Taking anammox out of the box for mainstream water reuse

New pilot-study results enhance understanding of how the water industry can apply deammonification to develop sustainable, fit-for-purpose reuse portfolios. **Sandeep Sathyamoorthy** of Black & Veatch and **Hongkeun Park** of BKT United share findings and insights about the role of biofiltration in facilitating the use of anammox for mainstream as well as sidestream treatment.

In years to come, wastewater treatment plants across the globe will be transformed into Integrated Resource Recovery Facilities (IRRFs). These IRRFs will incorporate a suite of resource recovery solutions to transform incoming wastewater and non-wastewater-derived (e.g., from municipal organic waste) raw material resources into valuable products as part of an integrated circular economy. In arid regions of the United States and other water-scarce areas of the world, key resource transformations will undoubtedly include development of water portfolios that include wide-array water reuse.

Potable water reuse is a critical transformative approach to sustainably and effectively provide water for the world's growing population. Central to effective potable reuse is use of an advanced water treatment facility (AWTF) to prepare high quality supply water for potable reuse. Management of nitrogen is an integral part of providing high-quality supply water advanced water purification, and anammox processes are an attractive option for total nitrogen management.

Deammonification (partial nitritation with anaerobic ammonia oxidation) offers the possibility of replacing conventional nitrification and denitrification processes to remove ammonia nitrogen from wastewater. Deammonification eliminates the need for an external carbon source (such as methanol), reduces energy consumption, and lowers sludge production. In addition to lower operations and maintenance costs, the process yields high-quality supply water for agricultural reuse, urban agronomic use, and potable reuse. It is now well proven for treatment of reject water from anaerobic digestion after centrifugation (i.e., centrate). However, key questions remain regarding deammonification as a viable process for mainstream treatment primarily due to the lower wastewater temperatures, lower ammonia concentrations, and competition for nitrite from nitrite-oxidizing bacteria (NOB).

Fortunately, the results of a pilot study completed in December 2016 at the Los Angeles County Sanitation District's Joint Water Pollution Control Plant (JWPCP) in Carson, California, USA, offer promising proof-of-concept for mainstream deammonification. Operation of a pilot-scale upflow anammox biofiltration process at the JWPCP for more than 6 months shows that the mainstream anammox process can consistently and effectively produce a filtered effluent well suited to developing a broad water reuse portfolio including potable reuse.

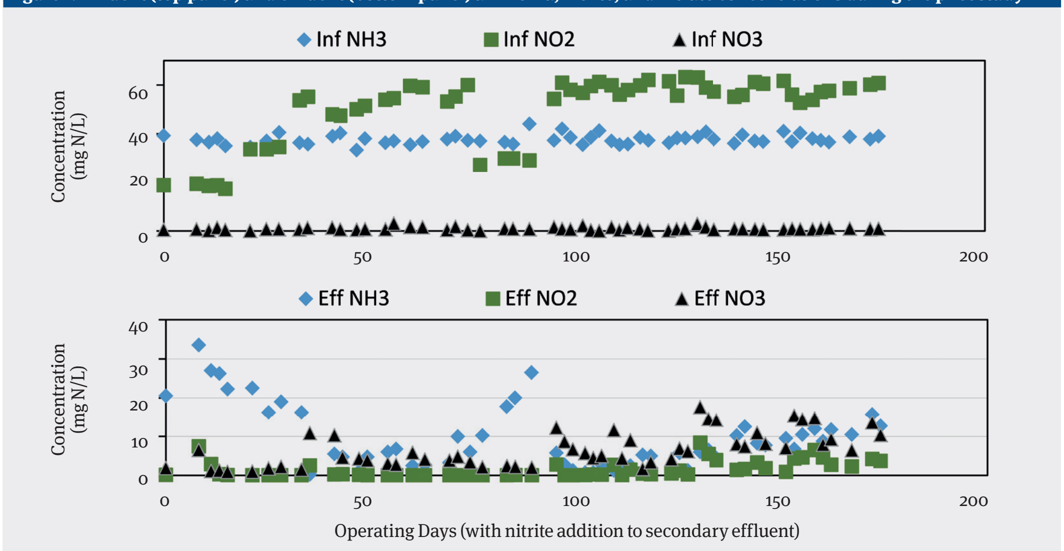
Behind the pilot

Over decades, anammox processes have been successfully implemented for nitrogen removal from centrate. Anammox processes typically require 60 percent less energy and no external carbon source compared with conventional treatment processes. The low specific growth rates and high susceptibility of anammox bacteria (AnAOB) to high dissolved-oxygen or nitrite concentrations are among the key challenges to mainstream applications.

Potential solutions to manage AnAOB in mainstream applications include decoupling the solid retention time (SRT) from the hydraulic retention time (HRT) of the AnAOB process using, for example, fixed-film media or anammox granules. Still, the low AnAOB growth rate in mainstream systems due to lower temperatures, limited substrate availability, and competition from other bacterial actors (e.g., heterotrophs and nitrite oxidizing bacteria) remains a challenge for mainstream applications. Researchers have previously reported success with mainstream anammox applications using fixed-film bioreactor and suspended growth systems. However, these systems require a large footprint due to downstream clarification prior to membrane filtration for direct/indirect potable reuse.

A pilot study was originally conducted by BKT in collaboration with the wastewater research group at JWPCP to assess BKT's BioFiltration (BBF), an upflow biological filtration process for nitrification-denitrification. The results from that study suggested a total inorganic nitrogen (TIN) reduction of approximately 25 percent across the nitrifying BBF. Additionally, red granules – the telltale sign of anammox bacteria – were discovered in the backwash waste holding tank. Although the nitrifying BBF was

Figure 1. Influent (top panel) and effluent (bottom panel) ammonia, nitrite, and nitrate concentrations during the pilot study



provided with sufficient oxygen to support nitrification, the research team hypothesized that deammonification may have been occurring within the BBF biofilm or granules within the biofilter due to substrate and oxygen diffusion limitations. The pilot was therefore extended to evaluate the feasibility of a mainstream deammonification for sustainable mainstream nitrogen management.

Testing the mainstream solution

Black & Veatch and BKT collaborated for the mainstream pilot study. The AMX BBF pilot unit constructed by BKT was an upflow biofilter consisting of expanded polystyrene media with an area of 0.2 square meters (m^2), or approximately 2 square feet (ft^2), and a media depth of 3 meters (m), or 10 feet (ft). Secondary effluent from the JWPCP was the influent to the AMX BBF. The JWPCP secondary effluent is of high quality with a relatively low chemical oxygen demand (COD) (Table 1). During the study, the secondary effluent had an average COD:NH_3-N ratio of 1:1.4. Initially, the two biofilters were operated in series, with the intention of promoting partial nitritation in the first, and deammonfication in the second. However, operation in this mode with direct application of secondary effluent (i.e., and influent with low biochemical oxygen demand [BOD] and high ammonia-N) showed poor and highly variable nitrogen removal. Furthermore, the effluent contained high nitrate-N and low nitrite-N concentrations, suggesting the presence of nitrite oxidizing bacteria (NOB) rather than the preferred anammox bacteria.

To test the concept of deammonification application for mainstream conditions, the research team added sodium nitrite to the secondary effluent to increase the nitrite concentration and achieve an ammonia-nitrogen to nitrite-nitrogen ratio favorable to promote anammox activity. Nitrite was only added to the secondary effluent to validate the proof of concept of mainstream anammox application. A full-scale solution would integrate a nitritation process upstream of an anammox biofilter.

Knowledge gained

The AMX BBF process was operated at a range of hydraulic loading rate (HLR) conditions during the pilot study ranging from ~0.5 gallons per minute per square foot (gpm/ft^2) to ~2.3 gpm/ft^2. This corresponded to TIN loading rates from ~1.7 kilograms Nitrogen per day per cubic meter (kg-N/m^3.d) to ~6.8 kg N/m^3.d. The lower end of the TIN loading rates have been previously tested in sidestream systems, but to the authors' knowledge, this is the first testing of TIN loadings at the higher end of this study. A low concentration of supplemental nitrite was initially added, resulting in a Nitrite-Nitrogen to Ammonia Nitrogen (i.e., NO_2-N/NH_3-N) influent ratio of approximately 0.5. The nitrite feed was increased in a step-wise fashion to ~1.45 over a 50-day period. Nitrogen removal performance improved significantly following initiation of the temporary, exogenous supplemental nitrite addition (Figure 1) with the pilot operated at a HLR of ~0.53 gpm/ft^2 and TIN.LR of ~1-2 kg N/m^3.d. Within approximately 50 days, the average effluent TIN concentration was less than 10 mg-N/L. Under these conditions, the AMX BBF process consistently achieved 90 percent nitrogen removal.

In subsequent phases, the process was tested at more challenging loading conditions by increasing the flowrate and, as a result, the TIN loading rate (Figure 2). Increasing the flow and loading rate initially resulted in poor performance largely due to NO_2-N/NH_3-N ratio not favorable for anammox bacteria. Alleviation of this pressure, however, soon resulted in excellent nitrogen removal efficiencies even at the high loading rates.

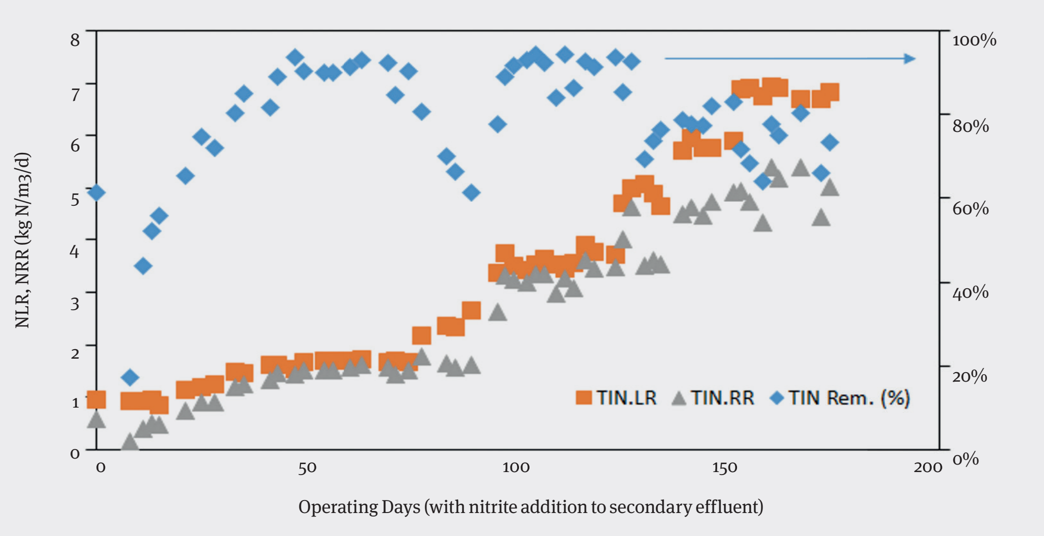
The finding that the nitrite-nitrogen fraction increased at higher TIN loading rates (Figure 3, page 33) requires consideration where chlorine disinfection is a possibility. Furthermore, the results suggest that the AMX BBF application would require additional nitrogen polishing for facilities that need to meet very stringent TIN limits (e.g., TIN < 5 mg-N/L with full nitrification). However, such low nitrogen levels are typically not required for wide-array water reuse applications.

Therefore, the AMX BBF process and other coupled anammox-filtration processes may hold significant value for utilities that seek to implement or expand water reuse opportunities.

Table 1. JWPCP secondary effluent quality during the pilot study

	N	Average	Std. Dev.
NH_3-N (mg-N/L)	57	37.83	2.02
NO_2-N (mg-N/L)	57	0.23	0.17
NO_3-N (mg-N/L)	57	0.83	0.61
TN (mg-N/L)	57	38.89	2.15
TCOD (mg/l)	15	51.10	8.04
SCOD (mg/l)	53	44.40	7.95
TCOD/NH_3-N (mg/mg-N)	15	1.39	0.24
SCOD/NH_3-N (mg/mg-N)	53	1.18	0.22
pH	50	7.14	0.07

Figure 2. TIN loading and removal rate and nitrogen removal performance during the deammonification pilot study



The future of anammox

The pilot-study results helped fill key knowledge gaps about the applicability of mainstream deammonification as part of a sustainable water reuse scheme. The results suggest that a mainstream anammox process can consistently and effectively achieve a TN of <10 mg N/L with no supplemental carbon addition when combined with an appropriate upstream nitrogen management strategy to support deammonification. The longer-term research objective of this research is to integrate a partial nitritation process upstream of the anammox biofilter.

As utilities expand their reuse portfolios to include agronomic reuse, industrial reuse, agricultural reuse, and potable reuse (indirect or direct), there is value in producing an array of fit-for-purpose effluents to meet each of these needs. Sustainable, low-cost, easy-to-manage solutions are critical for effective management of overall water and water-reuse portfolios. The anammox solution evaluated in this study provides an important tool to effectively achieve a high-quality effluent for various reuse applications. The relatively low nitrogen concentration, coupled with low TSS and turbidity, makes the filtered effluent highly suitable for multiple water reuse applications. Additional investigation is warranted to evaluate the performance of a downstream membrane-filtration process.

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Events 2017

September

24-28 Chicago, Illinois, USA
WEFTEC® 2017, Water Environment Federation's Annual Technical Exhibition & Conference. WEF Stormwater Congress will be held alongside WEFTEC.
www.weftec.org

29 Chicago, Illinois, USA
Microbiome Water Summit Organized by Microbe Detectives LLC
www.microbiomewatersummit.com

October

9-10 Bruges, Belgium
WRE's First Conference & Exhibition on Innovations in Water Reuse, organized by Water Reuse Europe
www.water-reuse.eu

26-27 Rome, Italy
Master Course on Best Practices for System Design and Development of Turnkey Desalination Projects. 2-day intensive course organized by European Desalination Society
eds@europeandesalination.org

October

30 – November 3 Toronto, Canada
Ontario Water Innovation Week Includes 3 events: 5th World Water-Tech North America Summit, Water Innovation in Action, and Ontario Municipal Water Association
www.rethinkevents.com

31 – November 3 Amsterdam, Netherlands
Aquatech Amsterdam, Co-located with Floodex Europe 2017 (Oct 31-Nov 1). Both will be held during Amsterdam International Water Week
Includes WEF International Pavilion
www.aquatechtrade.com/amsterdam

November

13-16 Buenos Aires, Argentina
IWA Water and Development Congress & Exhibition (WDCE), "Sustainable Solutions for Emerging Economies"
www.waterdevelopmentcongress.org

20-21 Eastern Province, Saudi Arabia
1st ISA Saudi Arabia Automation Conference & Exhibition Organized by International Society of Automation
www.isa-saudi-expo.org

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are well suited for tackling harsh industrial wastewaters. Currently, polymeric membranes are still widely used; however, ceramic membranes are gradually gaining popularity on account of favorable total expenditures (TOTEX). Though the capital costs of ceramic membranes are high, ceramic membranes have laudable credentials from a TOTEX perspective. Few ceramic membrane manufacturers predict that their capital cost is likely to reduce and follow a trend similar to that of polymeric membrane, which once was envisaging a higher cost. Besides being employed in municipal/industrial water and wastewater treatment, ceramic membranes are gaining prevalence in digestate treatment and landfill leachate in Europe.

Although membrane systems are gaining in usage in Europe, membrane companies face the challenge of inadequate operation and maintenance skills, which can result in end-user dissatisfaction. A key requirement for the membrane to perform efficiently is that the influent, or raw water, quality should remain constant, and the plant should be operating under a steady-state condition. Failure to monitor the raw water quality in addition to the lack of technical skills in plant operators often results in membrane degradation, fouling, frequent cleaning, and use of membrane cleaning chemicals, which leads to higher operational costs. Most industrial plants in Europe with membrane technology are automated, and highly skilled, well-trained, and experienced personnel are required to analyze and restore the operations within a short period of time following any breakdown. Most end users scout for membrane treatment options that require minimum operator attention and have a longer lifespan. Thus, companies that can address these prevailing challenges with ease are expected to create an edge among the competition.

Author's Note
Deepthi K. Sugumar is a research analyst at Frost & Sullivan, who is based in Chennai, India. She analyses water and wastewater treatment technology market mainly for Europe and is very interested in environmental sustainability.

Reference
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Authors' Note
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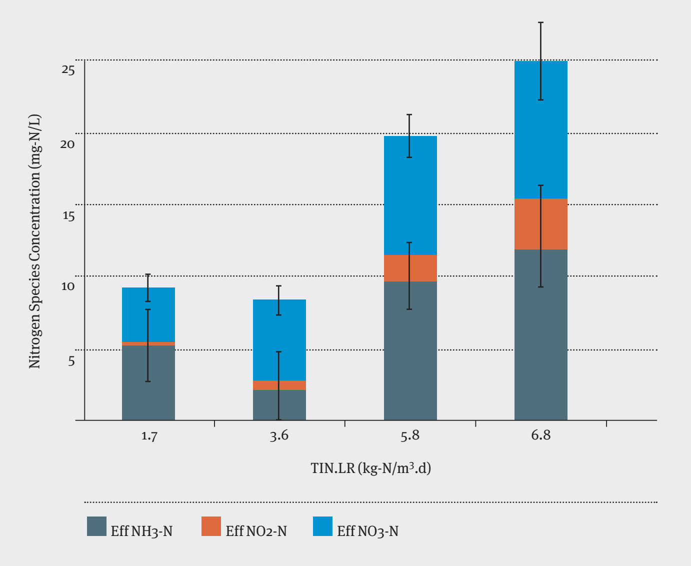
Additional Reading
Susanne Lackner, Eva M. Gilbert, Siegfried E. Vlaeminck, Adriano Joss, Harald Horn, Mark C.M. van Loosdrecht, Full-scale partial nitritation/anammox experiences – An application survey, *Water Research* 55(15) 292-303

T. Lotti, R. Kleerebezem, Z. Hu, B. Kartal, M.K. de Kreuk, C. van Erp Taalman Kip, J. Kruit, T.L.G. Hendrickx & M.C.M. van Loosdrecht (2015) Pilot-scale evaluation of anammox-based mainstream nitrogen removal from municipal wastewater, *Environmental Technology*, 36:9, 1167-1177

H. Park, D. Rhu, Mi-H. Kim and S. Sathyamoorthy (2017) The application of tertiary anammox biofilter for energy-efficient short-cut nitrogen removal, Nutrient Symposium 2017, Fort Lauderdale (FL)

Figure 3



Nitrogen fractions of the AMX BBF effluent in different phases of the pilot study