrification systems (Solley, D. 2000).

INNITRI® SYSTEM

1. Description and working principle

InNitri® (*Inexpensive Nitrification*) is a new, side stream nitrification process offered by Mixing & Mass Transfer (M^2T) Technologies, Inc. It allows nitrification at short SRT values, even at low winter temperatures and provides nitrification in a substantially smaller aeration tank than is required for conventional nitrification design. The InNitri® process was developed to provide an inexpensive alternative for plants in northern climates that need to upgrade their air or pure oxygen activated sludge process for year-round nitrification or nitrogen removal (M^2T 2002).

In general, the InNitri® process consists of supplemental nitrifiers being added constantly to the main activated sludge process to replenish nitrifiers removed with the wasted activated sludge. The supplemental nitrifiers are grown in a separate, small, side-stream aeration tank using either ammonia available in the digested sludge dewatering liquid and in the digester supernatant or commercial ammonia.

A conventional secondary treatment plant might consist of primary sedimentation, an aeration tank, secondary clarification, and sludge thickening, followed by anaerobic digestion and sludge dewatering. Upgrading such a plant to provide year-round nitrification using the InNitri® (short Solids Retention Time (SRT) nitrification) process requires the addition of a small aeration tank and clarifier for growing nitrifiers. In the process, the warm (typically 30 to 35 °C) dewatering liquid containing a high ammonia content (between 300 and 900 mg/L) is mixed with a small portion of primary effluent (to adjust the temperature and provide organic matter), and it is nitrified in the side stream nitrification aeration tank. A portion of the resulting biological sludge—containing a high percentage of nitrifiers—is discharged into the main aeration tank and provides the main activated sludge process with supplemental nitrifiers. This results in the plant being able to provide year-round nitrification.

The same process can also be applied in plants without digesters. In this case, commercial ammonia is used instead of the dewatering return stream.

The treatment sequence of the InNitri® system is schematically depicted in Figure2.

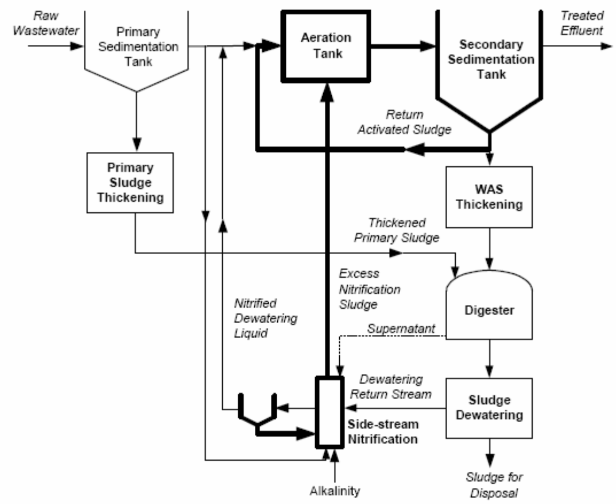

Figure 2. InNitri® system

2. Design Guidelines/Technical Data

The conventional nitrification process typically consists of a complete mix-steady-state aeration tank with 6 hr. hydraulic detention time, operating at 10 °C, and receiving an influent containing 25 mg/L of TKN (with 25 percent of the TKN contained in the side-stream dewatering liquid). To demonstrate the difference between the conventional nitrification process and nitrification with supplemental nitrifiers (InNitri process), KOS (1998) presented theoretical equations and results of modeling for a typical WWTP. Mathematical modeling results showed that, for conventional nitrification at 10 °C, as the operating SRT is decreased, the concentration of nitrifiers also decreased, while ammonia nitrogen in the effluent increased. For the InNitri® approach, results indicate that nitrifiers are present in the main aeration tank at all SRT values.

Nitrifiers cannot be washed out from the aeration tank even if operated at lower SRT values; therefore, partial nitrification takes place even at extremely low SRT values. In other words, the InNitri® process does not have a minimum SRT under which nitrification would not occur. Therefore, it will be much more stable and may not require as high a safety factor as conventional nitrification. The modeling was repeated at temperatures from 7.5 to 20 °C. Results showed the InNitri® process allowed for significantly lower design SRT than the conventional nitrification to achieve the same effluent ammonia concentration. Where the design effluent ammonia concentration is 2.0 mg/l, the minimum required design SRT for the InNitri® process is about 60 percent of that required for conventional nitrification. A comparison of the SRT necessary for nitrification using InNitri® versus conventional nitrification showed significant reductions in costs for low temperature wastewaters using the InNitri® process.

Research by the University of Manitoba indicated that the transport of nitrifying sludge from a warm side stream reactor to a cold mainstream reactor should pose no process problems. Also, the evaluation of the process to upgrade an existing facility showed significant cost savings using the InNitri® system versus using conventional and other advanced nitrification processes.

Brinjac, Kambic, and Associates (2000) completed a feasibility analysis for upgrading the Harrisburg City Advanced Wastewater Treatment Facility (Harrisburg, Pennsylvania) for nutrient control. This facility was considered to be typical of many of the plants designed to meet the effluent requirements of the federal Clean Water Act. The facility is in the colder climate in northeastern United States and is a principal point source contributor of nitrogen to the Susquehanna River. The river flows to the Chesapeake Bay where efforts are underway to improve water quality by reducing the nutrient load to the bay. The facility is site-constrained with little room for flow or process expansion. Due to the results of the feasibility study, Brinjac, et al. recommended that the facility implement the InNitri® process. (As of this date, the city has not yet initiated the project.)

3. Performance

Currently, there are no full-scale InNitri® installations. Capital and operations and maintenance (O&M) costs for the system vary by the type and size of facility. For site-specific unit design and costs, contacting the manufacturer directly is recommended.

BABE PROCESS

1. Description and working principle

The BioAugmentation Batch Enhanced (BABE®) process is comprised of a single batch reactor. Side stream waters high in ammonia content and return activated sludge (RAS) from the main biological treatment process are combined (STOWA 2006) with previously settled sludge in the batch reactor. The RAS is used to augment the bacteria in the settled sludge. By utilizing a batch reactor, the long residence times necessary to grow both the nitrifying and denitrifying bacteria are possible. There are five phases to the BABE® process: 1) filling, 2) mixing and aeration, 3) mixing, 4) settling, and 5) settling and decant (STOWA 2006).

The first two steps are done under aerobic conditions. The third involves mixing without aeration to achieve anoxic conditions. This condition is conducive to denitrification. Steps four and five complete the process.

2. Design and Performance

As with the SHARON® process, testing has shown that higher concentrations of ammonia in the influent to the BABE® process are preferable (STOWA 2006). The BABE® process operates at temperatures between 20 and 25 degrees C, which is lower than the SHARON® process.

If the process temperature in the BABE® reactor is less than 20°C, the reactor volume must increase dramatically. However, temperatures greater than the normal operating temperature range have minimal impact on the process.

OPERATION AND MAINTENANCE ISSUES

The SHARON® process has been shown to be able to tolerate suspended solids in the influent to the process. However, pH control is vital to the proper operation of the process and robust process controls must be in place to respond quickly to changes in process temperatures and pH.

The ANAMMOX® process can respond well to biomass that is washed out of the SHARON® process in a combined system. Due to the slow growth of the denitrifying bacteria, long start-up times are required. Again, pH and temperature control are imperative for proper operation of the system.

The InNitri® System's advantages are a low capital cost and small footprint at a facility. It also appears that process control is not as vital (M^2T 2002) when compared to other side stream nitrification processes.

COSTS

The SHARON® process has been compared with other techniques for nitrogen removal from reject water and was found to be the least expensive under Dutch circumstances. A cost estimate of 1.5 Euro/kg $N_{removed}$ (approximately \$2/kg $N_{removed}$) was given.

The investment costs for a SHARON®/ ANAMMOX® installation with a capacity of 1.200 kg NH_4-N/day are estimated at 2 million Euros (approximately 2.75 million U.S. dollars). The operating costs are linked to the costs for energy, methanol, and caustic chemicals (STOWA 2006).

Actual costs for the InNitri® and BABE® processes are not available; there is no full scale implementation of these systems.

OTHER TECHNOLOGIES INCLUDE:

Plug–flow, activated-sludge with denitrification filters

The Central Johnston County Wastewater Treatment Plant in Smithfield, North Carolina achieves biological phosphorus removal and nitrogen removal in a plug-flow, activated-sludge process and separate-stage denitrification filters.

The plug-flow, activated-sludge process utilizes anoxic and aerobic basins in series. This was a retrofit design implemented by facility personnel.

The two-stage biological processes in series offer high efficiency in nutrient removal at minimal costs. The source of wastewater is typical residential customers in the suburb of a large, metropolitan area. The BOD to total phosphorus (TP) ratio averages 55:1. The retrofitted, activated-sludge process consists of an anoxic stage with a 4.8-hour residence time, followed by an aerobic stage in two tanks with a residence time of 11.5 hours. The operating strategy developed at this facility is unique because the sludge blanket at the clarifiers is 3–4 feet deep, and the return activated sludge (RAS) flow rate is maintained at a low (10–25 percent) portion of the plant flow. The second-stage denitrification filters then remove the remaining nitrogen with a methanol feed.

The design and operation result in a high level of removals with an effluent TN concentration of 2.14 mg/L and an effluent TP concentration of 0.26 mg/L.

COSTS

The costs of removal were very low for both capital and O&M. The life-cycle cost for TP removal was $2.21/lb of TP removed, while the life-cycle cost for TN removal was $0.98/lb of TN removed, including the cost for methanol. The capital cost for the flow capacity was $0.58/gallon per day (gpd) capacity.

A/O Process with Alum Feed

The Clark County Water Reclamation Facility (WRF) is in Las Vegas, Nevada. Three major factors contribute to reliable phosphorus removal and nitrification at this facility: (1) multiple chemical feeding, (2) good biological phosphorus removal with in-plant volatile fatty acid (VFA) generation and full nitrification, and (3) good tertiary filters for suspended solids removal. This combination of chemical, biological, and physical processes in series is effective in providing exceptionally low phosphorus (0.09 mg/L) and ammonia-nitrogen (0.05 mg/L) concentrations.

COSTS

The capital cost for phosphorus removal and complete nitrification is estimated to be $2.01/gpd. The unit costs for capital and O&M were $5.43/lb for phosphorus and $1.38/lb of nitrogen removed. The unit costs for O&M were $1.84/lb of phosphorus removed and $0.51/lb of nitrogen removed.

The Clark County plant operation has been successful in reducing effluent phosphorus to a level that is considered to be the state-of-the science at the existing plant using a combination of biological and chemical treatment processes in series with good reliability. The plant is almost at capacity and yet has produced effluent far below the discharge limits. The technique of using several different technologies in series can achieve the treatment objective especially when the operation is computer controlled and the system has been designed with a reasonable amount of redundancies to allow for repairs and routine maintenance. Operational costs are reasonable, with life-cycle costs of $5.24/lb and $0.98/lb for phosphorus and nitrogen removal, respectively.

In addition to the technologies mentioned above, there are other treatment options available. For their applicability in removing nutrients at wastewater treatment facilities, examine::

1. Bioaugmentation with recycle treatment
   – MAUREEN (Mainstream Autotrophic Recycle Enabling Enhanced N-removal)
2. Fixed-film nitrification and de-ammonification processes
   – OLAND (Oxygen Limited Aerobic Nitrification-Denitrification)
   – CANON (Completely Autotrophic Nitrogen Removal Over Nitrite) (Stensel 2006)

SUMMARY

1. The treating of recycle side streams can provide more stable and effective nitrification.

2. Recycle side stream treatment can increase nitrification capacity of existing systems (BABE®, InNitri®, and MAUREEN).
3. Recycle side stream treatment can help reduce carbon demand for nitrogen removal (SHARON®, ANAMMOX®, OLAND, and CANON) (Stensel 2006).

ACKNOWLEDGMENTS

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