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Technical Memorandum

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Technical Memorandum No. 20

Subject: Side Stream Nitrogen Removal Alternatives Assessment

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Executive Summary

The City of Bellingham (City) is upgrading and expanding its biosolids processing systems, constructing new anaerobic digesters and associated dewatering facilities. The Washington Department of Ecology is concurrently developing a framework for nitrogen removal regulations for wastewater treatment facilities that discharge to Puget Sound. The dewatering recycle flow (centrate) has been identified as a key source of nitrogen loading to the secondary process.

This Technical Memorandum No. 20 evaluates alternative approaches for side stream nitrogen removal. The centrate generated in the dewatering process is projected to contribute up to 1,400 pounds per day of nitrogen to the secondary process. A large portion of this nitrogen can be removed by implementing a side stream treatment process. Side stream treatment processes include a variety of physical, chemical, and biological approaches. Several of these approaches, such as load pacing and bioaugmentation, are not applicable to Bellingham, which is not projected to have a nitrifying activated sludge system as its main stream process. The most applicable approaches would be those providing for stand-alone nitrogen removal. These approaches include biological short-cut nitrogen removal systems (such as deammonification [anammox]) and physical/chemical ammonia recovery systems. Ammonia recovery systems have proven to be at least as expensive as anammox-based treatment systems, with up to ten times the annual operating cost for a system of this size.

Alternatives screening determined that an anammox-based treatment system would provide the most cost-effective benefits to the City. An anammox system would be expected to remove up to 85 percent of the ammonia, and 80 percent of the total inorganic nitrogen in the centrate. This translates to an annual removal of close to 300,000 pounds of nitrogen from the plant’s discharge.

Three commercial anammox systems were compared. Each of these systems is well-established, with dozens of installations worldwide. Each vendor provided a detailed proposal, which was used to compare design assumptions, develop a conceptual layout, and estimate costs. While all three vendors are expected to deliver similar performance at similar annual operating costs, the initial capital outlay for the Veolia ANITA™ Mox system is projected to be approximately $3M less than the other systems. This difference is related primarily to a much lower vendor package cost for the Veolia system. It is recommended that the Veolia system be used as the basis of conceptual design, and that a formal preselection take place prior to the start of detailed design.

Section 1: Introduction

The City of Bellingham (City) is in the planning process to evaluate options for long-term biosolids management and beneficial reuse opportunities for the wastewater residual solids and energy recovered from the Post Point Resource Recovery Plant (Post Point). The Post Point Biosolids Project (Project) is being conducted in phases from alternative screening and evaluation through design and construction.

In Phase 1 and 2 of the Project, alternatives were evaluated and the final biosolids treatment and energy use processes were selected. The Project is currently in Phase 3, which further defines the selected alternative technical requirements and documents the planning effort within the Biosolids Facility Planning Report (Biosolids Facility Plan), an update to the City's existing, comprehensive 2011 Wastewater Facility Planning Report (Carollo, 2011).

This Technical Memorandum (TM) No. 20 – Side Stream Nitrogen Removal Alternatives Assessment (TM 20) was prepared as part of Project planning Phase 3 and documents the side stream treatment alternatives for the Project.

In addition to the City's biosolids improvements planning, the Washington Department of Ecology (Ecology) is concurrently developing a framework for nitrogen removal regulations for wastewater treatment facilities that discharge to Puget Sound. The dewatering recycle flow (centrate) has been identified as a key source of nitrogen loading to the secondary process.

In response to Ecology's nitrogen removal program, the City commissioned an evaluation of nutrient impacts that evaluated alternatives for providing nitrogen removal (TM No. 9 - Nutrient Impacts [BC/Carollo, March 2021]). The alternatives were grouped into two categories—one aimed at a moderate seasonal Total Inorganic Nitrogen (TIN) limit of 8 milligrams per Liter (mg/L), and the other targeting a more aggressive year-round TIN limit of 3 mg/L.

TM-9 recommended that tertiary nitrification and denitrification processes be added to the existing secondary process, along with side stream treatment of the dewatering recycle. The side stream process was assumed to be an anammox-based treatment process. The implementation plan envisions that the side stream treatment process will be constructed first to satisfy the anticipated requirements of Ecology's Nutrient General Permit. The proposed tertiary treatment facility would be constructed only if future regulations require additional removal.

The purpose of this TM is to evaluate side stream treatment process alternatives, and recommend the most suitable technology for this application. Design criteria, sizing, conceptual layouts, and costs for the recommended alternative are also discussed.

Section 2: Background and Basis of Comparison

This side stream treatment alternatives assessment and conceptual design depends on information developed in the Nitrogen Removal Process Optimization Review task. This information mainly relates to the quantity and characteristics of the dewatering recycle flow. Table 1 summarizes the background information upon which this assessment has been constructed. The design scenario envisions a side stream treatment facility operating in concert with the existing, non-nitrifying main stream system. A less likely scenario projects a condition with a tertiary Biological Nutrient Removal (BNR) facility in place, meeting a year-round TIN limit of 3 mg/L.

Table 1. Projected Centrate Characteristics					
Parameter	Design Scenario			With Tertiary BNR	Hydraulic Capacity
	Startup	Average	Max 2-week	Max 2-week	Peak flow
Flow, million gallons per day (mgd)	0.052	0.0635	0.077	0.106	0.119
Total suspended solids, mg/L	500	500	500	–	–
Soluble chemical oxygen demand (sCOD), mg/L	150	150	150	–	–
Ammonia nitrogen (NH_3N), mg/L	1,864	1,924	2,180	2,182	–
Phosphate (PO_4P), mg/L	400	400	400	–	–
Alkalinity, mg/L calcium carbonate ($CaCO_3$)	5,000	5,000	5,000	–	–
Temperature, degrees Celsius (°C)	28	28	28	–	–
NH_3N, pounds per day (lb/d)	809	1,020	1,401	1,930	–

For alternatives development, the basis of design is the maximum 2-week scenario, with an ammonia loading of 1,401 lb/d. Modifications required to meet the tertiary BNR scenario (with an ammonia loading of 1,930 lb/d) are also addressed.

Section 3: Side Stream Nitrogen Treatment

Side stream treatment is a relatively new approach to wastewater treatment–focusing on the dewatering recycle flow instead of the full influent liquid stream. As nutrient regulations have been implemented around the world, efforts have been made to reduce capital and operating costs, and improve the reliability of BNR processes. The dewatering recycle flow was identified as an area with potential for low cost and high reward investment.

3.1 Characteristics of the Side Stream

The dewatering recycle flow typically contains between 15 to 30 percent of the total nitrogen load to the secondary process, as shown schematically on Figure 1.

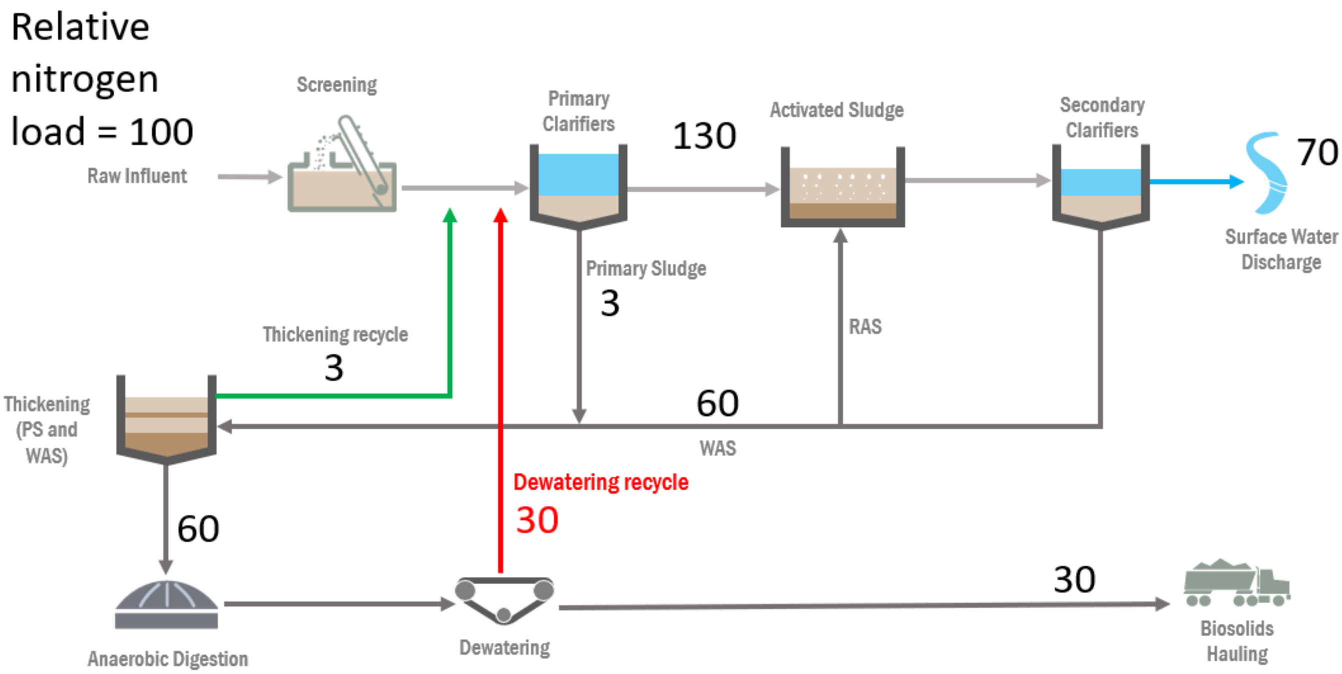

Figure 1. Relative nitrogen flux across a typical tertiary nitrogen removal plant

Nitrogen in the dewatering recycle flow is derived from the anaerobic hydrolysis of cells and other organic molecules within the digester. Hydrolysis releases soluble ammonia, orthophosphate, alkalinity, and a variety of other soluble products. The dewatering process removes solids (cell debris and inorganics), leaving behind a highly concentrated liquid recycle stream, loaded with these products. The dewatering recycle stream is a low flow/high concentration waste stream, which is highly amenable to focused treatment. In short, it is far less costly to remove highly concentrated pollutants from a small volume of water than to remove dilute pollutants from a large volume of water.

The dewatering recycle flow has several other features which make it an attractive target for focused treatment. These include high temperature, high alkalinity, and a steady and predictable flow regime.

3.2 Side Stream Treatment Approaches

There are three approaches to side stream nitrogen removal: temporal, physical/chemical, and biological.

- **Temporal** approaches are focused on optimizing the timing of feeding the dewatering recycle flow to the main biological process. Such approaches include flow equalization and load pacing. At facilities which dewater intermittently (shift operation, weekday/weekend, as needed dewatering), the dewatering recycle stream may impose a feast-or-famine condition on the biology. This can be mitigated by holding the recycle flow in an equalization basin, and feeding it at a constant, continuous flow. A more sophisticated approach would be to hold the recycle flow in an equalization basin, and feed it to the process during periods when the carbon-to-nitrogen ratio in the influent is high.
- **Physical/chemical** approaches involve stripping ammonia from the recycle stream as a gas, and then scrubbing that gas to generate an ammonium sulfide product. This approach typically involves a pair of packed towers (Figure 2) and are mainly used in industrial applications. The high operating cost of these systems has limited their use in municipal applications. Extrapolating from recent proposals in Utah and California, the average annual cost in caustic and sulfuric acid would be $510,000. Factoring in heating

and labor, the annual operating cost is likely to be over $600,000. The potential value of the ammonium sulfide product would be $100,000.

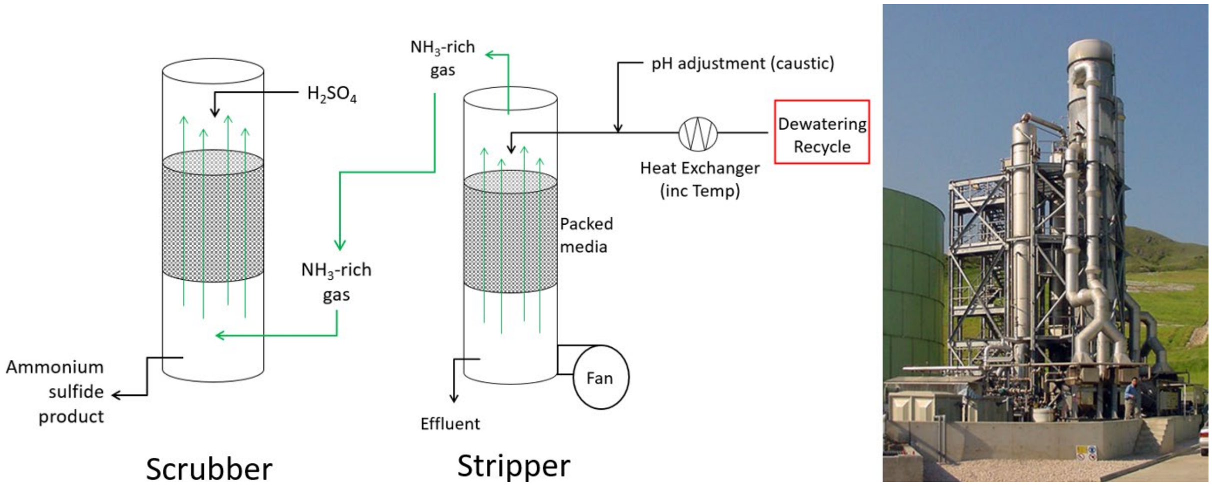

Figure 2. Ammonia stripping and scrubbing

- **Biological** approaches to side stream nitrogen removal fall into two general categories—bioaugmentation and shortcut nitrogen removal. Bioaugmentation involves growing a large and highly specialized community of nitrifying bacteria to treat the dewatering recycle flow, and then allowing those bacteria to seed the main biological process, enhancing the nitrification capacity of the overall system. The main benefit of bioaugmentation processes is capacity. A typical bioaugmentation system may decrease the treatment capacity of the plant by 20 percent. This translates into capital savings on the size of aeration basins, and may allow space-limited plants to treat additional flow without expansion. This benefit is only applicable to systems which have a nitrifying activated sludge community to augment, and would not be compatible with either the existing non-nitrifying activated sludge system, or the proposed system with tertiary nitrogen removal.

  Shortcut nitrogen removal approaches seek to bypass the traditional four-step nitrification and denitrification process, creating more efficient pathways which reduce operating costs. These approaches include simultaneous nitrification-denitrification (SND), nitritation, and denitritation, and anammox. The anammox process, first implemented about 20 years ago, has made most of the other shortcut approaches obsolete for side stream treatment, due to its efficient biological pathway, and its demonstrated record of performance at municipal facilities. There are now approximately 200 installations of anammox-based side stream treatment worldwide.

  Anammox bacteria are a specialized group of bacteria which have the ability to convert ammonia directly to nitrogen gas. This reaction requires no external carbon, and a fraction of the oxygen and alkalinity required by conventional nitrification. While anammox bacteria are ubiquitous in nature, they are very slow growing, and exist in such small quantities as to be insignificant in standard activated sludge systems. Anammox-based side stream treatment involves incubating anammox bacteria under controlled conditions (warm temperature, neutral pH, high ammonia concentration), and expanding the population using physical enrichment approaches. An anammox treatment system would be expected to remove an average of 85 percent of centrate ammonia and 80 percent of centrate inorganic nitrogen.

  Operating costs for anammox systems tend to be low. The system requires a small amount of aeration (less than 1,000 scfm), mechanical equipment is limited to mixers and pumps, and no chemical additional is typically required. The power cost should average less than $50,000 per year, with O&M

labor requirements of 1 FTE or less. The system would provide large annual cost savings for potential tertiary nitrogen removal systems, including reductions in aeration, carbon (methanol), and biosolids handling.

The assessment performed for TM-9 assumed an anammox system was in place-without one, methanol demands at the plant were projected to increase by 20 to 30 percent. Even with that system, methanol demands for the tertiary system were high, averaging 3,300 gallons per day (gpd) to meet an effluent TIN limit of 8 mg/L, and 3,800 gpd to meet an effluent TIN limit of 3 mg/L.

These methanol demands translate into annual costs from $1 to 3M (assuming a range of methanol costs from $1.00 to $2.50 per gallon, and application for 6 to 12 months per year).

Extrapolating from those numbers, an anammox system could save between $160,000 to $680,000 per year in annual methanol costs alone.

3.3 Alternatives Screening

Table 2 summarizes the three approaches described in Section 3.2 for their ability to support this application.

Table 2. Alternatives Screening Summary

Approach Type	Alternatives Analysis

Temporal Systems	• Equalization and Load Pacing
	  • Use is generally associated with nitrifying activated sludge systems.
	  • Feast-or-famine loading patterns need a larger bacterial population than would otherwise be required.
	  • Facilities already practicing 24-7 dewatering (as planned for the City) would not benefit.
	• For tertiary fixed-film systems:
	  • Any benefits of would be much smaller and unlikely to produce much operational cost saving.

Physical/ Chemical Systems	• Ammonia stripping and scrubbing
	  • Systems are expensive to install.
	  • Expected power and chemical costs of up to $500,000 per year (compared to $50K/year for anammox).
	  • Has higher operations and maintenance labor costs than anammox.
	  • Would generate ammonium sulfide which the utility would be responsible for marketing and selling.
	  • Not expected to be competitive with an anammox system in this application.

Biological Systems	• Bioaugmentation
	  • Not applicable for non-nitrifying systems or systems practicing tertiary nitrogen removal.
	• Anammox System
	  • Has a demonstrated record of performance at over 200 installations worldwide.
	  • The best-suited approach for this application due to carbon (methanol) savings. Based solely on methanol demand, the savings could be between $160,000 and $680,000/year.
	  • Additional savings would come from reducing the size and scope of tertiary facilities, aeration, and solids processing demands.
	  • Without an anammox system, methanol demands would increase by 20 to 30%.
	  • Plants with high methanol demands are likely to benefit the most from anammox-based side stream treatment.

Given the existing main stream treatment process, the proposed tertiary nitrogen removal system, and the 24-7 operation of the dewatering process, most of the more common side stream treatment processes are not applicable. The evaluation comes down to a comparison between biological, anammox-based treatment processes and the physical/chemical ammonia recovery system. With capital costs expected to be similar, the physical/chemical process is projected to have up to 10X higher annual operating cost, mainly due to the cost of the stripping and scrubbing chemicals. The physical/chemical process would be a much more complex mechanical system, with higher annual operating and maintenance costs, and would produce an end-product which would require marketing and sales. On balance, the physical/chemical process is not expected to be competitive with an anammox-based biological process in a life cycle cost analysis.

Based on the above, the alternatives assessment will be limited to the various anammox-based technologies which currently exist in the market.

Section 4: Anammox System Alternatives

There are currently three major vendors in the North American market with anammox-based side stream treatment processes. Each vendor takes a slightly different approach to the process.

4.1 DEMON® (World Water Works, Inc.)

The DEMON system is the oldest and most widespread anammox technology, with over 60 operational facilities, mostly in Europe, and four in the United States. The DEMON system is a sequencing batch reactor (SBR), which is gradually filled with dewatering recycle. The reactor cycles through periods of filling, aeration, and anaerobic mixing. The anammox bacteria form large, heavy granules. When the reactor is full, it enters into a quiescent sedimentation phase, where the granules settle to the bottom of the reactor, and the supernatant is decanted off as effluent. The system uses hydrocyclones to enrich the anammox granules within the reactor, and to waste non-specific bacteria. Figure 3 shows the anammox treatment system at the Chambers Creek Regional Wastewater Treatment Plant (CCRWWTP) in University Place, Wash. This system was installed in a retrofitted 925,000 gallon aeration basin.

More recent innovations include an effluent weir system, which selectively retains the heavy anammox-rich granules; and a shift from hydrocyclone-based enrichment to a microscreen. The purpose of these innovations is to create a continuous-flow system (as opposed to sequencing batch reactors), which does not require a large influent flow equalization basin.

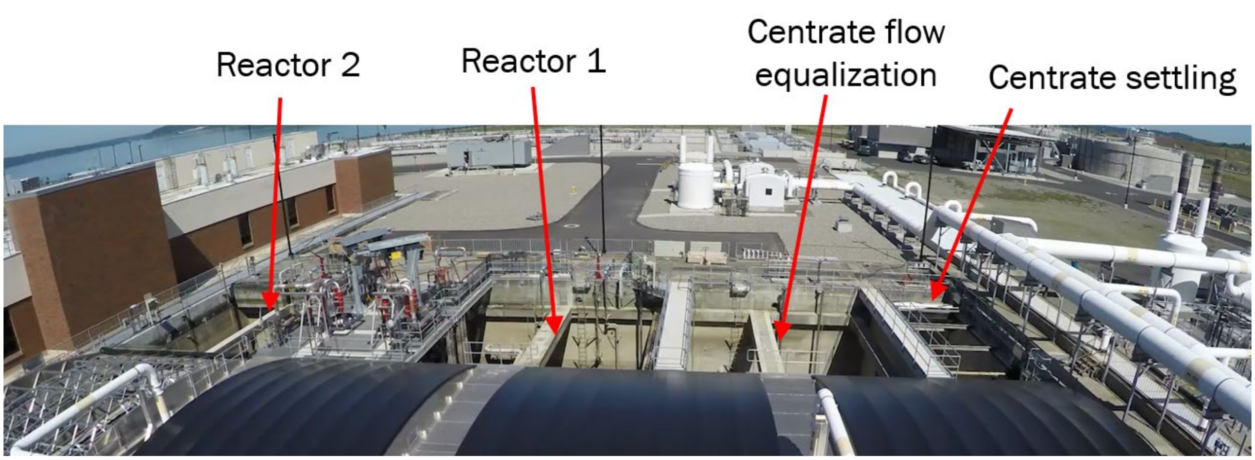

Figure 3. DEMON system at Chambers Creek RWWTP

4.2 ANITA™ Mox (Veolia)

With seven active installations in the United States, this system has the largest market share in North America. This is a continuous flow process, which houses the anammox bacteria on plastic chip media (Figure 4). Large bore sieves keep the plastic media in the reactor. Bacterial growth on the plastic media allows for aerobic conditions near the surface and anaerobic conditions deep in the biofilm. This enables the process to act continuously, without the cycling aeration used in the DEMON process.

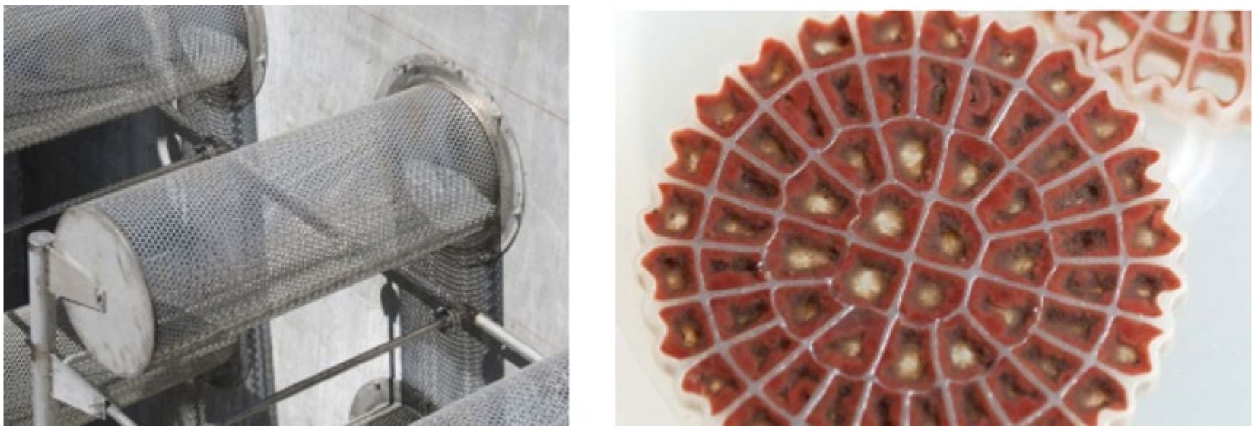

Figure 4. ANITA™ Mox effluent sieve and colonized plastic media

Source: Veolia

4.3 AnammoPAQ® (Ovivo)

The Ovivo system has a large industrial user base, with over 30 active facilities in China, but only one installation in the United States at this time. The AnammoPAQ process is similar to ANITA™ Mox, in that it offers a continuous flow process; it is similar to DEMON in that it fosters the growth of biological granules to house the anammox bacteria. The AnammoPAQ system relies upon a patented clarifier mechanism to keep the granules in the reactor, while allowing continuous effluent discharge. Figure 5 shows the clarifier being installed within a circular reactor.

Figure 5. AnammoPAQ clarifier mechanism being installed

Source: Ovivo

Table 3 compares the three commercial anammox products.

Table 3. Comparison of Commercial Anammox Systems

Parameter	DEMON	ANITA™ Mox	AnammoPAQ
Flow	Most facilities use SBR technology, but new facilities are continuous flow	Continuous	Continuous
Method of retaining anammox bacteria	System of effluent weirs which retain granules	Coarse screens to retain chip-based media	Lamella clarifier inside reactor
Enrichment or wasting equipment	Hydrocyclones, microscreens	None	None
"Moving parts"	Some	Few	Fewest
Performance	Similar ammonia and N removal rates		
Worldwide installations (Oct. 2020)	65 (mostly municipal)	27	63 (mostly industrial)

Notably, the performance of the three systems is comparable, as are the operating costs. The systems are intended to remove 85 percent of the centrate ammonia, and 80 percent of the centrate total inorganic nitrogen. Operating costs, mostly related to power, should average approximately $50,000 per year.

Section 5: Design Criteria

This discussion summarizes key design criteria associated with an anammox-based side stream treatment processes. Most of these design criteria are common to all three of the vendor-provided systems introduced in the previous section.

5.1 Pretreatment

Dewatering recycle often has high solids content, consisting of cellular debris and inert material. The recycle flow also typically carries excess polymer from the dewatering system, which can create floatable solids within any side stream treatment process. Dewatering recycle has been observed to cause rapid fouling of aeration diffusers and instrumentation, and excess polymer makes the liquid prone to foaming.

A pretreatment system, focused on settled and floating solids removal, is recommended for any type of side stream treatment. The simplest application would be a gravity settling tank with a scum removal system. A typical design criteria for gravity settling is a surface overflow rate of 500 gpd/ft^2. That equates to a tank surface area of 154 ft^2 at the maximum two-week flow. If there is concern over the potential for struvite accumulation, the pretreatment step may include ferric chloride addition and chemical precipitation.

5.2 Flow Equalization

The dewatering process is being designed to operate continuously, 24 hours/day, 7 days/week. However, it is typical to expect variation in centrate flow rates. The three anammox vendors have different approaches to equalization. Both WWWI (DEMON) and Ovivo (AnammoPAQ) recommend equalization, with WWWI recommending a 2-hour detention time. Veolia (ANITA™ Mox) does not specifically recommend equalization.

Regardless of the selected vendor, centrate flow equalization offers several advantages, and should be a part of this design. Assuming that the dewatering recycle flows by gravity to the side stream treatment process, it is likely that the flow will need to be pumped at some point in the process—either at the reactor feed, or at the effluent discharge. In either case, a wet well would be required to accommodate pumping. A flow equalization basin, located downstream of pretreatment, could serve a dual purpose of equalizing the flow and acting as a wet well for reactor feed pumps.

While a typical wet well may be quite small, a large equalization basin offers additional benefits. Any anammox-based treatment system is likely to perform more reliably given a steady and stable feed. An equalization basin would also offer protection against unforeseen issues which can impact the quality of the recycle flow, and could provide some flexibility towards operating the side stream treatment system.

For planning purposes, a flow equalization basin has been included in this TM. This basin has been sized to hold 4-hours worth of dewatering recycle at the maximum month flow rate.

5.3 Anammox Reactors

To allow for regular and unexpected maintenance, the system should have at least two equally-sized anammox reactors. Additional reactors are not recommended, given the projected loadings of this system, as this would increase both the cost and complexity of the system. The system should have full redundancy, and the two reactors should be sized such that either reactor could treat the design load at the maximum acceptable loading rate.

Anammox reactors are typically sized on the basis of ammonia loading. The three vendors have different benchmarks for loading. WWWI uses a maximum specific loading rate of 1.0 kilograms N/cubic meter/day (kgN/m^3/d). Ovivo targets double that loading rate, 2.0 kgN/m^3/d. Veolia factors in the media fill percentage, typically targeting a fill rate of 30 percent at design, and a corresponding specific loading rate of 1.2 kgN/m^3/d. As a result of the different benchmarks, the reactor volume ratio for the three vendors would scale from Ovivo (smallest) to WWWI (largest).

Vendor proposals will typically vary from these benchmarks to accommodate specific reliability concerns or to emphasize performance under average conditions. As part of this analysis, the vendors were asked to submit proposals based on the maximum 2-week loading of 1,401 lb/d, but also provide a plan to accommodate the tertiary N removal scenario with a loading rate of 1,930 lb/d.

Table 4 summarizes the vendor proposals comparing the loading rates to those typically associated with each system.

Table 4. Vendor Proposals and Loading Rates

Parameter		WWWI	Veolia	Ovivo
Proposed reactor volume, gallons		188,509	148,114	68,000
Typical maximum loading rate, kgN/m^3/d		1.0	1.2	2.0
Condition	Ammonia load, lb N/d	Specific loading rate, kgN/m^3/d[a]		
Startup	809	0.51	0.65	1.43
Average	1,020	0.65	0.83	1.80
Design (Maximum 2-week)	1,401	0.89	1.13	2.47
Tertiary N removal	1,930	1.23	1.56	3.40

a. With one reactor in service.

Of the three potential vendors, Ovivo has the most aggressive proposal, discounting the redundancy requirement and assuming that the process could absorb short-term surges in loading associated with a reactor being out of service. The other two vendors were much more conservative, taking the redundancy requirement at face value, and designing around that condition. Of the three, WWWI provided the most conservative design, while the Veolia design is very close to the expected target.

None of the vendors provided a system capable of treating the tertiary N removal scenario without some reduction in performance, or a loss of redundancy. WWWI offers a reactor expansion to accommodate that scenario, while Veolia can mitigate the loading with increased media fill (to a point).

5.4 Equipment

The anammox system includes the following major equipment, which may be housed in a separate building or gallery. A representative process flow diagram has been included in Attachment A.

- **Pretreatment equipment.** The pretreatment system must remove both settled and floating solids. This may be accomplished in a gravity settling tank equipped with chain and flight mechanisms. At the surface, a helical scum skimmer may be used to move floating solids into a discharge standpipe. At the bottom, a settled solids trough and sump may be used to pump solids.
- **Influent and/or effluent pumps.** At least one set of pumps will be required to provide the necessary head to move flow across the side stream treatment process and send effluent back to the main stream biological process. The most reasonable location for these pumps would be downstream of pretreatment and flow equalization, where the pumps may serve as reactor feed pumps.
- **Aeration blowers.** Aeration blowers are required, with an anticipated capacity of less than 1,000 standard cubic feet per minute (scfm). The vendors have proposed between two (Ovivo) to six (WWWI) blowers, reflecting different approaches to turndown and reliability. Typically, a system of this size should include a minimum of three blowers—one for each reactor, and one standby unit.
- **Solids pumps.** The pretreatment system would be designed to remove both settled and floating solids, with positive displacement pumps to move these solids to the solids thickening process.
- **Heat exchanger.** The anammox bacteria function best at a temperature near 30°C. While digested solids are typically heated near this temperature, there is expected to be some heat loss across dewatering, and within the pretreatment basins. If the system is shut down for any period of time, temperatures in the reactors may decrease to ambient levels. Temperature control may be provided either by covering the side stream treatment system, or by providing a heat exchanger. A cover would provide for odor containment and control, and would be consistent with the way the rest of the plant's liquid stream processes are designed. A heat exchanger offers better control, and wouldn't restrict access to the system the way a cover would. At the projected centrate flow rate, it would require up to 0.6 MMBTU per hour to heat the system. Heating would likely be required 4 to 6 months per year. The cost of such heating would depend upon the capacity of the plant's overall heating hot water system, and has not been factored into estimates of the annual operating cost for this facility. A heat exchanger will be shown in conceptual layouts and diagrams, but a decision on covers versus heat exchanger will be deferred to preliminary design.
- **Mixers.** The DEMON and ANITA™ Mox systems both require mechanical mixing, with an anticipated two to four mixers per reactor. Additional mixers would be required in the flow equalization basin.
- **Diffusers.** All three vendor systems require aeration diffusers. The ANITA™ Mox system employs medium bubble diffusers, while the other vendors use fine bubble diffusers.
- **Biomass retention and enrichment.** The DEMON system would include a set of submersible pumps feeding a microscreen. Effluent discharge would take place across a set of fixed weirs. The ANITA™ Mox system would employ large pore sieves at the effluent discharge. The AnammoPAQ system would have a clarifier mechanism with no moving parts installed within the reactor.
- **Foam suppression.** Foam is common problem, given the high polymer content of dewatering centrate. The DEMON and ANITA™ Mox systems both offer spray systems using submersible pumps. The AnammoPAQ system does not include this in their scope of supply.
- **Instruments.** Each reactor would be equipped with pH, DO, and level sensors. An ammonia/nitrate probe would also be recommended. Control is achieved mainly through the pH and DO sensors. The ammonia/nitrate probe is present for operational guidance. WWWI would include a conductivity probe, Ovivo would include specific nitrate and nitrite probes, instead of the more general nitrate probe.

Section 6: Layout and Sizing

The facility layout includes the following elements:

- Centrate settling tank
- Centrate flow equalization basin
- Two anammox reactors
- Equipment gallery
- Electrical room

The vendor proposals, included in Attachment C to this TM, differ mainly in the size of the anammox reactors. Figure 6 shows the relative arrangement of the three facilities.

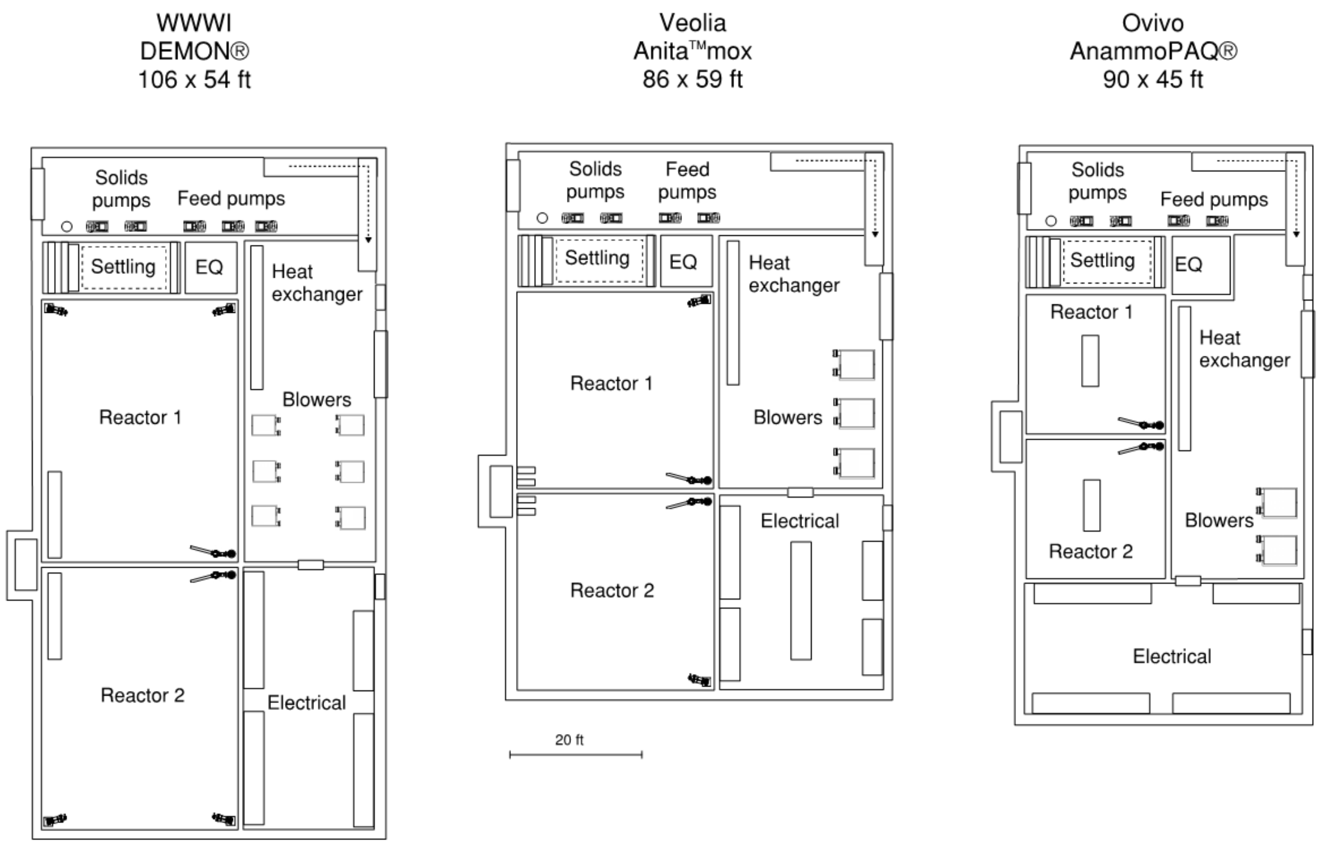

Figure 6. Plan view comparison of three vendor layouts

While the Ovivo facility offers a smaller footprint, all three facilities would fit into the proposed site. Figure 7 shows the three facilities superimposed on the site's aerial photo.

Figure 7. Side stream treatment facility footprints superimposed on site map

Section 7: Cost Comparison

Table 5 summarizes the scope of supply for each vendor system, along with the quote.

Table 5. Scope and Cost Comparison of Vendors

Component	WWWI	Veolia	Ovivo
Reactors	2	2	2
Reactor size, gallons	188,500	148,100	68,000
Site footprint per Figure 6, ft^2	5,724	5,074	4,050
SLR at design, $kg/m^3/d$	0.89	1.13	2.47
Design SLR as % of typical maximum	89%	97%	123%
Enrichment equipment	2 settlers and microscreen	4 screens	2 settlers
Diffusers	46 panels	8 medium bubble grids	2 fine bubble aeration grids
Feed pumps	3 x 110 gallons per minute (gpm) with variable frequency drive (VFD)	Not included	Not included
Blowers	6 x 325 scfm with VFD	Not included	2 x 750 scfm
Mixers	4 with VFD	2 with VFD	N/A
Other equipment	3 submersible pumps with VFD	2 airlift pumps 2 air control valves 2 influent control valves 12,005 ft^3 of media	
Instruments	pH, DO, conductivity, level	pH, DO, level	pH, DO, NO_3, NH_4
Air flow meters	2	2	Not included
Water flow meters	6	2	Not included
Inspection, startup, training	5 trips/20 days	Not specified	20 days
Remote monitoring	3-4 months	Through startup and performance testing	1 year
Vendor quote	$2,150,000	$1,296,000	$2,600,000

Operational costs for the three systems are expected to be similar, as is performance. The Ovivo system has the highest quoted cost, at $2.6M, and has a relatively sparse list of included equipment. Additional costs for this system would include feed pumps, foam suppression, and air and water flow meters. While the relatively small reactor size and site footprint would be expected to reduce overall capital costs, the Ovivo proposal is by far the most aggressive in terms of loading rate and redundancy, which increases operating risk.

The Veolia system, quoted at $1.3M, is by far the lowest price of the three systems. The Veolia scope of supply excludes both feed pumps and aeration blowers, which accounts for some of that difference. A package of three, 700-scfm blowers and two, 110-gpm feed pumps, with associated VFDs, could add another $500,000 in equipment costs.

The WWWI system is the most conservatively-designed of the three systems, with a projected loading rate at only 89 percent of a typical target. The WWWI scope of supply is more complete than either of its competitors, including feed pumps, blowers, foam suppression, and extensive instrumentation.

Conceptual cost estimates were developed for each system, using the layouts presented on Figure 6. The estimates consider costs associated with concrete tankage, excavation and hauling, and major equipment. Standard multipliers are used to estimate costs for yard piping, HVAC, electrical, and instrumentation and control. These costs are summarized in Table 6. Details are provided in Attachment B.

Table 6. Conceptual Cost Comparison Between Vendors

	WWWI	Veolia	Ovivo
Concrete	$852,000	$800,000	$664,000
Excavation and hauling	$1,381,000	$1,198,000	$853,000
Vendor package	$2,150,000	$1,296,000	$2,600,000
Package installation	$645,000	$389,000	$780,000
Equipment outside of package	$815,000	$1,300,000	$975,000
Yard piping[a]	$584,000	$498,000	$587,000
HVAC2[b]	$292,000	$249,000	$294,000
Electrical, instrumentation, and control[c]	$2,045,000	$1,744,000	$2,055,000
Subtotal	$8,764,000	$7,475,000	$8,808,000
Undesigned contingency[d]	$2,629,000	$2,242,000	$2,642,000
Base cost	$11,393,000	$9,717,000	$11,451,000
Bid cost[e]	$16,524,000	$14,093,000	$16,608,000
Total project cost[f]	$21,068,000	$17,969,000	$21,175,000

a. Yard piping at 10%.

b. HVAC at 5%.

c. Electrical, instrumentation, and control at 35%.

d. Undesigned contingency at 30% of subtotal.

e. Bid cost includes contractor overhead and profit (15%), general conditions (12%), bonds and insurance (3.5%) and sales tax (8.8%).

f. Total project cost includes final engineering (15%), construction engineering (7.5%), and legal/administrative/permitting costs (5%).

The Veolia ANITA™ Mox system is projected to have the lowest cost, with the other two systems both projected to cost $3M more (an 18-19 percent difference). The difference is related primarily to the vendor quote, with the Veolia system quoted at 60 percent of the WWWI system, and half the price of the Ovivo system.

While the Ovivo system is smaller, with lower concrete and excavation costs, these savings do not offset a much higher quote for vendor equipment. The WWWI system is the largest, but it also has the most complete scope of supply, so the total projected cost ends up being similar to that of the Ovivo system.

Section 8: Recommendation

An anammox-based centrate treatment system is expected to remove 80 percent of the inorganic nitrogen content of the centrate. As a stand-alone process, this translates into a reduction of approximately 800 lb/d, or 150 tons/year, from the plant's total nitrogen discharge. The effluent discharge from these systems should have minimal impact on the performance of the non-nitrifying main stream treatment process or any of the biosolids processing systems.

Three vendors are currently marketing anammox-based side stream treatment processes, each of which is expected to deliver similar performance and operating cost. Given the differences between systems in terms of reactor size and equipment, we recommend that one vendor be selected prior to beginning the detailed design.

Based on the proposals received as part of this evaluation, Veolia's ANITA™ Mox system appears to offer some cost savings when compared to its competitors. It is recommended that the Veolia system be used as the basis of the conceptual design, and that a formal preselection in the form of an evaluated bid take place before beginning detailed design.

Attachment A: Process Flow Diagram

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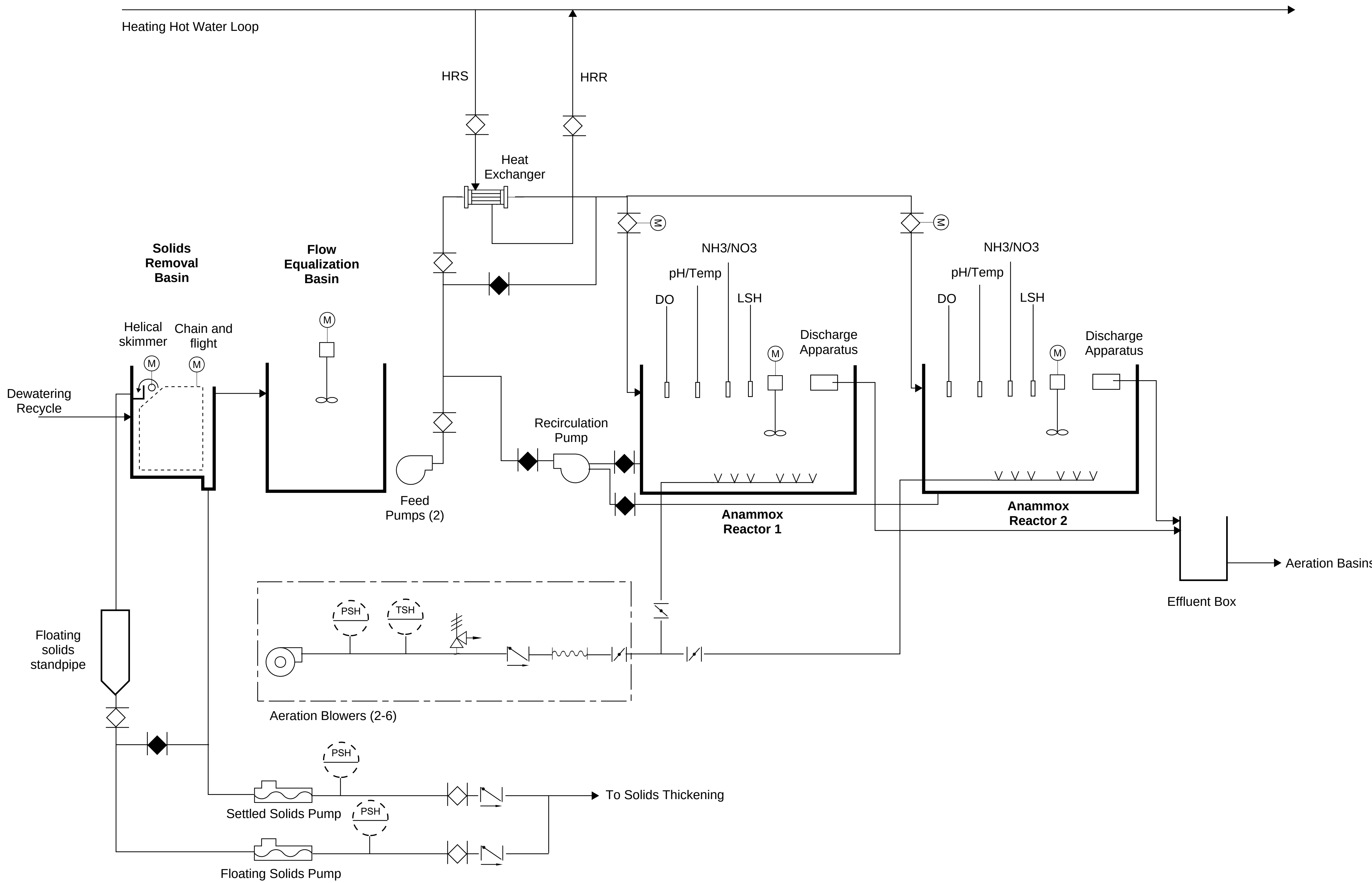

Side Stream Nitrogen Removal Alternatives Assessment and Conceptual Design
Appendix A

Attachment B: Conceptual Cost Estimate Detail

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Appendix B. Conceptual Cost Estimate Detail									
August 26, 2021									
			Amount				Cost		
	Unit Cost	Unit	WWWI	Veolia	Ovivo		WWWI	Veolia	Ovivo
Walls	1,150	CY	511	485	423		$588,012	$557,803	$486,833
Slabs	600	CY	320	284	174		$191,700	$170,117	$104,400
Elevated slabs	700	CY	103	103	104		$72,003	$72,068	$72,593
Dewatering	50	CY	12,696	11,018	7,846		$634,813	$550,924	$392,290
Excavation and backfill	40	CY	12,696	11,018	7,846		$507,850	$440,739	$313,832
Regular haul and disposal	15	CY	15,870	13,773	9,807		$238,055	$206,596	$147,109
Package	1	LS	2,150,000	1,296,000	2,600,000		$2,150,000	$1,296,000	$2,600,000
Package installation	30%		645,000	388,800	780,000		$645,000	$388,800	$780,000
Equipment outside of package									
Settling tank									
Grouting and grading	20,000	LS	1	1	1		$20,000	$20,000	$20,000
Chain and flight	175,000	EA	1	1	1		$175,000	$175,000	$175,000
Helical skimmer	200,000	EA	1	1	1		$200,000	$200,000	$200,000
EQ basin									
Mixers	50,000	EA	1	1	1		$50,000	$50,000	$50,000
Heat exchanger	250,000	EA	1	1	1		$250,000	$250,000	$250,000
Gallery									
Solids pumps	30,000	EA	2	2	2		$60,000	$60,000	$60,000
Solids standpipe	25,000	EA	1	1	1		$25,000	$25,000	$25,000
Roll up doors	8,000	EA	2	2	2		$16,000	$16,000	$16,000
Exterior doors	8,000	EA	2	2	2		$16,000	$16,000	$16,000
Interior doors	3,000	EA	1	1	1		$3,000	$3,000	$3,000
Equipment scoped by some									
Blowers	100,000	EA	0	3	0		$0	$300,000	$0
Blower VFDs	25,000	EA	0	3	0		$0	$75,000	$0
Feed pumps	40,000	EA	0	2	2		$0	$80,000	$80,000
Feed pump VFDs	15,000	EA	0	2	2		$0	$30,000	$30,000
Air flow meters	10,000	EA	0	0	2		$0	$0	$20,000
Water flow meters	15,000	EA	0	0	2		$0	$0	$30,000
Subtotal							$5,842,432	$4,983,046	$5,872,057
Yard Piping	10.0%						$584,243	$498,305	$587,206
HVAC	5.0%						$292,122	$249,152	$293,603
E&IC	35.0%						$2,044,851	$1,744,066	$2,055,220
Subtotal							$8,763,648	$7,474,570	$8,808,086
Undesigned contingency	30.0%						$2,629,094	$2,242,371	$2,642,426
Base Cost							**$11,392,742**	**$9,716,940**	**$11,450,512**
Contractor overhead and profit	15.0%						$1,708,911	$1,457,541	$1,717,577
							$13,101,654	$11,174,481	$13,168,088
Contractor general conditions	12.0%						$1,572,198	$1,340,938	$1,580,171
							$14,673,852	$12,515,419	$14,748,259
Bonds and insurance	3.5%						$513,585	$438,040	$516,189
							$15,187,437	$12,953,459	$15,264,448
Tax	8.8%						$1,336,494	$1,139,904	$1,343,271
Bid Cost							**$16,523,932**	**$14,093,363**	**$16,607,719**
Allied Costs									
Final Engineering	15.0%						$2,478,590	$2,114,004	$2,491,158
Construction Engineering	7.5%						$1,239,295	$1,057,002	$1,245,579
Legal, Admin, Permitting	5.0%						$826,197	$704,668	$830,386
Total Project Cost							**$21,068,013**	**$17,969,038**	**$21,174,842**

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Attachment C: Vendor Proposals

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DATE: 2 August, 2021
TO: Adam Klein – Brown & Caldwell
FROM: Jason Boyd – World Water Works (WWW)
CC: Chandler Johnson – WWW, Chris McCalib – Treatment Equipment Company (TEC)
RE: Information on DEMON® Process – Bellingham, WA WWTP – Rev0

Per your request for design and sizing for a DEMON® treatment system based on the **design criteria provided**, please find below our design summary based on the information provided. Below are some graphs showing the typical cycle of a DEMON® treatment system.

1. DEMON® TREATMENT PROCESS

Deammonification represents a short-cut in the N-metabolism pathway and comprises of 2 steps. About half the amount of ammonia is oxidized to nitrite and then residual ammonia and nitrite is anaerobically transformed to elementary nitrogen. See this shortcut in the diagram below. By using this process there is no excess oxygen required or external carbon source to achieve nitrogen removal.

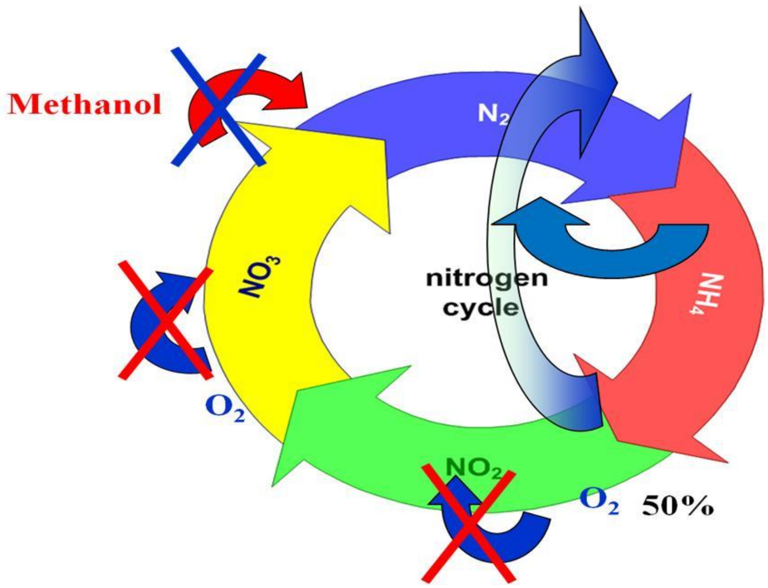


Figure 1 – NITROGEN CYCLE WITH SHORT CUT NITROGEN REMOVAL ADDED

Implementation of the University of Innsbruck pH controlled strategy for the DEMON® process for deammonification of reject water in a single sludge system is what this design is proposed around. The **specific energy demand of the side stream process results in 1.4 kWh per kg ammonia nitrogen removed comparing to about 6.5 kWh of mainstream treatment.** This process is achieving results of greater than 90% at the Strass WWTP (see data presented below). Biomass enrichment and Continuous Demon® -start up is key for this process to achieve its results in a short period of time and this proposal provides the seed sludge and start up assistance to ensure achieving the goal of efficient nitrogen removal.

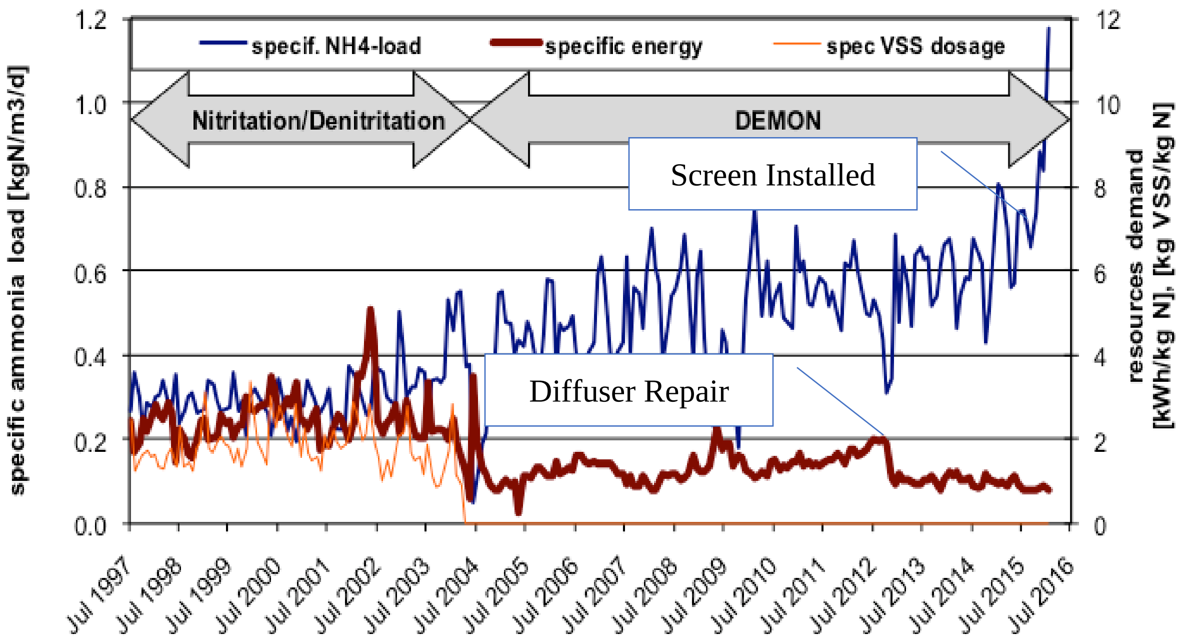


FIGURE 2 – STRASS NITROGEN PROFILE (1997 – 2016) WITH LOADING RATE AND SPECIFIC ENERGY

Design Concept

The overall design concept for is to use two (2) new reactors to create DEMON® treatment systems and EQ tank for the design conditions provided below. This allows for treating 100% of the flows and loads in each reactor (2 @ 100%). Peak flows of 120,000 gpd is used for the internal settler per reactor.

Parameter	Start up	Average	Max A	Max B
TSS, mg/L	< 500	< 500	< 500	< 500
TKN, mg/L	1,864	1,924	2,180	2,182
Alkalinity, mg/L as CaCO3	5,000	5,000	5,000	5,000
Temp, °C	28 - 35	28 – 35	28 – 35	28 - 35
Design Loading	**809 lb/day**	**1,020 lb/day**	**1,401 lb/day**	**1,930 lb/day**
Design Flow	**0.052 MGD**	**0.0635 MGD**	**0.077 MGD**	**0.106 MGD**

We envision using concrete tanks for the DEMON® process. New mixers and aeration system will be placed in each reactor for providing the mixing energy for re-suspension of the granules, proper mixing distribution of the influent feed flow and provide the necessary aeration for nitritation. An internal settling zone will be used to settle out the MLSS / Anammox biomass and allow the treated wastewater to be discharged. A single control panel will be provided to control process.

Parameter	Start up	Average	Max A	Max B
Number of Trains	2	2	2	2
Length (ft)	40	40	40	**50**
Width (ft)	30	30	30	30
SWD (ft)	21	21	21	21
Air Flow (SCFM)	280	350	480	650
bHP / Blower	10.3	13.3	17.1	22.8
Air Flow/ Blower (SCFM)	140	175	240	325
Installed Blower HP	40	40	40	40
# Blowers provided	3 (2 duty + 1 standby)	3 (2 duty + 1 standby)	3 (2 duty + 1 standby)	3 (2 duty + 1 standby)

We see many advantages in operating the system as a continuous process as it will allow for a lower installed HP for the blowers and feed pumps, not require the Decanter and operate continuously with higher Anammox biomass retention which allows for higher operating loading rates.

Strass WWTP has been operating with a new Anammox retention system, which has proven to be very successful at allowing for higher Anammox retention then

We have designed the system based on having removal efficiencies of 90% for ammonia and 80% for TIN however the aeration system is sized based on 95% ammonia removal. We have also assumed minimum operating temperature of 25C. Below is a summary of the designs presented.

Under design loads with influent ammonia loads listed below, the estimated effluent ammonia & total nitrogen using two (2) reactors will be as follows.

Parameter	**Start up**	**Average**	**Max A**	**Max B**
Influent NH3-N (lb/day)	**809**	**1,020**	**1,401**	**1,930**
Effluent NH3-N (lb/day)	162	204	280	386
Effluent TIN (lb/day)	322	406	558	768

DEMON® TANK COMPONENTS

a) **Biomass Separation System** – A micro-screen will be used for this project and will have submerged pumps feeding it for a period time to waste out the AOB and NOB bacteria. The waste sludge of AOB and NOB bacteria will be discharged from the system while the underflow (Anammox bacteria) will be returned to the reactor.

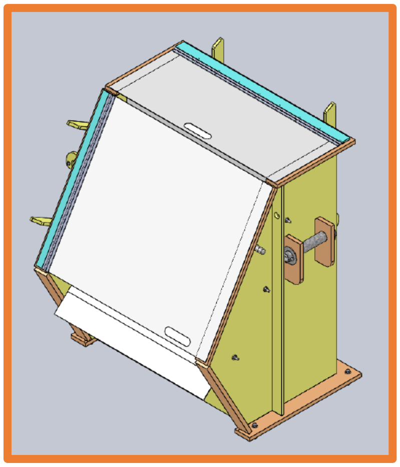


FIGURE 3 – MICRO-SCREEN VIEW

Below are graphs of the loading and % removal of the Anammox treatment system at Strass WWTP in Austria using the microscreen since fall 2015. In February 2016, The specific load was increased to over 1.4 kg/m3-day while still maintaining greater than 90% removal of Ammonia-nitrogen.

b) **Instrument Float** – the instruments for control of the process will be installed on a float system which will float with the level of the system. One (1) pH probe & one (1) DO probe for control of the overall operation of the process will be provided. A dedicated controller for the DO and pH is our recommendation. The conductivity probe is also to be provided with its own controller. Spare instrument locations will be provided in the instrument float for adding additional analyzers over time.

FIGURE 4 – INSTRUMENT FLOAT EQUIPMENT

c) **<u>Seed Sludge</u>** – for the quick start-up of the DEMON® treatment process, an adequate amount of seed sludge will be supplied. The seed sludge will be shipped in as dry content possible based on the harvesting technique used and will be added to the systems as they are started up.

FIGURE 5 – SEED SLUDGE SHIPPING CONTAINER

d) **<u>Aeration System</u>** – The Messner aeration system will be supplied in each tank. The amount of panels is provided in the scope of supply section and is subject to final design.

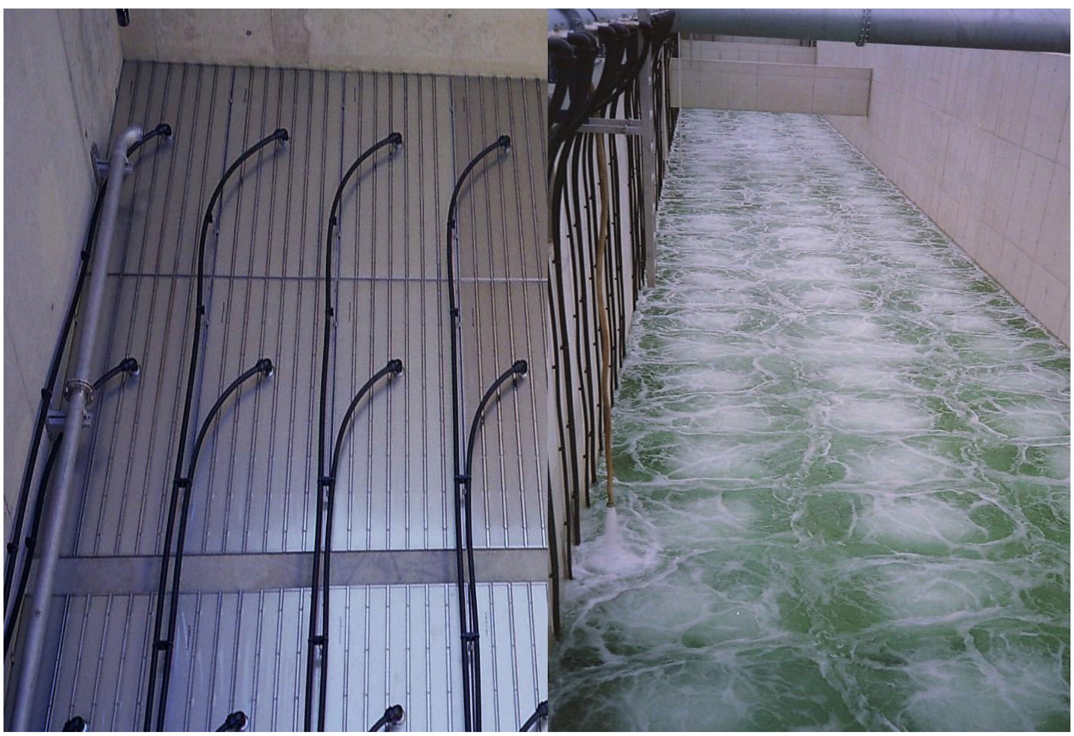


FIGURE 6 – MESSNER PANEL INSTALLED / AERATION PATTERN TEST

e) **<u>Side Mounted Mixers</u>** – Landia side mounted mixers will be used to maintain mixing energy within each reactor. The mixers will help suspend the "reds" during the non-aerated cycles of the process. VFD's will be provided to allow the mixers to be turned down and save on energy during the overall operation of the cycle.

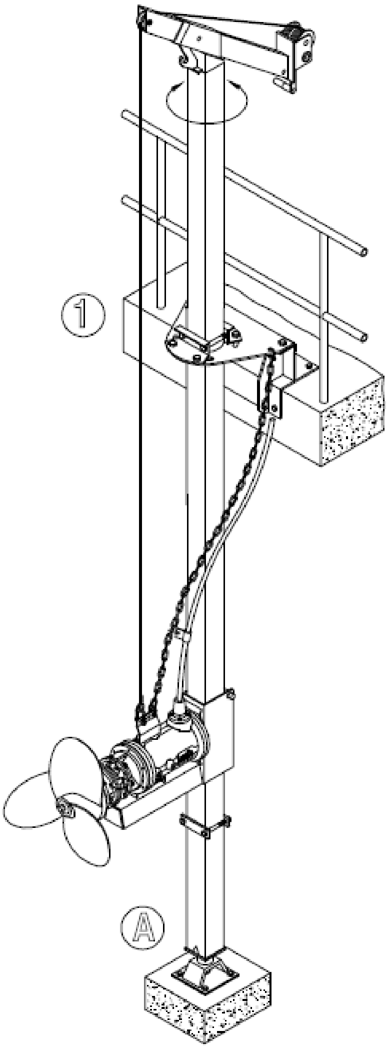


FIGURE 7 – LANDIA MIXER

f) **Internal Settling Zone** – An internal settling zone will be provided to allow for a continuous operation of the Anammox treatment system. Clarified effluent will be discharged back into the main process while the settled MLSS will be returned to the Anammox reactor. The waste stream enters the vessel and immediately the velocity is reduced to enhance particle separation. The vessel is polypropylene, so the operating pH has no effect on the systems longevity. The “clean” liquid is continuously removed from the top of the settling area and passes through holes into an effluent collection piping system. From the effluent collection piping system, the wastewater gravity feeds out of the system. Heavy solids settle into the bottom where they fall back into the main DEMON® process tank on a automatic basis. The system is compact, robust, cleanable, and does not have moving parts.

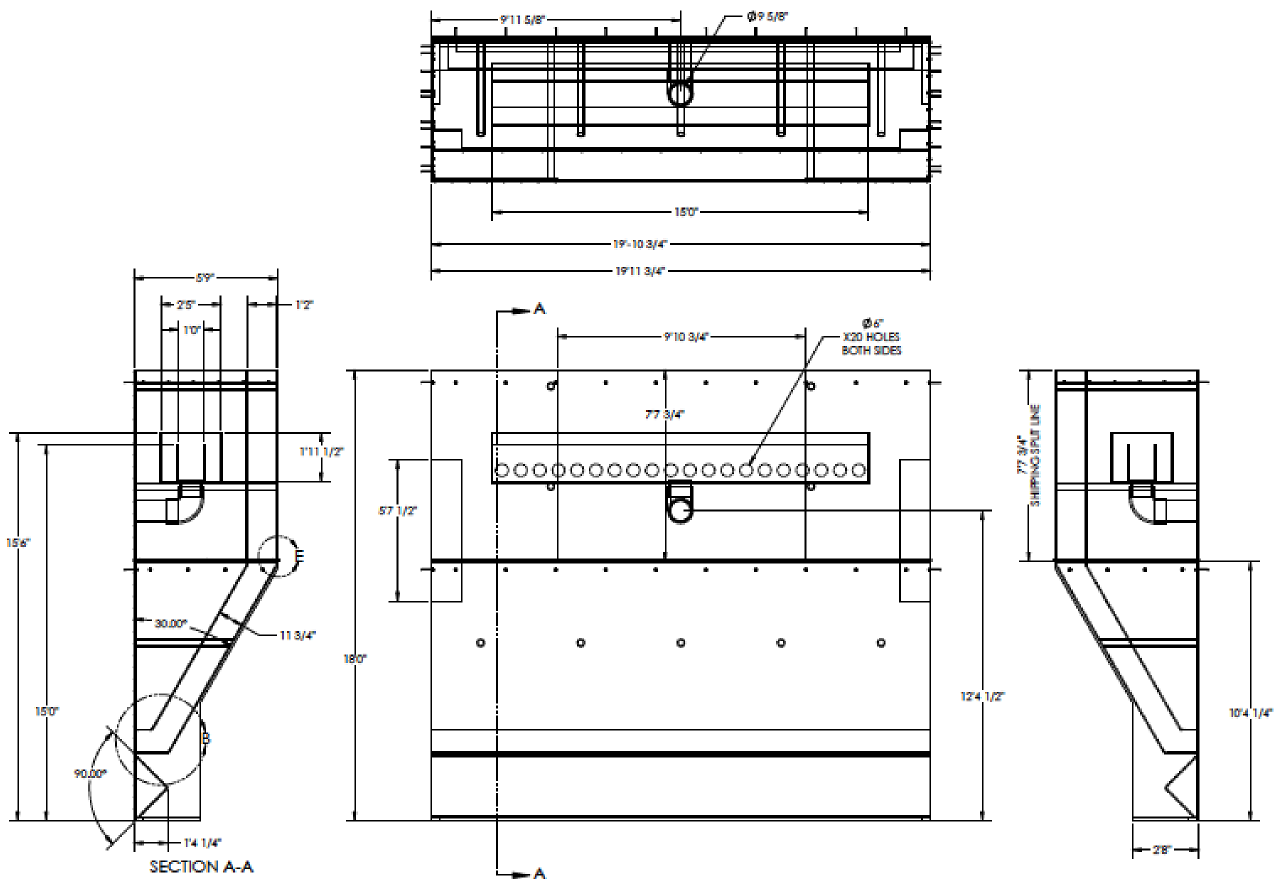


FIGURE 8 - View of the Settling Zone from Top, Front and back sides. To be anchored to outside and back concreate walls.

g) **<u>Blowers</u>** – Positive displacement blowers capable of providing the necessary turndown for operation of the DEMON® system are to be provided.

Design Case	**Model**	**Total Air Flow**	**Est. HP**	**Est. bHP**
2 duty + 1 standby per Process train If operating 2 trains, 1 blower per train will be required.	GM 10S	280 SCFM 350 SCFM 480 SCFM 650 SCFM	40 HP	10.3 bHP / blower – Start up 13.3 bHP / blower – Avg Month 17.1 bHP / blower – Max A 22.8 bHP / blower – Max B

This blower design will allow the most flexibility in allowing the system have efficient use of blower capacity during start up and low load periods of time. The blowers will each have its own sound enclosure to maintain < 75 db sound rating. Each blower will also be equipped with a variable frequency drive unit to allow efficient turndown of the blower while maintaining the proper dissolved oxygen concentration in the DEMON® reactor.

FIGURE 9 – AERZEN BLOWER WITH SOUND ENCLOSURE

h) **<u>Documentation / Design / License</u>** – All necessary documentation and design information will be provided as well as a license for treating the Maximum Month Loads.

2. CONTROLS

World Water Works provides pre-wired control panels to optimally control all equipment provided within the scope of this proposal. World Water Works includes an Ethernet connection with the control panel to allow remote access to the program and to assist in troubleshooting.

INSTRUMENTATION

Electrical Enclosure	**Hoffman, NEMA 4**
PLC	**Allen Bradley**
Software	**Allen Bradley**
Touchscreen	**15 inch Color Touch Screen**
	UL Listed Panel

FIGURE 10 – CONTROL PANEL WITH PLC

PLC Panel – The PLC panel and control program is the heart of the DEMON® process and its integral to our scope of supply. The PLC program will have each reactor created as a separate reactor. The reactor will have independent feed of raw centrate, aeration and mixing time. A touch panel with remote access is standard for allowing WWW access to the system and provides operational oversight.

DESIGN FOR 28C – Start-Up Conditions

Influent Flow and Wastewater Characteristics	Design		Design	
Wastewater temperature in DEMON® Anammox-tank	28	°C	82.4	F
Daily water flow	197	m^3/d	0.052	MGD
Ammonia (NH4-N) Load	367	kg/d	809	lb/day
Ammonia (NH4-N) Concentration	1,864	mg/L	1,864	mg/L
Soluble COD, degradable (estimate)	150	mg/L	150	mg/L
Suspended Solids Concentration (TSS)	500	mg/L	500	mg/L
Soluble COD, degradable Load	30	kg/d	65	lbday
Suspended Solids Load (TSS)	98	kg/d	217	lb/day
Alkalinity Concentration	5,000	mg/L	5,000	mg/L
Alkalinity Load	984	kg/d	2,170	lbday
DEMON® Anammox Tank Information				
Number of tanks	1	in parallel	1	in parallel
Max. water depth	6.40	m	21.0	ft
Total volume per DEMON® Anammox Reactor	714	m^3	25,206	ft^3
Length of Each DEMON® Anammox Treatment Reactor	12.2	m	40	ft
Width of Each DEMON® Anammox Treatment Reactor	9.1	m	30	ft
Total Treatment Volume Provided	714	m^3	25,206	ft^3
Influent Feeding Design				
Feeding pump per tank	12	m^3/h	53	gpm
Design of aeration system				
Biological Oxygen Requirements System Design				
Actual Oxygen Requirements (AOR), operating conditions	643	kg O2/d	1,417	lb O2/d
Actual Oxygen Required (AOR) in DEMON® Anammox tank	38	kg O2/h	84	lb O2/h
Aeration System & Blower Design Air Flow Requirements				
Design Air Flow (per DEMON® Anammox-tank)	460	Nm^3/h	271	SCFM

Air flows are based on 21 ft operating water level and discharge pressure of 10.5 psig

Rough Footprint would be one (1) basin at 30 ft wide x 40 ft long x 21 ft SWD

Above design is based on 1 basin treating 100% of the influent flow and load. A total of two (2) process trains is being provided in our overall scope of supply.

DESIGN FOR 28C – Average Conditions

Influent Flow and Wastewater Characteristics	Design		Design	
Wastewater temperature in DEMON® Anammox-tank	28	°C	82.4	F
Daily water flow	240	m^3/d	0.064	MGD
Ammonia (NH4-N) Load	462	kg/d	1,020	lb/day
Ammonia (NH4-N) Concentration	1,924	mg/L	1,924	mg/L
Soluble COD, degradable (estimate)	150	mg/L	150	mg/L
Suspended Solids Concentration (TSS)	500	mg/L	500	mg/L
Soluble COD, degradable Load	36	kg/d	79	lbday
Suspended Solids Load (TSS)	120	kg/d	265	lb/day
Alkalinity Concentration	5,000	mg/L	5,000	mg/L
Alkalinity Load	1,202	kg/d	2,650	lbday
DEMON® Anammox Tank Information				
Number of tanks	1	in parallel	1	in parallel
Max. water depth	6.40	m	21.0	ft
Total volume per DEMON® Anammox Reactor	714	m^3	25,206	ft^3
Length of Each DEMON® Anammox Treatment Reactor	12.2	m	40	ft
Width of Each DEMON® Anammox Treatment Reactor	9.1	m	30	ft
Total Treatment Volume Provided	714	m^3	25,206	ft^3
Influent Feeding Design				
Feeding pump per tank	15	m^3/h	65	gpm
Design of aeration system				
Biological Oxygen Requirements System Design				
Actual Oxygen Requirements (AOR), operating conditions	810	kg O2/d	1,786	lb O2/d
Actual Oxygen Required (AOR) in DEMON® Anammox tank	48	kg O2/h	106	lb O2/h
Aeration System & Blower Design Air Flow Requirements				
Design Air Flow (per DEMON® Anammox-tank)	580	Nm^3/h	342	SCFM

Air flows are based on 21 ft operating water level and discharge pressure of 10.5 psig

Rough Footprint would be one (1) basin at 30 ft wide x 40 ft long x 21 ft SWD

Above design is based on 1 basin treating 100% of the influent flow and load. A total of two (2) process trains is being provided in our overall scope of supply.

DESIGN FOR 28C – Max 2 Weeks Condition A

Influent Flow and Wastewater Characteristics	Design		Design	
Wastewater temperature in DEMON® Anammox-tank	28	°C	82.4	F
Daily water flow	291	m^3/d	0.077	MGD
Ammonia (NH4-N) Load	635	kg/d	1,401	lb/day
Ammonia (NH4-N) Concentration	2,180	mg/L	2,180	mg/L
Soluble COD, degradable (estimate)	150	mg/L	150	mg/L
Suspended Solids Concentration (TSS)	500	mg/L	500	mg/L
Soluble COD, degradable Load	44	kg/d	96	lbday
Suspended Solids Load (TSS)	146	kg/d	321	lb/day
Alkalinity Concentration	5,000	mg/L	5,000	mg/L
Alkalinity Load	1,457	kg/d	3,213	lbday
DEMON® Anammox Tank Information				
Number of tanks	1	in parallel	1	in parallel
Max. water depth	6.40	m	21.0	ft
Total volume per DEMON® Anammox Reactor	714	m^3	25,206	ft^3
Length of Each DEMON® Anammox Treatment Reactor	12.2	m	40	ft
Width of Each DEMON® Anammox Treatment Reactor	9.1	m	30	ft
Total Treatment Volume Provided	714	m^3	25,206	ft^3
Influent Feeding Design				
Feeding pump per tank	18	m^3/h	78	gpm
Design of aeration system				
Biological Oxygen Requirements System Design				
Actual Oxygen Requirements (AOR), operating conditions	1,113	kg O2/d	2,453	lb O2/d
Actual Oxygen Required (AOR) in DEMON® Anammox tank	66	kg O2/h	146	lb O2/h
Aeration System & Blower Design Air Flow Requirements				
Design Air Flow (per DEMON® Anammox-tank)	798	Nm^3/h	469	SCFM

Air flows are based on 21 ft operating water level and discharge pressure of 10.5 psig

Rough Footprint would be one (1) basin at 30 ft wide x 40 ft long x 21 ft SWD

Above design is based on 1 basin treating 100% of the influent flow and load. A total of two (2) process trains is being provided in our overall scope of supply.

DESIGN FOR 28C – Max 2 Weeks Condition B

Influent Flow and Wastewater Characteristics	Design		Design	
Wastewater temperature in DEMON® Anammox-tank	28	°C	82.4	F
Daily water flow	401	m^3/d	0.106	MGD
Ammonia (NH4-N) Load	876	kg/d	1,930	lb/day
Ammonia (NH4-N) Concentration	2,182	mg/L	2,182	mg/L
Soluble COD, degradable (estimate)	150	mg/L	150	mg/L
Suspended Solids Concentration (TSS)	500	mg/L	500	mg/L
Soluble COD, degradable Load	60	kg/d	133	lbday
Suspended Solids Load (TSS)	201	kg/d	442	lb/day
Alkalinity Concentration	5,000	mg/L	5,000	mg/L
Alkalinity Load	2,006	kg/d	4,423	lbday
DEMON® Anammox Tank Information				
Number of tanks	1	in parallel	1	in parallel
Max. water depth	6.40	m	21.0	ft
Total volume per DEMON® Anammox Reactor	891	m^3	31,474	ft^3
Length of Each DEMON® Anammox Treatment Reactor	15.2	m	50	ft
Width of Each DEMON® Anammox Treatment Reactor	9.1	m	30	ft
Total Treatment Volume Provided	891	m^3	31,474	ft^3
Influent Feeding Design				
Feeding pump per tank	25	m^3/h	108	gpm
Design of aeration system				
Biological Oxygen Requirements System Design				
Actual Oxygen Requirements (AOR), operating conditions	1,533	kg O2/d	3,380	lb O2/d
Actual Oxygen Required (AOR) in DEMON® Anammox tank	91	kg O2/h	201	lb O2/h
Aeration System & Blower Design Air Flow Requirements				
Design Air Flow (per DEMON® Anammox-tank)	1,099	Nm^3/h	647	SCFM

Air flows are based on 21 ft operating water level and discharge pressure of 10.5 psig

Rough Footprint would be one (1) basin at 30 ft wide **x 50 ft long** x 21 ft SWD

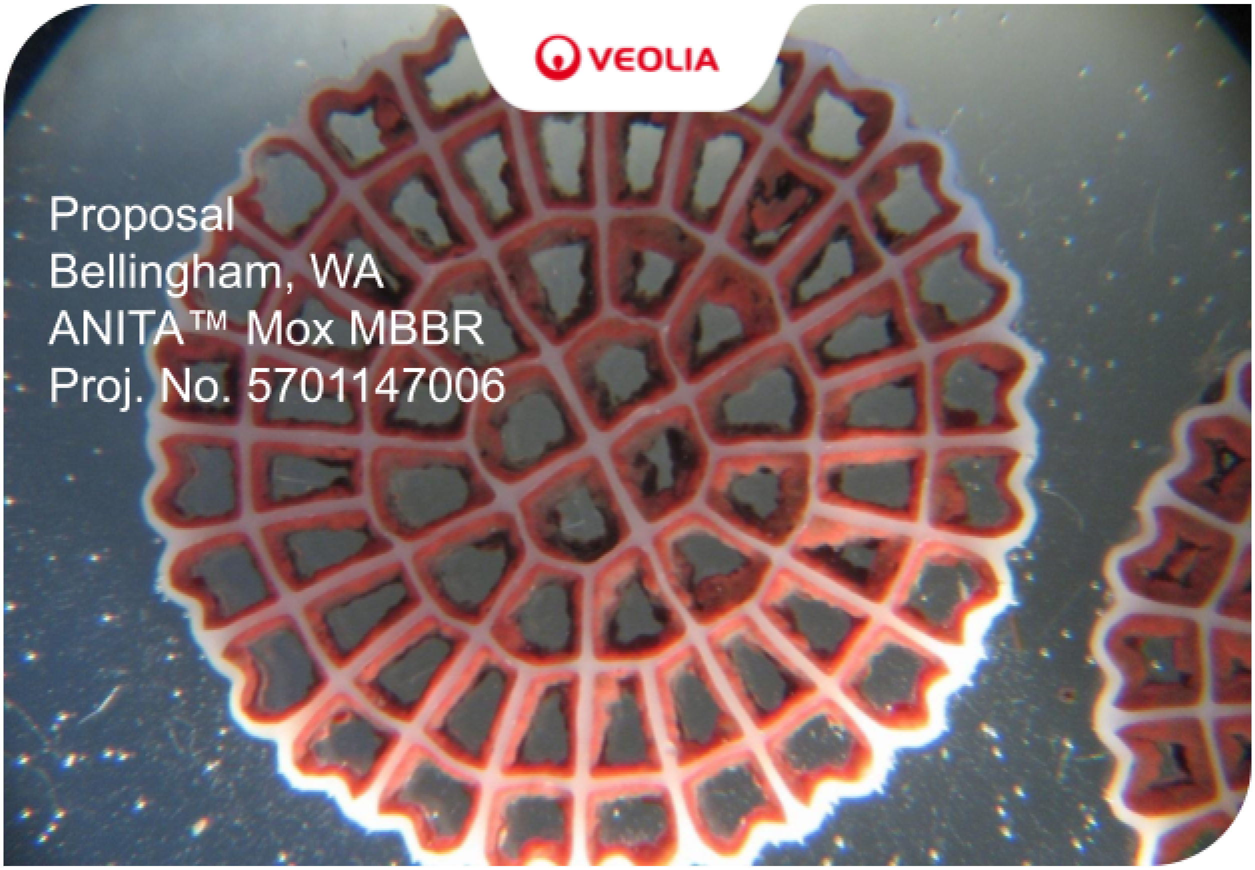
Above design is based on 1 basin treating 100% of the influent flow and load. A total of two (2) process trains is being provided in our overall scope of supply.

WWW Scope of Supply – Base Case – Start-Up, Average and Max 2 Weeks Condition A

- Design & Engineering for System
- Two (2) – 20 ft wide x 5 ft deep x 18 ft tall internal settling zone made from Polypropylene
- Forty-six (46) Messner Aeration panels for the reactors (23 per train)
- Two (2) SS 304L Drop pipe with manifold to feed Messner panels
- Two (2) DEMON® Biomass Separation Systems
- Three (3) submersible pumps (one duty + one standby) rated at 125 gpm and 7.5 HP motor with VFD's on each pump (operated up to 8 hrs per day)
- Three (3) Radar type level control for each DEMON® Tanks & EQ Tank
- Three (3) influent feed pumps to the DEMON® reactor each rated for 110 gpm with VFD's on each pump. (operated 12 - 24 hrs per day) (2 duty + 1 standby)
- Six (6) Positive Displacement blowers (325 SCFM each) with VFD's on each blower (40 HP motors) (operated 14 hrs per day at design load) – (4 Duty + 2 Standby)
- Four (4) – 9.0 HP side mounted mixers with VFD's for each mixer (operated 6 hr/day)
- Seed Sludge for start-up of system delivered to the site
- DEMON® Control program with panel with VFD's for blowers, submersible pump and mixers
- Two (2) pH and DO probe with two (2) SC1000 controller
- Two (2) Conductivity probe with two (2) SC200 controller
- Two (2) Air flow insertion meter and six (6) water flow magnetic meters
- Inspection, start up and training services (5 trips / 20 days)
- 3-4 months of off-site / remote monitoring services
- **Estimated Price for above scope of supply: $2,150,000 USD**

Items not included:

Tankage for EQ tank sized for 2 hours HRT (for systems with dewatering 24 hours per day or 8 – 12 hours for systems with dewatering 8 – 16 hours per day)
DEMON® tanks
Unloading, storage, installation of equipment
Electrical connections and interconnecting piping



Submitted to: Adam Klein, PE
Brown and Caldwell

Submitted by: Sarah Spivey
Application Engineer

Date: August 18, 2021

Veolia Water Technologies Inc. (dba Kruger)
4001 Weston Parkway
Cary, NC 27513
tel. +1 919-677-8310 | fax. +1 919-677-0082
www.veoliawatertech.com

Water Technologies

Dear Adam,

Veolia Water Technologies, Inc (dba Kruger) appreciates this project opportunity and is pleased to present this budgetary proposal for our ANITA™ Mox MBBR process for deammonification of the anaerobic digester centrate in Bellingham, WA. We also appreciate your help on the Central Valley ANITA Mox project.

Based on your request and the design basis provided, we have proposed a two (2) train ANTIA Mox MBBR system, each train consisting of one reactor with the dimensions of 30 L × 30 W × 22 SWD. Please note that the number of trains and dimensions of each reactor can be adjusted if site specific conditions or certain engineering design goals/drivers necessitate such adjustments. If the plant has any available tanks that have roughly the same volume as the proposed reactors, the system can be retrofitted into the existing tanks.

This system is designed to provide full treatment for the projected 2-week ammonia loading of 1,400 lb/d, with the flexibility to adapt to the less likely 1,930 lb/d condition at a reduced treatment efficiency. If this scenario is later confirmed as a more permanent condition, additional media can be incorporated to improve performance.

To accommodate the requirements for full redundancy while minimizing costs and operational risk, media has been provided only for the design conditions. Each of the two tanks has been sized for 30% media fill so that in the event a train needs to be taken offline, media can temporarily be transferred to the train in operation.

Please also note that blowers have not been included in our scope. However, we have helped size the blowers to facilitate the design of the system. The blowers and air grids have been sized to provide sufficient air to one reactor in the event that the entire 1,930 lb/d is sent to one reactor. If this is not necessary, the size of the blowers can be reduced. It is possible to tap air from the blower station of the mainstream treatment plant if there is adequate air available. Most of our full-scale plants get the air supply in this way. Further discussion on the blowers may be needed at a later stage.

The system has proven to be simple, stable and robust with more than thirty full-scale projects and multiple pilot studies. We sincerely hope that our unique ANITA Mox technology, Veolia's unparalleled experience and excellent services discussed above and below add value to your proposal and enable you to achieve your overall project goals in this endeavor.

We appreciate the opportunity to provide this proposal to you. If you have any questions or need further information, please contact our local Representative, Bill Reilly of Wm. H. Reilly & Co., or our Regional Sales Manager, Rodrigo Lara, at (503) 380-3995 (rodrigo.lara@veolia.com).

cc: Process, Sales, project file (Kruger)
Bill Reilly(Wm. H. Reilly & Co.)

Revision	Date	Process Eng.	Comments
0	08/17/2021	JLY	Initial, budgetary proposal.

ANITA Mox Unique Advantages

ANITA Mox provides several key differentiators for deammonification treatment as manifested in multiple full scale installations and pilot studies:

- The media based process is proven to be extremely simple and requires fewer specialty equipment than suspended/granular sludge technologies and significantly less maintenance and attention.
- Proven. All Veolia's installations show that the performance of the system is very stable and much less prone to process upset due to unforeseen or random fluctuations in sidestream characteristics.
- Anammox bacteria grow as a fixed film on HDPE media carriers and are securely retained within the reactor by maintenance-free media retention screens. Unlike suspended growth/granular technologies, there is little risk of anammox washout, substantially improving operational simplicity and reducing maintenance and life cycle cost of the system.
- The AnoxK™ 5 media has a very high protected surface area per unit volume (244 ft2/ft3) for biofilm growth, retention and protection, enabling a compact system design.
- The ANITA Mox system is tolerant of temporary limitations or fluctuations in pH, temperature and parameter concentrations. Therefore, the system can withstand a wide range of short-term influent variations without being upset.
- The ANITA Mox process can tolerate higher design TSS concentrations without the need for dedicated pretreatment equipment. This is another benefit of the anammox bacteria being securely retained on the carriers.
- The ANITA Mox System can be expanded without the need for additional construction. As flows and loads increase carriers can be incrementally added, which provides the ultimate flexibility for future system expansion.
- Carriers are manufactured from HDPE resins and are designed to last the life of the system. Veolia has MBBR installations in service for over 20 years without carrier replacement.

- Seed media is readily available from multiple US-based bio-farms for quick startup. Once one reactor is started up, the media in that reactor can be used as seed for the startup of other reactors.

Robustness

- The ANITA Mox system is tolerant of temporary limitations or fluctuations in pH, temperature and parameter concentrations. Therefore, the system can withstand a wide range of short-term influent variations without being upset.
    - Tolerates variability in dewatering schedules and dewatering starts/stops
    - Tolerates higher TSS and swings in TSS, do not typically require solids pretreatment.
    - Tolerates episodes of high polymer residual
    - Tolerates wide range of DO, BOD, TP, pH and other parameters
    - Tolerates episodes of high NO_2-N and ammonia residual
    - Proven by third-party robustness testing (by LA County) to be an incredibly resilient process that overcomes operational perturbations. For each of the following, LA County purposely upset the biofilm system for a 24-hour period and timed the system's recovery. In each case, ANITA Mox rebounded quickly and efficiently:

Scenario	Recovery Time
24 hour power outage	0 hr
24 hr no feed	0 hr
240 hr Excess Polymer (10x normal)	32 hr
24 hr Excess Polymer (2x normal)	0 hr
24 hr no aeration	16 hrs
24 hr over aeration (2x normal)	0 hr

- Proven at various installations, the ANITA Mox system is able to withstand short term or even pro-longed system shutdowns. The system can be placed into low-flow and/or low-loading mode. This allows the facility to have flexibility in dewatering schedules and perform routine or even emergency maintenance to their digesters and/or dewatering equipment without significant impact to system performance.

Unparalleled ANITA Mox Expertise in Both the US and Rest of World

Veolia/Kruger is a leader in providing the media based deammonification solution to the US municipal market. The Veolia US team (i.e. Kruger) works directly with our counterparts at Veolia Engineering and Research Institute in France and AnoxKaldnes AB in Sweden to incorporate the latest knowledge and developments in the design of the media based deammonification technology. The delivery of cutting edge and global knowledge, coupled with the robustness of the technology, has enabled us to gain the trust of our customers and resulted in rapid adoption. Veolia has a total of thirty (30) full scale ANITA Mox projects worldwide (including 10 projects in the US since 2013) since 2010 with more than sixty years of combined successful operating history. The team has published numerous papers on the technology at various national and international conferences.

Strongest US Technical Support and Customer Service

Kruger, the Veolia US team, has served the US municipal market for more than 25 years and is headquartered in Cary, NC. A group of more than 10 core process and project experts have each been with Kruger for more than 10 to 25 years. All these experts have been involved in the modeling, design, delivery, startup and troubleshooting of our full scale ANITA Mox projects in the US and to some extent in those of the international installations. These experts have more than 250 years of combined experience and work as a team to provide critical technical support to our customers whenever it is needed.

For services and parts, we have a customer support center and warehouse in Raleigh, NC to respond to your needs in a timely manner. Our local representative, Wm. H. Reilly & Co., can also provide immediate support and spare parts in most cases.

Strongest Financial Backing

Veolia is the world's #1 ranked waste and water treatment company, bringing not only expertise and experience, but also vast resources and financial backing that can be leveraged by your project team and the City. Veolia will guarantee process performance and is willing to support such guarantee with a process performance Guarantee Bond. A bid bond and/or payment and performance bonds can also be supplied if desired. We believe such bonds provide more value and protection to your interest.

State of the Art Digital Services Offer

The ANITA Mox process includes the use of our Hubgrade Performance Plant start-up kit, which offers many advantages during the critical period of growth and acclimation of the Anammox bacteria. With the use of a Veolia-provided temporary nitrite probe and remote PLC access provided through a highly secure OPC bridge on a separate "DMZ" network, Veolia's advanced algorithms and ANITA Mox expert input ensure that the system is fully optimized 24/7 for the proper reactor conditions. Continued use of the Hubgrade Performance Plant system for full-time optimization is also available via an additional service contract. Key benefits include:

	Hubgrade Performance ANITA™Mox Start-Up Kit	+Hubgrade Performance Advanced Offer
Focus/Driver	Start-up Time Minimized Start-up Labor Minimized Sampling Minimized Optimized Conditions 24/7	Optimized Conditions 24/7 Energy Minimized

Process Description

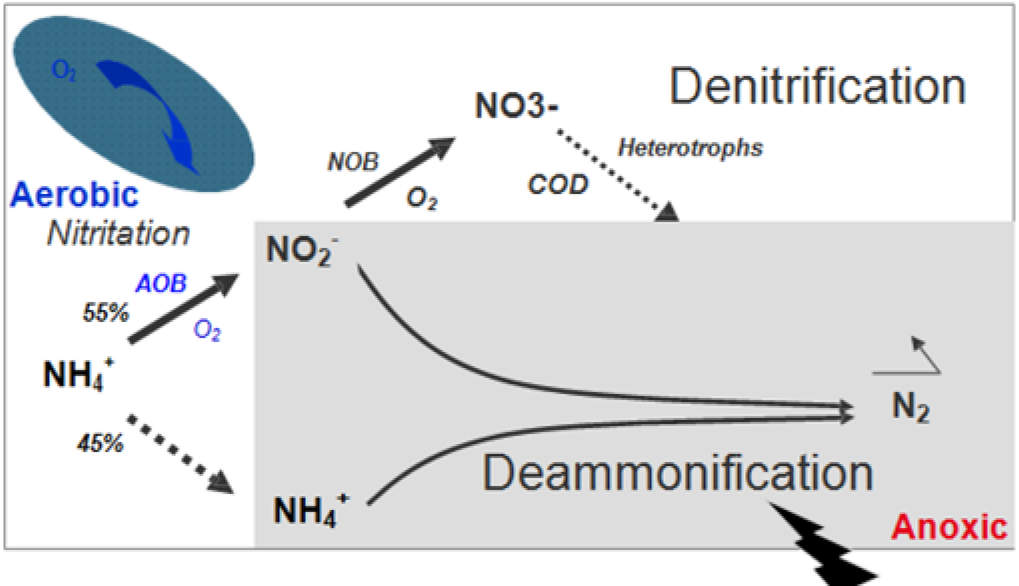
AnoxKaldnes MBBR

The MBBR process is a continuous-flow, non-clogging biofilm reactor containing moving "carrier elements" or media. The media flows with the water currents in the reactor and does not require backwashing or cleaning.

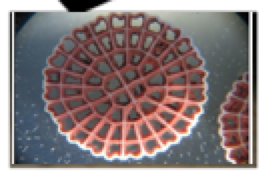
The anammox biomass that is critical to the deammonification process is attached to and securely protected by the surfaces of the media. The media is designed to provide a large protected surface area for the biofilm and optimal conditions for biological activity when suspended in water. Media of different shapes and sizes provide flexibility to use the most suitable type depending on wastewater characteristics, discharge standards and available volumes. In addition, a phased approach with different media fill percentage makes expansion of the ANITA Mox system much easier. More media can simply be added for future increase of flow and loads. AnoxKaldnes media is made from virgin HDPE and has a density slightly less than water.

The ANITA™ Mox MBBR process is a single-stage nitrogen removal process based on the MBBR platform. The process is specifically designed for treatment of waste streams with high ammonia concentrations. The system can achieve ammonia removals of up to 80-90% and total nitrogen removals of up to 75-85%. The treatment method uses only 40% of the oxygen demand of conventional nitrification, and it requires no external carbon source.

Nitrogen removal with ANITA Mox

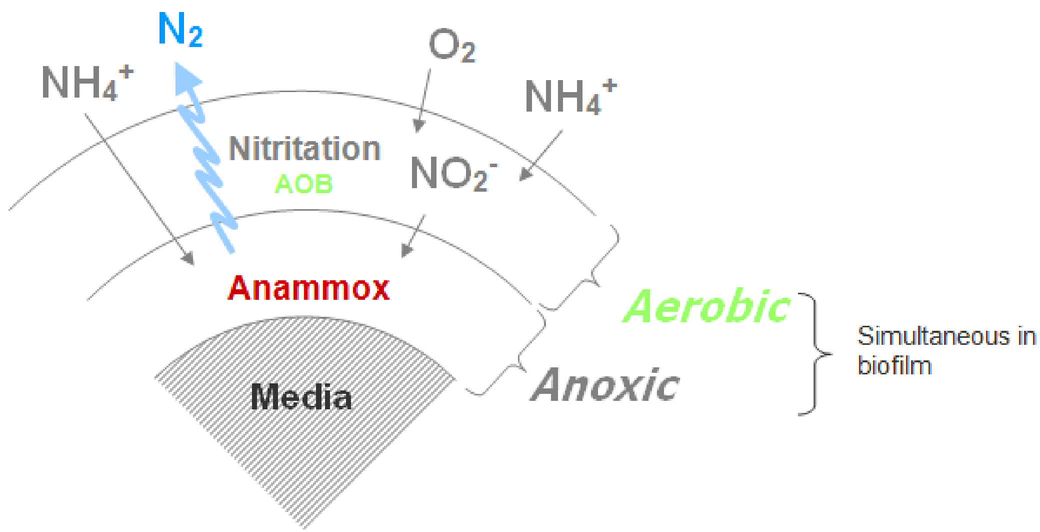


$$NH_4^+ + 1.32\ NO_2^- + .066\ HCO_3^- + .13\ H^+ \rightarrow$$
$$1.02\ N_2 + .26\ NO_3^- + .066\ CH_2O_{0.5}N_{0.15} + 2.03\ H_2O$$



Anammox Reaction

The ANITA Mox process consists of an aerobic nitritation reaction and an anoxic ammonia oxidation (anammox) reaction. The two steps take place simultaneously in different layers of the biofilm. Nitritation occurs in the outer layer of the biofilm. Approximately 55% of the influent ammonia is oxidized to nitrite (NO_2^-). Anammox activity occurs in the inner layer. In this step, the nitrite produced and the remaining ammonia are utilized by the anammox bacteria and converted to nitrogen gas (N_2) and a small amount of nitrate (NO_3^-).



ANITA Mox minimizes the risk of anammox washout. With ANITA Mox, the retention of the anammox bacteria within the reactor is easily achieved through the retention of the AnoxKaldnes media by stainless steel media screens. This bacteria retention method is proven to be simple and effective in more than 1,000 AnoxKaldnes MBBR/IFAS systems. Unlike other anammox retention systems, this system is designed to be maintenance free and requires little attention/maintenance from the operators. Anammox retention is an important characteristic of the system, since the anammox bacteria growth rate is very slow compared to conventional wastewater bacteria growth rates. Washout of the anammox bacteria can cause serious upsets of the deammonification process and even irreversible loss of performance.

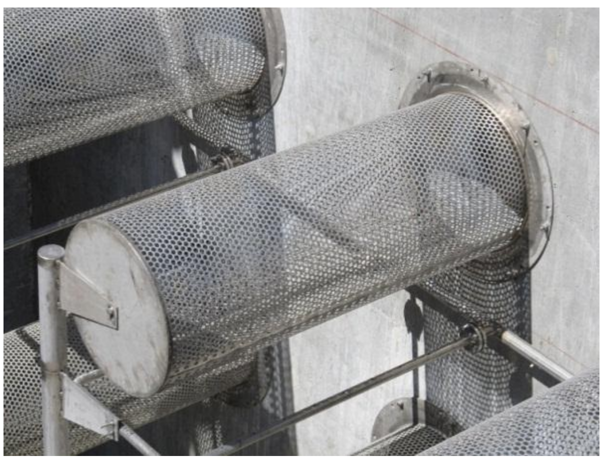
The ANITA Mox MBBR system consists of four major in-basin mechanical components, media, media retaining screens, air grids and mixers. The media, media retaining screens and air grids are designed to be maintenance-free throughout the lifetime of the system.

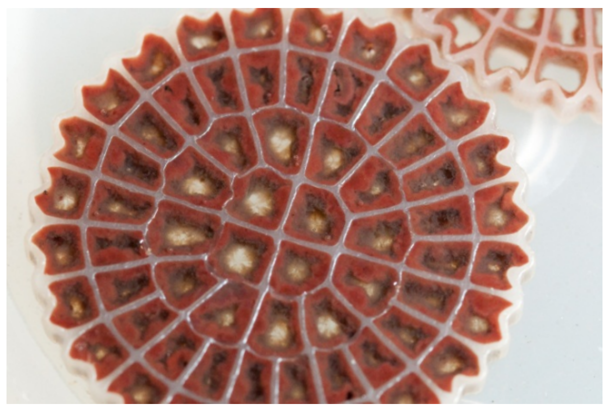
The ANITA Mox MBBR system does not require RAS/WAS pumps or recirculation pumps within the system. Moreover, it requires neither internal nor external sludge settlers because it's a biofilm system with all biofilms attached to and securely protected by the media carriers.

Another benefit of the ANTIA Mox MBBR system is that it does not require the addition of micronutrients for the process to work. Unlike certain suspended growth systems that need micronutrients for sludge conditioning or granule formation, the ANITA Mox system takes advantage of the more robust and adaptive biofilm that is more resistant to adverse influent centrate/filtrate conditions.

AnoxKaldnes ANITA™ Mox System Configuration

Kruger's minimum scope of supply includes the AnoxKaldnes media, screen assemblies (to keep media in each reactor), medium bubble aeration grids, and mixers. In cases where they are needed, Kruger also provides the blowers, instrumentation and controls, SCADA, and field instruments (dissolved oxygen, nitrate, ammonia, etc.) for single-source responsibility.





Design Summary

The ANITA Mox influent design basis is summarized in Table 1. The target effluent criteria for the ANITA Mox system are listed in Table 2. In order to achieve the expected removals as summarized in Table 2, we recommend constructing two (2) ANITA Mox process MBBR process trains, using our AnoxK™5 media, for deammonification of centrate at Bellingham, WA. The process design is summarized in Table 3.

The tank dimensions along with other important process parameters are summarized in Table 3. It is important that each reactor have the capability for independent control of influent feed and aeration. This can be accomplished through dedicated pumps and blowers or by using high performance modulating valves. We have proposed two (2) modulating influent valves and one (1) modulating airflow control valve per train, along with a blower station dedicated to the sidestream system. Depending on the facilities dewatering schedule some equalization volume may provide benefits to the operations of the process.

The design assumes that the side stream entering into the proposed ANITA Mox system contains no toxic compounds and has sufficient alkalinity and that none of the equipment provided would be used in a classified area (e.g. Class 1, Division 1 or Class 1, Division 2).

Due to the high ammonia concentrations in the centrate, along with the additional tank volume requirements for full redundancy, Kruger recommends having dilution water available to blend the influent centrate with an equal volume of dilution water. This will allow the system to maintain a reasonable HRT and reduce the risk of process upset. At a minimum, the system will require dilution water to achieve a maximum influent ammonia concentration of 1,500 mg/L.

To accommodate the requirements for full redundancy while minimizing costs and operational risk, media has been provided only for the design conditions. Each of the two tanks has been sized for 30% media fill so that in the event a train needs to be taken offline, media can temporarily be transferred to the train in operation. Each tank also includes four air grids in order to accommodate the full flow in a single train. With both trains online during normal operations, one or two of the grids in each reactor will be turned off for even distribution of the required airflow.

Table 1: Influent Design Basis

Parameter	Units	Values, Centrate	Values, Dilution Water, treated WW*	Values, Combined*
Flow, Design	MGD	0.077	0.035	0.112
Flow, High Loading	MGD	0.106	0.225	0.331
sCOD	mg/L	150	30	107
TSS	mg/L	500	20	350
NH_4-N	mg/L	2,180	5	1500
PO_4-P	mg/L	200	2	138
Alkalinity	mg/L	5,000	50	5,550**
Elevation	ft	65		
Min/Max Temperature*	°C	28/35		

*Assumed values. Increased dilution ratios may be required at times to reduce the risk of process upset.
**Minimum recommended alkalinity.

Table 2: Target Effluent Concentrations

Parameter	Units	Value
NH4-N	mg/L	< 240
Total Inorganic Nitrogen	mg/L	< 380

* Listed values represent anticipated performance; any performance guarantees may be different.

Table 3: Process Design Summary

Parameter	Units	Values
Number of Process Trains	-	2
Reactor Dimensions (Each)	ft	30 L × 30 W × 22 SWD
Reactor Volume (Total)	ft^3	39,600
Recommended Freeboard for all reactors	ft	2 – 3
Media Type:	-	AnoxK™5
Fill of Biofilm Carriers (All Reactors)	%	30
Media Volume (All Reactors)	ft^3	12,005
Aeration System Type	-	Medium Bubble
Residual DO, Design	mg/L	1.5
Estimated Process Air Requirement, Design	SCFM	~780
Pressure From Top of Drop Pipe	psi	9.4

Scope of Supply

Kruger is pleased to present our scope of supply which includes process engineering design, equipment procurement, and field services required for the proposed treatment system, as related to the equipment specified. The work will be performed to Kruger's high standards under the direction of a Project Manager. All matters related to the design, installation, or performance of the system shall be communicated through the Kruger representative giving the Engineer and Owner ready access to Kruger's extensive capabilities.

Process and Design Engineering

Kruger will provide process engineering and design support for the system as follows:

- Process Engineering consisting of aeration system sizing and configuration, sieve and outlet design.
- Review and approval of P&I Diagram for the AnoxKaldnes ANITA Mox portion of the process. Preliminary General Arrangement Drawings and review and approval of final General Arrangement Drawings for the process. Review of reactor drawings with respect to penetrations and dimensions, excluding structural design.
- Equipment installation instructions for all equipment supplied by Kruger.

Field Services

Kruger will furnish a Service Engineer to perform the following tasks:

- Inspect installation of key pieces of equipment during construction.
- Inspect the completed system prior to startup.
- Assist the Contractor with initial startup of the system.
- Train the Owner’s staff in the proper operation and maintenance of the AnoxKaldnes ANITA Mox system.
- Test and start any Kruger-supplied control equipment, including PLC programming and SCADA systems.

Hubgrade Performance Plant - ANITA Mox Start-up Kit

The start-up kit includes software implementation and expert assistance during the start-up period. Specifically, Veolia will:

- Provide the temporary use of one (1) Hach EZ Series nitrite analyzer
- Deliver the communication software package OPC Bridge (UA client to client) software along with all functional specifications for proper implementation with the PLC/SCADA, including Watchdog interaction for safe communication

- Work with the client's systems integrator to complete implementation of the software package and verify communication to/from the Hubgrade Performance cloud server
- Implement, configure, tune and test of the Hubgrade Performance Plant features
- Provide remote expert review of system operation via the Hubgrade Performance Plant cloud platform throughout the start-up phase and completion of effluent performance tests

AnoxKaldnes ANITA™ Mox System Equipment

Mechanical Equipment Items	Qty	Description
AnoxKaldnes AnoxK™5 Media, (ft^3)	12,005	Carrier elements are made of high density polyethylene. The total media quantity will include a volume of ~5% seeded media.
Cylindrical Screen Assemblies	4	Two (2) per reactor. 304L SS. 23"ø perforated plate pipes terminated in ANSI flanges for mounting directly to the tank wall. One (1) manual BFV for each air grid drop pipe is also provided.
Medium Bubble Aeration System	8	Four (4) air grids per reactor. 304L SS including header, lateral piping, and hardware (excluding concrete anchor bolts).
Specially Designed Mechanical Mixers	2	One (1) per ANITA Mox Reactor. Includes VFD.
Airlift Pump	2	Two (2) airlift pumps per ANITA Mox reactor for foam suppression.
Modulating Airflow Control Valves	2	One (1) actuated BFV for each aerobic reactor.
Modulating Influent Control Valves	2	One (1) actuated BFV for each train.
Mechanical Equipment Items (NOT INCLUDED)	**Qty**	**Description**
Positive Displacement Blowers	2 + 1	Two (2) duty plus one (1) standby. Each blower will be rated for 700 SCFM and 60 NPHP at 10.6 psig differential pressure. Includes VFD.

Instrumentation and Controls Equipment Items	Qty	Description
PLC Control Panel	1	NEMA 12 Freestanding or Wall Mount Control Panel (For Indoor Use). ControlLogix PLC; Panelview HMI; 120V Feed.
pH-based Control Logic	1	Provides an additional method of aeration control.
High Level Float Switch	2	One (1) for each media zone.
DO Probe (LDO)	2	One (1) for each Aerobic zone. Aerobic Zone DO Monitoring.
pH meter	2	One (1) pH meter for each ANITA Mox reactor.
Thermal Mass Flowmeter	2	One (1) for each ANITA Mox reactor for air flow control.
Magnetic Flowmeter	2	One (1) magnetic flow meter per reactor to measure influent flow.

Instrumentation and Controls (NOT INCLUDED)*	Qty	Description
Centrate Feed Pump	1+1	One (1) duty plus one (1) standby to feed centrate from equalization tank. Includes VFD.
Ammonia Nitrogen Analyzer (optional)	2	One (1) Amtax ammonia nitrogen analyzer with one (1) Filtrax unit (sample line) to measure the ammonia within the ANITA Mox reactor.
ISE Nitrate probe (optional)	2	One (1) NO_3-N probe per ANITA Mox reactor.

* These instrumentation and controls equipment are recommended. Not all of them are absolutely required for a fully functioning system. Further discussions can be had regarding instrumentation and controls based on owner or engineer's preference.

Notes Regarding System Design and Installation

- A note on concrete specifications: For any MBBR or IFAS system, regardless of manufacturer, it is sound practice to require good, quality concrete work for the process reactors. The Consulting Engineer's standard concrete specification section is typically adequate to eliminate large holes, excessive form marks, large pockets, and excessively rough areas. It is particularly important to eliminate the potential for annular space around media retention screens.
- A note on construction sequencing: It is important, particularly for IFAS installations, to have level detection and level communication systems in place and operational prior to the filling of process tanks with water and media.

Scope of Supply BY INSTALLER/PURCHASER

The scope of supply by others for the AnoxKaldnes ANITA™ Mox system should include, but is not limited to, the following items:

- All civil/site and electrical work.
- A concrete foundation for the tanks.
- Reactors to house the MBBR treatment equipment.
- All provisions for interconnecting piping.
- Unloading, storage and installation of equipment.
- Install and test all level floats, level transmitters, level alarms, and alarm communication devices prior to filling a process tank with media and water
- Centrate equalization tanks
- Cover for reactor tanks (if necessary)
- Temporary provisions for screened primary or secondary effluent during startup.
- Temporary reactor heating during startup.
- Mixer bridges and other structural modifications for the reactors.
- Video recording of any training activities.

Design Options

In addition to the proposed system as detailed herein, Kruger is able to further incorporate our process and controls expertise into wastewater treatment plants, allowing municipalities to meet stringent effluent requirements and future plant upgrades. Kruger is also able to offer our instrumentation and controls expertise to build upon the proposed system by providing a **customized plant-wide SCADA system** or designing a **Motor Control Center (MCC)**, providing clients a single source responsibility for plant controls. Please contact Kruger if the options above are of interest or to be included in the current proposed system or future upgrades. ***Please note that the design options listed above are not included in the pricing noted herein.*

Schedule

- Shop drawings will be submitted within 6-8 weeks of receipt of an executed contract by all parties.
- All equipment will be delivered within 18-20 weeks after receipt of written approval of the shop drawings.
- Installation manuals will be furnished upon delivery of equipment.
- Operation and Maintenance Manuals will be submitted within 90 days after receipt of approved shop drawings.

Pricing

The price for the AnoxKaldnes ANITA™ Mox system, as defined herein, including process and design engineering, field services, and equipment supply is: **$1,296,000.**

Pricing is FOB shipping point, with freight allowed to the job site. This pricing does not include any sales or use taxes. In addition, pricing is valid for sixty (60) days from the date of issue. The proposed goods may be affected by the ongoing market fluctuations impacting material and shipping costs. Kruger reserves the right to re-evaluate the Proposal price prior to order acceptance.

Please note that the above pricing is expressly contingent upon the items in this proposal and are subject to Kruger's Standard Terms of Sale detailed herein.

Kruger Standard Terms of Payment

The terms of payment are as follows:

- 10% on receipt of fully executed contract
- 15% on submittal of shop drawings
- 75% on the delivery of equipment to the site

Payment shall not be contingent upon receipt of funds by the Contractor from the Owner. There shall be no retention in payments due to Kruger. All other terms per our Standard Terms of Sale are attached.

All payment terms are net 30 days from the date of invoice. Final payment not to exceed 120 days from delivery of equipment.

Statement Regarding Competitive Transparency

Veolia takes all issues surrounding probity and confidentiality very seriously in all of its dealings with competitors and stakeholders. In this spirit and for the sake of transparency, we inform you that the publicly traded parent company Veolia Environnement S.A., recently acquired a 29.9% interest in Suez S.A ("Suez") and launched a public bid for the remainder of Suez' share capital. Consistent with our commitment to competition law compliance, Veolia will continue to act entirely independent of Suez until all relevant antitrust approvals of Veolia's acquisition of Suez have been obtained and we will of course let you know if this would change before the end of the tender proceedings.

Specifically, none of Veolia's representatives sit on the board of Suez, Veolia has no influence over the strategy or operations of Suez, and Veolia has no access to competitively sensitive information about Suez's operations. Accordingly, Veolia's ongoing project to acquire Suez will have no effect on our participation in, or response to, this tender.

Kruger Standard Terms of Sale

1. Applicable Terms. These terms govern the purchase and sale of the equipment and related services, if any (collectively, "Equipment"), referred to in Seller's purchase order, quotation, proposal or acknowledgment, as the case may be ("Seller's Documentation"). Whether these terms are included in an offer or an acceptance by Seller, such offer or acceptance is conditioned on Buyer's assent to these terms. Seller rejects all additional or different terms in any of Buyer's forms or documents.

2. Payment. Buyer shall pay Seller the full purchase price as set forth in Seller's Documentation. Unless Seller's Documentation provides otherwise, freight, storage, insurance and all taxes, duties or other governmental charges relating to the Equipment shall be paid by Buyer. If Seller is required to pay any such charges, Buyer shall immediately reimburse Seller. All payments are due within 30 days after receipt of invoice. Buyer shall be charged the lower of 1 ½% interest per month or the maximum legal rate on all amounts not received by the due date and shall pay all of Seller's reasonable costs (including attorneys' fees) of collecting amounts due but unpaid. All orders are subject to credit approval.

3. Delivery. Delivery of the Equipment shall be in material compliance with the schedule in Seller's Documentation. Unless Seller's Documentation provides otherwise, Delivery terms are F.O.B. Seller's facility.

4. Ownership of Materials. All devices, designs (including drawings, plans and specifications), estimates, prices, notes, electronic data and other documents or information disclosed by Seller or prepared solely by Seller or Buyer or jointly by Seller and Buyer in connection with this Agreement, and all intellectual property rights therein, shall be and remain the confidential and proprietary property of Seller, whether or not patented by Seller ("Work Product"). Buyer hereby irrevocably assigns all rights in any Work Product to Seller. Seller grants Buyer a non-exclusive, non-transferable (except to a successor-in interest to the ownership of the Equipment), paid-up license to use the Work Product solely in connection with Buyer's use, operation, repair and maintenance of the Equipment at the Jobsite defined in this Agreement. Buyer may not disclose, share, transfer, or sell any such Work Product to third parties without Seller's prior written consent and such consent may be arbitrarily withheld. Buyer agrees not to resell, transfer or give any of the biologically colonized media or bacteria from the system to any party other than Seller or any of Seller's affiliates without the prior written consent of Seller for a period of fifteen (15) years from the effective date of this Agreement. Buyer shall not cultivate bacteria or use biomass carriers retrieved from the ANITA Mox system for any research or non-research purposes without prior written consent of the Seller. Any new developments, discoveries or inventions resulting from the operation of the ANITA Mox system in which the ANITA Mox process is a component or is in any way incorporated in whole or in part shall be owned solely by the Seller.

5. Changes. Seller shall not implement any changes in the scope of work described in Seller's Documentation unless Buyer and Seller agree in writing to the details of the change and any resulting price, schedule or other contractual modifications. This includes any changes necessitated by a change in applicable law occurring after the effective date of any contract including these terms.

6. Warranty. Subject to the following sentence, Seller warrants to Buyer that the Equipment shall materially conform to the description in Seller's Documentation and shall be free from defects in material and workmanship. The foregoing warranty shall not apply to any Equipment that is specified or otherwise demanded by Buyer and is not manufactured or selected by Seller, as to which (i) Seller hereby assigns to Buyer, to the extent assignable, any warranties made to Seller and (ii) Seller shall have no other liability to Buyer under warranty, tort or any other legal theory. If Buyer gives Seller prompt written notice of breach of this warranty within 18 months from delivery or 1 year from beneficial use, whichever occurs first (the "Warranty Period"), Seller shall, at its sole option and as Buyer's sole remedy, repair or replace the subject parts or refund the purchase price therefore. If Seller determines that any claimed breach is not, in fact, covered by this warranty, Buyer shall pay Seller its then customary charges for any repair or replacement made by Seller. Seller's warranty is conditioned on Buyer's (a) operating and maintaining the Equipment in accordance with Seller's instructions, (b) not making any unauthorized repairs or alterations, and (c) not being in default of any payment obligation to Seller. Seller's warranty does not cover damage caused by chemical action or abrasive material, misuse or improper installation (unless installed by Seller). THE WARRANTIES SET FORTH IN THIS SECTION ARE SELLER'S SOLE AND EXCLUSIVE WARRANTIES AND ARE SUBJECT TO SECTION 10 BELOW. SELLER MAKES NO OTHER WARRANTIES OF ANY KIND, EXPRESS OR IMPLIED, INCLUDING WITHOUT LIMITATION, ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR PURPOSE.

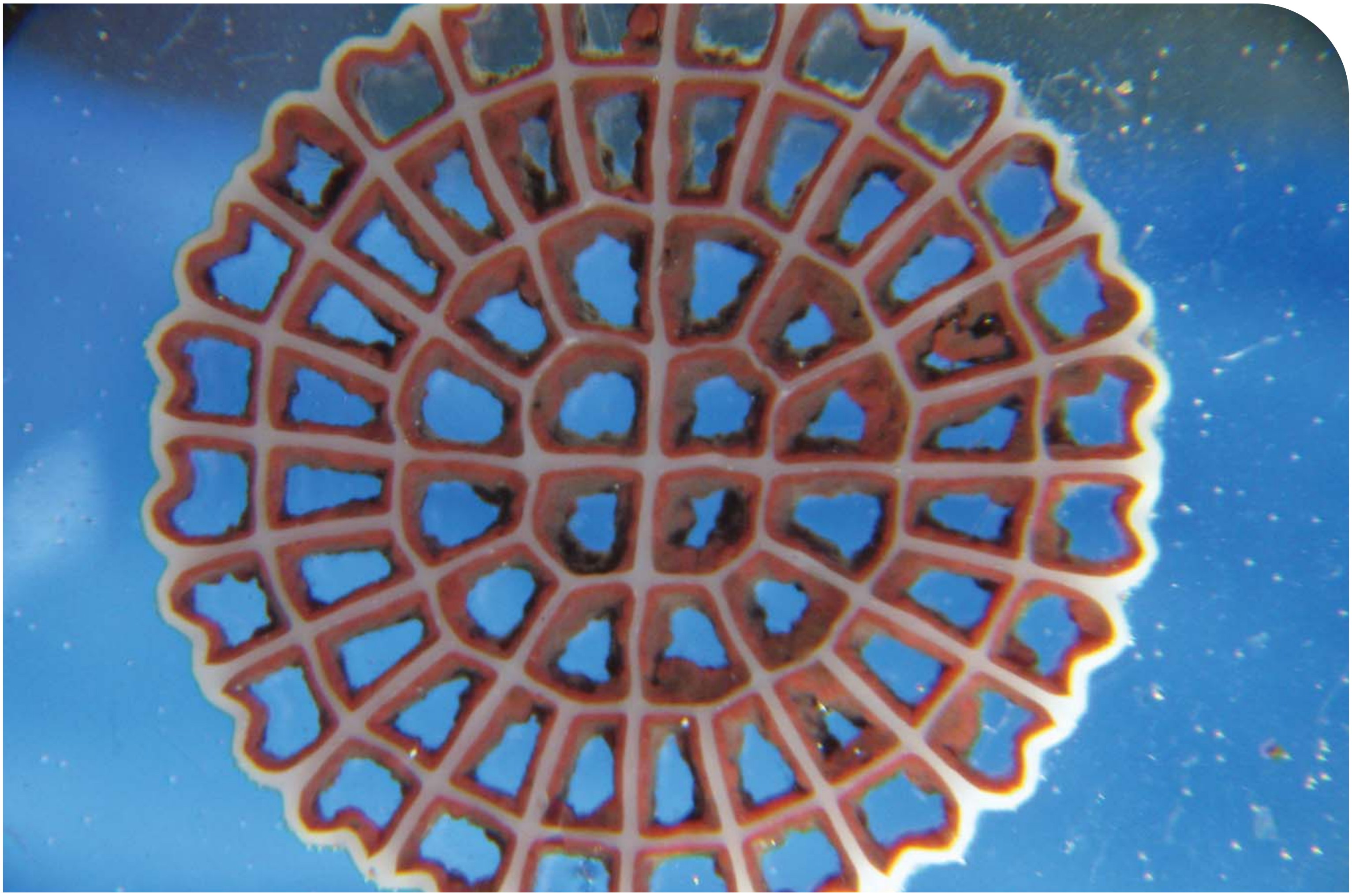
7. Indemnity. Seller shall indemnify, defend and hold Buyer harmless from any claim, cause of action or liability incurred by Buyer as a result of third party claims for personal injury, death or damage to tangible property, to the extent caused by Seller's negligence. Seller shall have the sole authority to direct the defense of and settle any indemnified claim. Seller's indemnification is conditioned on Buyer (a) promptly, within the Warranty Period, notifying Seller of any claim, and (b) providing reasonable cooperation in the defense of any claim.

8. Force Majeure. Neither Seller nor Buyer shall have any liability for any breach (except for breach of payment obligations) caused by extreme weather or other act of God, strike or other labor shortage or disturbance, fire, accident, war or civil disturbance, delay of carriers, failure of normal sources of supply, act of government or any other cause beyond such party's reasonable control.

9. Cancellation. If Buyer cancels or suspends its order for any reason other than Seller's breach, Buyer shall promptly pay Seller for work performed prior to cancellation or suspension and any other direct costs incurred by Seller as a result of such cancellation or suspension.

10. LIMITATION OF LIABILITY. NOTWITHSTANDING ANYTHING ELSE TO THE CONTRARY, SELLER SHALL NOT BE LIABLE FOR ANY CONSEQUENTIAL, INCIDENTAL, SPECIAL, PUNITIVE OR OTHER INDIRECT DAMAGES, AND SELLER'S TOTAL LIABILITY ARISING AT ANY TIME FROM THE SALE OR USE OF THE EQUIPMENT SHALL NOT EXCEED THE PURCHASE PRICE PAID FOR THE EQUIPMENT. THESE LIMITATIONS APPLY WHETHER THE LIABILITY IS BASED ON CONTRACT, TORT, STRICT LIABILITY OR ANY OTHER THEORY.

11. Miscellaneous. If these terms are issued in connection with a government contract, they shall be deemed to include those federal acquisition regulations that are required by law to be included. These terms, together with any quotation, purchase order or acknowledgement issued or signed by the Seller, comprise the complete and exclusive statement of the agreement between the parties (the "Agreement") and supersede any terms contained in Buyer's documents, unless separately signed by Seller. No part of the Agreement may be changed or cancelled except by a written document signed by Seller and Buyer. No course of dealing or performance, usage of trade or failure to enforce any term shall be used to modify the Agreement. If any of these terms is unenforceable, such term shall be limited only to the extent necessary to make it enforceable, and all other terms shall remain in full force and effect. Buyer may not assign or permit any other transfer of the Agreement without Seller's prior written consent. The Agreement shall be governed by the laws of the State of North Carolina without regard to its conflict of laws provisions.



VEOLIA

ANITA™ Mox

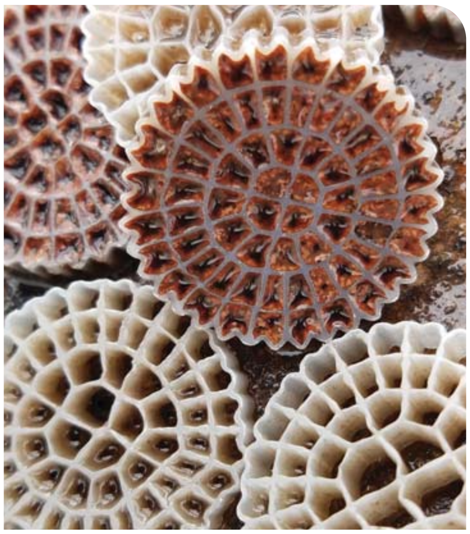
Deammonification Process
Simple, Stable and Robust

WATER TECHNOLOGIES

ANITA™ Mox

Sidestream Deammonification

ANITA™ Mox is a robust, single-stage ammonia and total nitrogen removal biofilm process based on the Moving Bed Bioreactor (MBBR) or Integrated Fixed-film Activated Sludge (IFAS) platform. It utilizes the AnoxK™ 5 media to cultivate anaerobic ammonia oxidizing bacteria (anammox) and ammonia oxidizing bacteria (AOB) enriched biomass for both mainstream and sidestream deammonification applications. It is the simplest and most stable technology in the market in terms of operation and maintenance in treating centrate or filtrate from either conventional anaerobic digestion (AD) or AD following thermal hydrolysis process (THP).



Sidestream Benefits Compared to Conventional Nitrification/ Denitrification

- 3x lower in total cost per pound of nitrogen removed
- Much smaller footprint with high loading/removal rates
- 90% less sludge production
- 60% less in energy consumption
- No external carbon required; less carbon footprint

System Configuration

- **MBBR** - for centrate from conventional anaerobic digestion
- **IFAS** - for centrate from thermal hydrolysis process + anaerobic digestion
- **Phased IFAS** - for centrate from any anaerobic digestion

Unique Advantages

- The simplest and most stable technology in the market
- Robust and forgiving design/operating parameters
- 90% ammonia removal and 80% TIN Removal
- Can work with both shallow (< 10 ft) and high side water depth (> 26 ft)
- Media-based solution eliminates the risk of anammox washout without the need for anammox/MLSS separation equipment
- Small footprint and easliy expandable by adding media or converting MBBR to IFAS with higher loading rates.
- Zero maintenance needed for in-basin components such as SS media screens, SS medium bubble diffusers and media carriers.
- Seed media readily available from multiple large US-based bio-farms for quick startup
- No need for media replacement

Full scale performance data has demonstrated ANITA Mox's ability to withstand:

> High TSS and swings in TSS (between 1,500 and 17,000 mg/L) without the need of pretreatment unit process

> High polymer residual

> Wide DO concentration and PH ranges

> Variations in dewatering schedules and dewatering starts/stops

> Extended shutdowns due to dewatering equipment maintenance

> High NO2-N residual with less NOB suppression requirements

> Inhibitory effects of recalcitrant COD and complex nitrogen compounds generated by THP or other special processes

Mainstream Deammonification

Paving the Way for Energy Neutrality

ANITA Mox is now offered as a compact and robust media based process for ammonia and nitrogen removal in mainstream applications while unlocking the possibility for energy production through COD diversion to digestion.

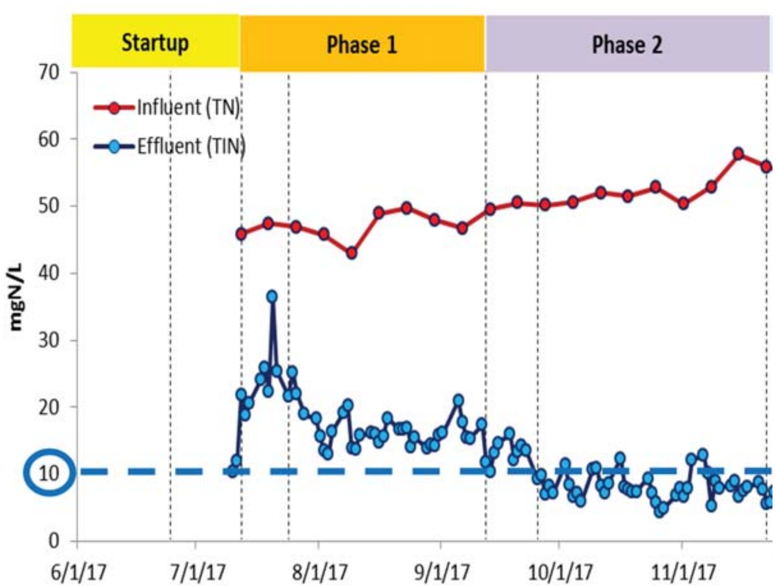
For mainstream deammonification, ANITA Mox provides an easy and purely mechanical solution to securely retain anammox biomass with the combination of biofilm carriers and retention screens. This simple and maintenance-free physical separation between anammox-rich biofilm carriers and nitrifier-rich suspended sludge allows for easy control of the sludge and therefore better AOB selection and control and better selective wash-out of NOB while retaining anammox.

Compared to conventional BNR treatment, Mainstream ANITA™ Mox reduces aeration demand by 60% and eliminates the need for carbon. Minimizing the operating cost of nitrogen removal and generating power through COD diversion, Mainstream ANITA™ Mox makes it possible for facilities to achieve energy neutrality.

Benefits of Mainstream ANITA™ Mox

- Eliminates carbon needs, enables power generation through COD diversion
- 60% less aeration required
- Targets 10-15 mg/L effluent TN concentration
- Works at low temperatures (15°C)
- Simple to control and operate
- Retains anammox easily
- Sidestream/Maintstream ANITA™ Mox ecosystem

Proven Results



Pilot Services

Veolia offers the following Pilot Services:

- On-site pilot testing trailors
- Startup and remote data collection
- Monitoring through Veolia's Aquavista™ smart water management system

ANITA™ Mox: Simple Start Up with High Influent TSS

Deammonification | Case Study

Little Patuxent Water Reclamation Plant

The Client

Little Patuxent Water Reclamation Plant (LPWRP) is located in Howard County, Maryland. This is a 29 MGD ENR (Enhanced Nutrient Removal) plant that discharges to the Little Patuxent River which goes to the Chesapeake Bay.

Design Criteria

- Design flow: 0.176 MGD
- Influent NH_4-N: 1,100 mg/L

Effluent criteria:

- 80-85% of NH_4-N Removal
- 70-75% TN Removal

The Client's Needs

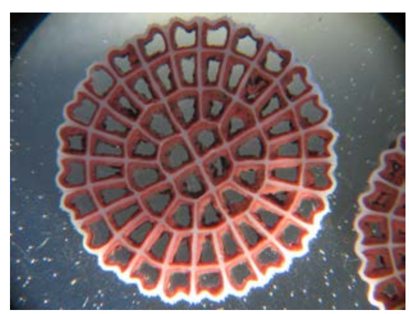
In 2013, Howard County began plans for an upgrade to its biosolids management facilities at LPWRP with high rate anaerobic digestion, rebuilt centrifuges for dewatering, a phosphorus recovery system and a sidestream deammonification system. The sidestream process is designed to reduce the impact of nitrogen load returned back to the mainstream treatment process and ensure that the plant meets the stringent discharge TN limit of 3 mg/L. LPWRP required the sidestream process to meet the following:

- Treat centrate with a high solids concentration (800 mg/L or higher) without requiring solids pretreatment.
- Proven, simple and robust treatment process that is supported by successful installations throughout the US.
- Easy to operate and requires minimal maintenance.
- Stable system that retains anammox bacteria easily and is not prone to washout, and more importantly,
- Fit into existing tankage.

The Solution

Howard County and the CMAR team chose Veolia's ANITA™ Mox MBBR sidestream deammonification process to meet the plant's requirements while offering project cost savings.

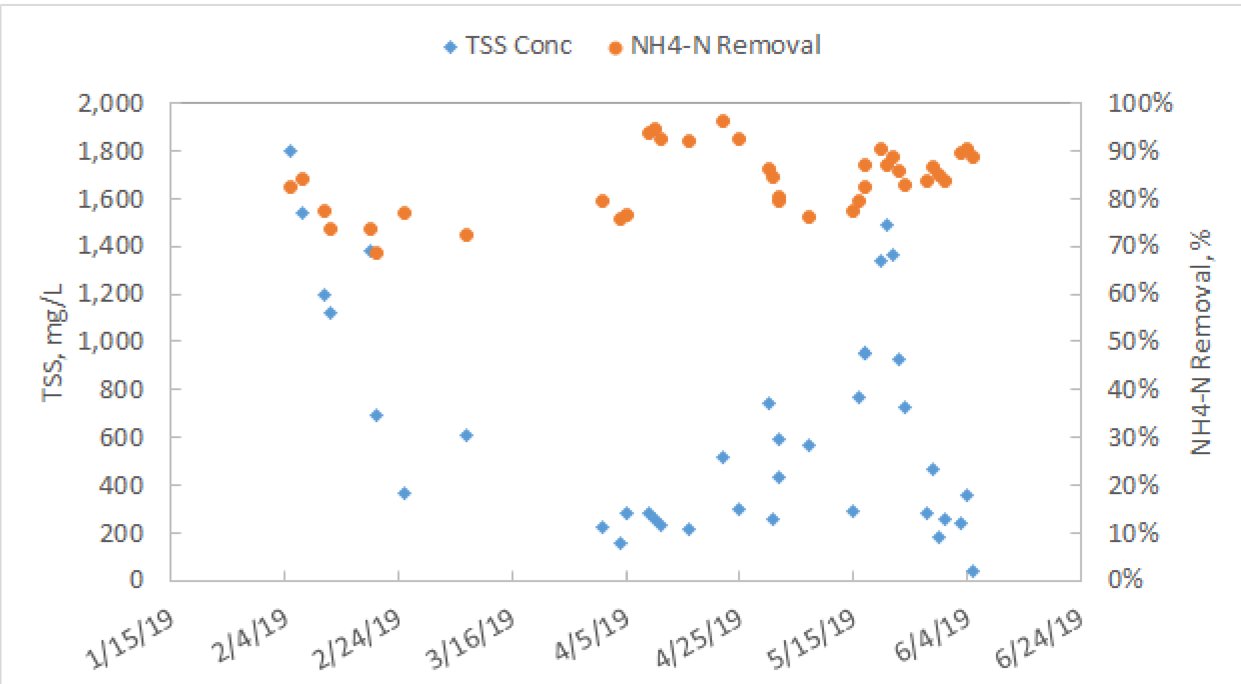
ANITA™ Mox utilizes K5 biofilm carriers and media retaining screens, eliminating anammox washout. Biomass (including anammox and AOBs) remains attached to the carriers as high TSS passes through the system.



ANITA™ Mox: Simple Start Up with High Influent TSS

Process Description

The ANITA™ Mox system was retrofitted into existing tanks with relatively shallow side water depth. The tanks were originally aeration tanks for an industrial waste pretreatment system that was mothballed before the Biosolids Project started. The system components such as the media, media retaining screens and medium bubble aeration diffusers are designed to be maintenance free for the lifetime of the system. The media fill volume of each of the two reactors leaves room for future expansion by simply adding more media if ammonia loading increases. Air for the ANITA™ Mox system is supplied via dedicated blowers as required by the plant. The small footprint of the system is able to save room for two small EQ tanks, designed to provide consistent loading to the reactors for enhanced performance. The patented ANITA™ Mox process controls strategy has the flexibility to be controlled by DO, pH, and/or ammonia for optimal energy savings.



Results

After adding seeded media from an existing BioFarm in the US, the reactors reached the design loading and removal rates despite high influent TSS concentrations. Reactor operation and performance is largely unaffected by high TSS concentrations. Since startup in early 2019, the ANITA™ Mox system continues to meet the design Nitrogen removal rates. The two small ANITA™ Mox reactors are able to remove approximately 15% of the total nitrogen load of the plant with low cost.

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www.veoliawatertech.com

Meeting Strict TN Limits: ANITA™ Mox

Biological Treatment | Case Study

South Durham Water Reclamation Facility

The Client

The City of Durham is located in the Research Triangle Region of North Carolina. The City operates two wastewater treatment plants – the North Durham Water Reclamation Facility and the South Durham Water Reclamation Facility, both permitted to treat 20 million gallons per day (MGD).

Design Flow: 0.08 MGD;
Peak Design Flow: 0.16 MGD
Effluent Criteria:
- ≥75% NH_4-N Removal
- ≥65% TN Removal

The Client's Needs

In 2011, the City of Durham completed a comprehensive wastewater master plan that evaluated different treatment techniques for meeting strict total nitrogen (TN) limits at the South Durham Water Reclamation Facility (SDWRF). The SDWRF will need to meet a TN limit of 3 mg/L at its design flow to comply with the total maximum daily load (TMDL) in the Jordan Lake Watershed, which serves as a source of drinking water in the region. The SDWRF uses anaerobic digesters to break down the plant's sludge. Downstream of the digesters, the plant uses belt filter presses for dewatering. The resulting liquid – the pressate from dewatering, or what is referred to as "sidestream" flow – historically accounted for about 20 percent of the nitrogen load in the plant's biological nutrient removal (BNR) process. While this sidestream nitrogen contribution sounds high, it is typical for many plants with anaerobic digestion.

The Solution

As a result of the evaluation, Durham selected Veolia's ANITA™ Mox sidestream deammonification system for ammonia and total nitrogen removal. The City studied mainstream and sidestream treatment alternatives to meet its TN limits. In its cost comparisons, ANITA™ Mox was calculated to be three times lower in cost per pound of nitrogen removed when capital and operating costs were considered. ANITA™ Mox was estimated to cost $0.93 per pound of nitrogen removed ($/lb N), while the most cost-effective mainstream BNR solution was estimated at $2.66/lb N. The City thus selected ANITA™ Mox as the most cost-effective nitrogen removal alternative.

Process Description

ANITA™ Mox is Veolia's sidestream deammonification technology for short-cut nitrogen removal. When compared to conventional mainstream nitrification/denitrification, ANITA™ Mox uses about 60% less oxygen, requires no external carbon source, and produces less sludge.

ANITA™ Mox is offered in both Moving Bed Biofilm Reactor (MBBR) and Integrated Fixed Film Activated Sludge (IFAS) configurations, depending on site conditions. As such, the system consists of engineered polyethylene carriers – in this case AnoxKaldnes™ K5 media – to provide ample protected surface area for biofilm to thrive. The K5 media (approximately the diameter of a quarter) host two types of bacteria in the same reactor. The outer layer consists primarily of ammonia oxidizing bacteria (AOBs) which convert about half of the ammonia to nitrite. The inner layer consists mainly of anammox (anaerobic autotrophic ammonia oxidizer) bacteria. These bacteria utilize the resulting nitrite and much of the remaining residual ammonia and convert them to nitrogen gas, which is released harmlessly to the atmosphere.

Since ANITA™ Mox has a high removal rate and treats the smaller sidestream flow at a wastewater plant, it has a compact treatment footprint. At many plants, the system can fit into a spare or abandoned tank on site. At the SDWRF, for example, the MBBR system was constructed in an abandoned aerobic digester.

SDWRF – Nitrogen Returned to the Influent Pump Station Requiring Additional Treatment

Parameter	With ANITA™ Mox (pounds per year)*	Before ANITA™ Mox (pounds per year)*	Guaranteed Removal by ANITA™ Mox
Ammonia Nitrogen	**< 61,000**	244,000	≥ 75%
Total Nitrogen	**< 94,000**	268,000	≥ 65%

* Values based on Design Flow and Loads for 365 days per year.

ANITA™ Mox Removes Nitrogen Efficiently – Requiring Less Aeration Energy, Chemical Usage, and Sludge Management than Conventional Nitrogen Removal

Parameter	ANITA™ Mox	Conventional Nitrogen Removal	Sidestream Savings with ANITA™ Mox
Oxygen Requirement ($lb\ O_2$ / lb N)	**1.9**	4.6	60%
Methanol Consumption (lb / lb N)	**0**	3.0	100%
Sludge Production (lb VSS / lb N)	**0.1**	0.5 – 1.0	80% to 90%

Results

At the SDWRF, the ANITA™ Mox MBBR system was started up in 12 weeks – an efficient time given the slow growth of anammox bacteria. Now operating full-scale, the system is achieving greater than 80% ammonia removal and 70% total inorganic nitrogen (TIN) removal – both exceeding guaranteed values. The ANITA™ Mox system is thus helping the SDWRF meet its strict effluent nitrogen limits using the most cost-effective solution.

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ANITA™ Mox Reference List

No.	Name	Country	Configuration	ANITA Mox Start-up	NH4-N Load (ppd NH4-N)
1	Sjölunda WWTP, Malmö	Sweden	MBBR	2010	440
2	Sundets WWTP, Växjö	Sweden	MBBR	2011	440-590
3	Holbæk WWTP	Denmark	MBBR	2012	265
4	Grindsted WWTP	Denmark	MBBR	2012	235
5	James River TP	USA (VA)	MBBR	2014	560
6	South Durham WRF	USA (NC)	MBBR	2015	670
7	Industrial Client	Europe	MBBR	2015	750
8	Locarno WWTP	Switzerland	MBBR	2015	660
9	John E. Egan WRP	USA (Schaumburg, IL)	MBBR	2,017	2,070
10	Robert W. Hite WWTF	USA (Denver, CO)	MBBR	2,017	9,000
11	Viikinmäki (Large-Scale Pilot)	Finland	MBBR	2017	661
12	Bromma WWTP	Sweden	MBBR	2017	310
13	Borås WWTP	Sweden	IFAS	2,018	1,680
14	Five Fords WWtW	UK	IFAS	2,019	1,940
15	Osberstown WWTP	Ireland	IFAS	2,019	1,125
16	Gryaab WWTP	Sweden	MBBR	2,018	3,900
17	Little Patuxent WRP (Howard County)	USA (Savage, MD)	MBBR	2,019	1,615
18	Tomahawk Creek WWTF	USA (Kansas City, KS)	MBBR	2,020	1,000
19	Ginestous WWTP	Europe	IFAS	2,019	2,795
20	LeMans WWTP	Europe	MBBR	2,020	660
21	Nordre Follo WWTP	Europe	IFAS	2019	250
22	Ljubjlana WWTP	Europe	IFAS	2019	
23	Piscataway WRRF	USA (WSSC, MD)	IFAS	2,020	4,500

Updated: October 2019. Do not disclose to third parties without Veolia's prior written conscent.

What are clients saying about ANITA™ Mox?

Johnson County Kansas Wastewater

Metropolitan Water Reclamation District of Greater Chicago

Metro Wastewater Reclamation District

DENVER, CO

City of Durham

City of San Luis Obispo

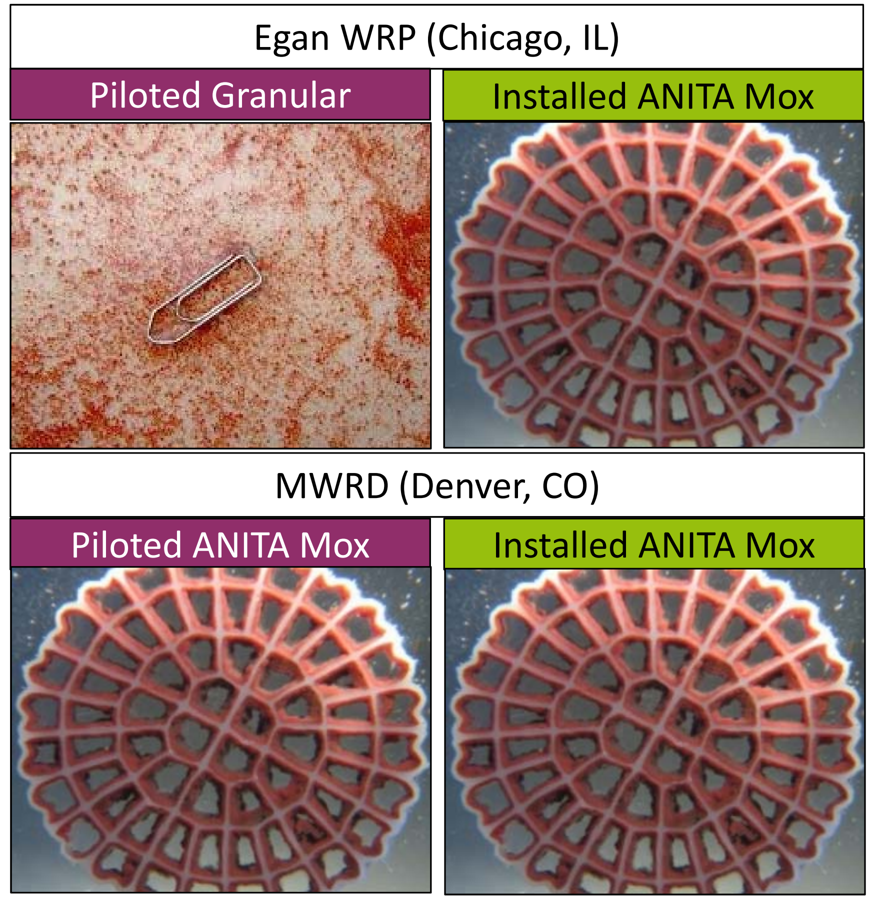
HRSD – Cleaning wastewater every day for a better Bay.

SANITATION DISTRICTS OF LOS ANGELES COUNTY

Converting Waste Into Resources

ANITA™ Mox Testimonial

- Evaluated sidestream Technologies:
  - Chicago piloted granular deammonification process
  - Denver piloted ANITA™ Mox (fixed film)
- Shared results through the LIFT Group:
- Both Facilities Chose ANITA™ Mox:
  - Fit within existing reactors
  - More robust system = more forgiving
  - No risk of anammox washout due to upset conditions
  - Operational flexibility
  - Ease of Operation



ANITA™ Mox Testimonial - MWRDGC (Chicago, IL)

Chicago's published reasons for selecting ANITA Mox:

The justification for the sole source request is as follows:

- This process is the only nitrogen removal process available on the market that does not require management of a separate sludge. The Biofilm process does not produce sludge.
- The biological process of the ANITA Mox MBBR can withstand weekend shutdown based on the Monday through Friday operating cycle of the centrifuges.
- The only other process that is currently marketed to completely remove most of the nitrogen from centrate requires a sludge management system and very close pH control.
- The agreement with VWSNA will include performance standards that guarantee greater than 75% ammonia removed from the process stream.

ANITA™ Mox Testimonial - SDWRF (Durham, NC)

DURHAM
1869
CITY OF MEDICINE

CITY OF DURHAM | NORTH CAROLINA

Date: January 3, 2013

To: Thomas J. Bonfield, City Manager
Through: W. Bowman Ferguson, Deputy City Manager
From: Donald F. Greeley, Director, Water Management
Subject: Sole Source Purchase Agreement with I. Krüger Inc. for the Purchase of the ANITA Mox Ammonia Removal System

Executive Summary

The Falls Lake and Jordan Lake rules that become effective in 2016 will require significant reductions in the amounts of nutrients discharged from the North and South Durham Water Reclamation Facilities (NDWRF and SDWRF). The recent Water Reclamation Facility Master Plan developed by Hazen and Sawyer recommended that that the Department utilize the patented and proprietary ANITA Mox nitrogen removal system ("ANITA Mox System") owned by I. Krüger Inc. (Krüger) as the preferred approach to meet the stringent nutrient limits at SDWRF. There is no competitive process that performs at the same level of the ANITA Mox System, and Krüger is the only source and vendor of the ANITA Mox System. Staff recommends the direct purchase of the system equipment from Krüger. The equipment will be installed in an upcoming construction contract at the SDWRF.

the lowest cost over time. In other words, none of the other available nitrogen reducing side stream technologies could perform at the level of the ANITA Mox System. The ultimate selection of the ANITA Mox System requires that we also select the sole vendor and company authorized to sell the ANITA Mox System. The SDWRF Master Plan recommends the ANITA Mox system as being the best suited technology for the SDWRF application.

Advantages of ANITA™ Mox over other Arrangements

- Less prone to loss of annamox organisms – attached growth
- Increased SRT with plastic carrier media
- Easily increase capacity of the process by adding media
- Reduced operational complexity
  - Continuous flow-through process
    - SBRs require settling and wasting phase
  - Single phase system with smaller footprint
    - SBRs require aerobic and anoxic phase

ANITA™ Mox Testimonial - Tomahawk WWTF (Johnson County, KS)

JOHNSON COUNTY KANSAS
Wastewater

Tomahawk Creek WWTF Section objectives:

- Provide the most cost-effective, long-term solutions for customers.
- Improve water quality using the latest, <u>proven technologies.</u>
- Preserve the high quality of life enjoyed by Jonson County residents.

3.5.2 Nitrogen Removal

Nitrogen removal via separate centrate treatment offers efficiency through the use of specialized bacteria, such as anammox, capable of removing nitrogen without organic carbon (such as methanol) and at 60% less aeration energy by taking equal parts of nitrite and ammonia to produce nitrogen gas. Anammox bacteria coexist with nitrifying bacteria in a relatively low DO environment.

The candidate vendors offer differing systems, all utilizing the slow-growing anammox bacteria, each having certain advantages and disadvantages. For this evaluation the moving-bed bio reactor (MBBR) style, marketed as Anita-Mox by Veolia, was selected as the best technology due to robustness and operational simplicity. Certain design considerations are listed in Table 3-8.

Technical Memorandum – Tomahawk Wastewater Treatment Facility expansion - June 2016

ANITA™ Mox Testimonial - LA County Sanitation District

SANITATION DISTRICTS OF LOS ANGELES COUNTY

Converting Waste Into Resources

"We tested both the MBBR version and the IFAS version of the ANITA Mox process. I was very impressed by the performance of the system. It was **easy to control, robust, and did what we expected it to do**. We're currently pilot testing the MBBR version at another plant (Valencia, 15 MGD). When we started a couple of weeks ago, there was a problem with the pipe feeding the pilot system. The pipe was clogged over the weekend, but the compressor continued to operate. Consequently the system got over-aerated (DO>9 mg/L) and the pH was down to ~5.5 when we came back on Monday. Once we fixed the problem, **the system quickly responded and started removing N** (I guess it was an unplanned robustness test). After one week of operation, we've observed **very high volumetric and surface N removal rates.** "

– Chi-Chung Tang, LACWSD

ANITA™ Mox Testimonial - MWRD (Denver, CO)

- “The pilot-scale evaluation of the ANITA Mox MBBR technology at the RWHTF supported the conclusion that performance of the continuous flow deammonification process was **compact, consistent, and reliable.**”

- “The **aeration control strategy** used for operating the pilot system **was straightforward and simple to operate**.”

- “The pilot system **was able to recover in about two days after an extended interruption to aeration and feed**.”

- – from *Evaluation of the Anita-Mox Moving Bed Biofilm Reactor Process for Sidestream Deammonification at the Robert W. Hite Treatment Facility, Denver Colorado* by Hollowed, Meg, et al.

METRO WASTEWATER RECLAMATION DISTRICT

Resourcing the world

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processes

MDPI

Article

Lessons Learned from 10 Years of ANITA Mox for Sidestream Treatment

Romain Lemaire [1] and Magnus Christensson [2,*]

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Abstract: When a wastewater treatment plant (WWTP) uses anaerobic digestion (AD) on its sludge treatment line, the opportunity to install a sidestream deammonification process for the cost-effective removal of the N-rich reject water load generated by the sludge digester should be considered. In this context, the ANITA™ Mox process based on the moving bed biofilm reactor (MBBR) technology has been implemented at more than 30 full-scale facilities over the last 10 years to treat reject water from conventional AD or after thermal hydrolysis process (THP) to reduce the N-load and associated treatment costs on the WWTP. This paper reviews the lessons learned in the implementation of the ANITA™ Mox process at several WWTP in the US, Europe, and Australia.

Keywords: anammox; deammonification; IFAS; MBBR; nitrogen removal; return of experience; THP

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1. Introduction

As populations grow, it is important for municipal wastewater treatment plants (WWTPs) to identify cost-effective methods to manage total nitrogen (TN) levels and meet their environmental obligations. Untreated reject water from anaerobic digestion leads to 10–20% additional TN and ammonium load to the main treatment process in a WWTP. This leads to extra cost for (i) infrastructure (tank volume, equipment), (ii) chemicals such as external carbon source addition to increase denitrification capacity, and (iii) energy due to higher aeration capacity for nitrification [1]. With infrastructure delivery costs also increasing, there is also a focus on finding the lowest cost solutions for the greatest benefit.

In addition, many utilities are now looking beyond conventional anaerobic digestion (AD) to increase methane production and further reduce the volume of final biosolids and associated costs. Thermal Hydrolysis Process (THP) is one of the processes being considered to achieve these outcomes [2]. THP pre-treatment also allows reducing considerably the size of the downstream digester due to the lower viscosity of hydrolysed sludge. The downside of all these benefits, return sidestream from a THP + AD sludge treatment, can generate up to 30% additional N-load to the WWTP and produce intermediate inhibitory compounds [3,4]. Therefore, a sidestream treatment process installed today for the dedicated treatment of conventional anaerobic digester reject water should consider the possibility that THP may be installed in the future, leading to higher N-load to be treated and a specific process operation strategy to overcome the toxicity of THP.

Sidestream deammonification processes using anaerobic ammonium oxidation (Anammox) bacteria are now widely implemented to treat the N-load generated by the sludge treatment line in a very cost-effective manner. Due to the slow growth rate of anammox bacteria, long sludge ages have to be maintained, making biofilm systems a robust technology to perform deammonification. Ammonium Oxidising Bacteria (AOB) and anammox bacteria are maintained in a biofilm on moving carriers with no risk of biomass wash-out [5]. Moving bed biofilm reactor (MBBR) systems are less sensitive to high total suspended solids (TSS) level surges in the reject water inherent to the operation of dewatering units at all WWTPs, as incoming TSS can simply pass through the MBBR in most cases without impacting the anammox biomass safely retained on the biofilm carrier.

In this context, the ANITA™ Mox technology has been implemented at more than 30 full-scale facilities over the last 10 years to treat reject water from conventional AD or after THP. It is a one-stage MBBR deammonification process where partial nitrification to nitrite (i.e., nitritation) and autotrophic N-removal (i.e., anammox) occur simultaneously within the biofilm [6] (Figure 1). Aerobic and anoxic zones reside adjacent to each other due to the oxygen mass transfer limitation under limited and controlled bulk dissolved oxygen (DO) concentration. AOB oxidise ammonium (NH_4) to nitrite (NO_2) in the aerobic zone of the biofilm (i.e., outer part), while anammox bacteria located in the anoxic zone of the biofilm (i.e., inner part) consume NO_2 produced by AOB together with the residual NH_4 (Figure 1). The use of high-surface-area AnoxK^{TM}5 carrier material allows for compact design and simple process operation with maximal biomass retention security [7].

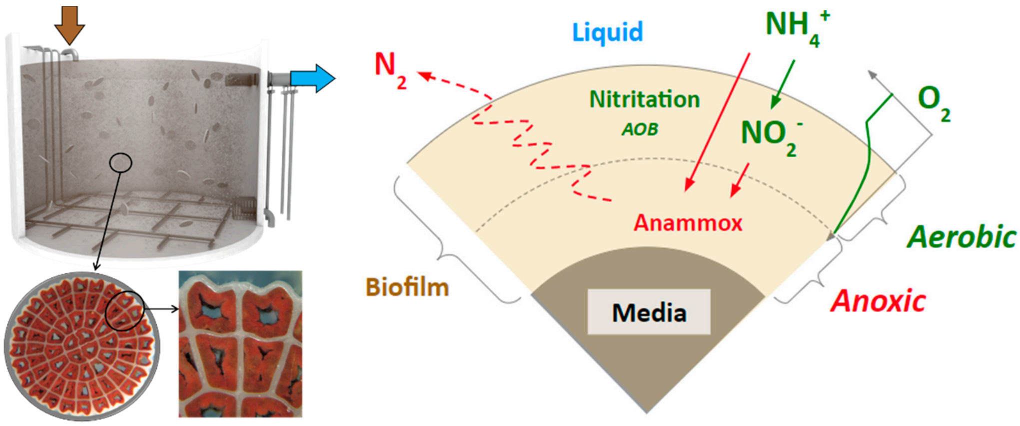

Figure 1. Biological mechanisms occurring in the biofilm of the AnoxK^{TM}5 carriers of the ANITA^{TM} Mox MBBR process.

This paper reviews the lessons learned in the implementation of the ANITA™ Mox process at several WWTP in the US and more recently in Australia for conventional AD sidestream treatment using MBBR configuration and in Europe for THP + AD application using the more adapted integrated fixed-film activated sludge (IFAS) configuration. Table 1 summarises the different ANITA Mox case studies that will be presented in more detail in this paper.

Table 1. ANITA Mox case studies treating conventional AD or THP + AD centrate presented in this paper.

Name	Flow WWTP (MLD)	Type of Centrate	Design Load (Kgn/D)	Design Flow (M^3/D)	Design NH_4 Level (Mgn/L)	ANITA Mox Config.	Start-Up Year
James River (US)	76	AD	250	280	900	MBBR	2014
South Durham (US)	20	AD	300	300	1000	MBBR	2015
Egan (US)	30	AD	940	860	1100	MBBR	2016
Denver (US)	850	AD	4000	3400	1200	MBBR	2017
Luggage Point (AU)	130	AD	975	1000	975	MBBR	2021
Växjö (SE)	20	THP + AD	430	300	1400	IFAS	2011
FiveFords (UK)	26	THP + AD *	850	425	2000	IFAS	2019
Toulouse (FR)	160	THP + AD	1800	1000	1800	IFAS	2020

* FiveFords THP + AD unit is designed to treat external sludge in addition to that produced by the plant itself.

2. Lessons Learned from Treating Conventional Reject Water

2.1. James River, VA: 1st ANITA Mox in the US

The Hampton Roads Sanitation District (HRSD) installed the 1st ANITA Mox in the US at its James River Wastewater Treatment Plant treating 76,000 m^3/d (76 MLD) in Newport News, VA. An existing pre-aeration tank was retrofitted to install the ANITA Mox process. Centrate design flow is 280 m^3/d with a NH_4 load of 250 kgN/d at a concentration of 900 mgN/L. The warm centrate temperature after anaerobic digester (30–35 °C based on buffer tank size and tank/pipe insulation) means that no heating device is usually required to keep the optimum design temperature of 30 °C in the ANITA Mox reactor. The process started in December 2013 with 10% of the total media volume supplied with pre-colonised biofilm from an established ANITA Mox located in Malmö, Sweden. This 1st ANITA Mox plant in Sweden was used as a "Biofarm" to provide seed media with pre-colonised Anammox biofilm to reduce the start-up time of new ANITA Mox plants (typically 5–15% of total media volume). Anammox activity was detected on the virgin media 3 months after seeding.

Ref. [8] reported that 4 months after seeding, the ANITA Mox reactor was achieving more than 85% NH_4 removal at design load condition (Figure 2). During the 1-month performance test done in May 2014, the maximum NH_4 load applied to the system was 375 kgN/d (50% more than design load) and the average NH_4 removal rate was 90% (83% TIN = NH_4 + NO_3 + NO_2 removal). The average NH_4 level in the outlet was 100 mgN/L.

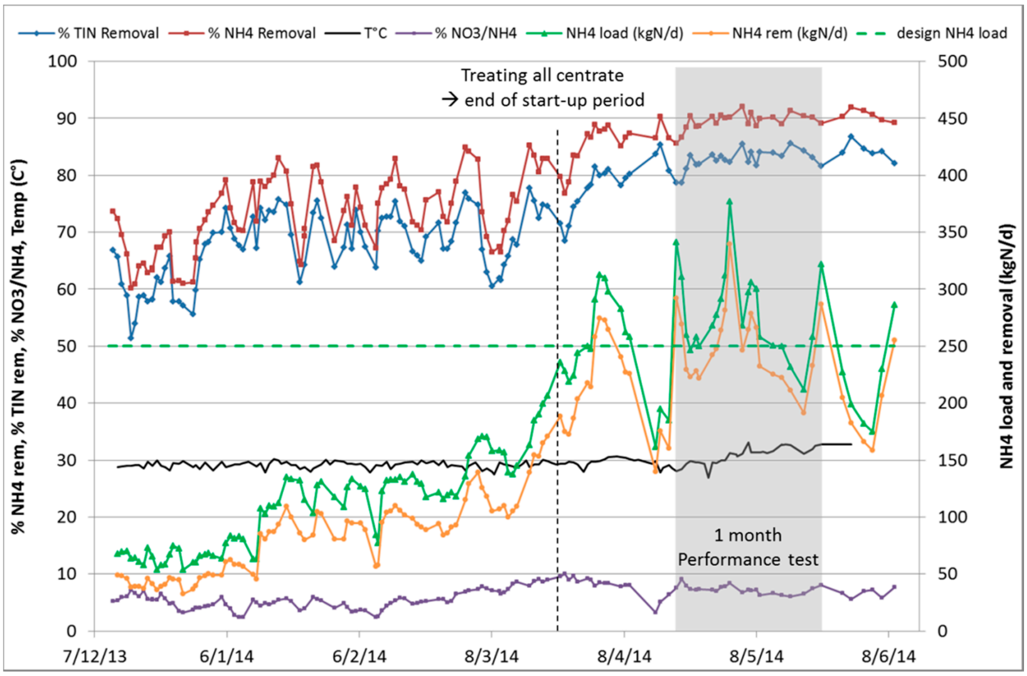

Figure 2. ANITA Mox start-up performance adapted from [8]. TIN (Total Inorganic Nitrogen) = NH_4 + NO_3 + NO_2.

2.2. South Durham, NC: Most Cost-Effective Solution

The City of Durham, NC in the US completed a comprehensive wastewater master plan that evaluated different treatment techniques for meeting strict total nitrogen limits (TN < 3 mgN/L) at the South Durham Water Reclamation Facility (SDWRF). The city studied mainstream and sidestream treatment alternatives to meet its TN limits considering both capital and operating costs. ANITA Mox was estimated to cost $2.1/kg N-removed, while the most cost-effective mainstream biological nutrient removal (BNR) solution was estimated at $5.9/kg N-removed [9]. Thus, the city selected ANITA Mox to meet its strict effluent nitrogen limits using the most cost-effective solution.

The ANITA Mox design consists of two identical and parallel MBBR reactors that were retrofitted in sludge aeration basins that were no longer in use. Filtrate design flow is 300 m^3/d with a NH_4 load of 300 kgN/d at a concentration of 1000 mg/L. The minimum design temperature is 24 °C due to the lack of insulation and large buffer tank size. The process started in August 2015 with 7% of seed media coming from the James River plant (Figure 3). The system was treating the full centrate load by Nov 2015 and achieved greater than 80% NH_4 removal and 70% TN removal, both exceeding guaranteed values. Hollowed et al. 2018 describes a few imbalance process events that occurred at the plant such as short-term nitrate (NO_3) accumulation due to higher activity of Nitrite Oxidising Bacteria (NOB) or NH_4 accumulation from uneven feed flow between the two parallel tanks. Each time, these process disturbances were quickly fixed through better process control of the aeration and centrate feed flow to the reactors, demonstrating the robustness of the ANITA Mox system.

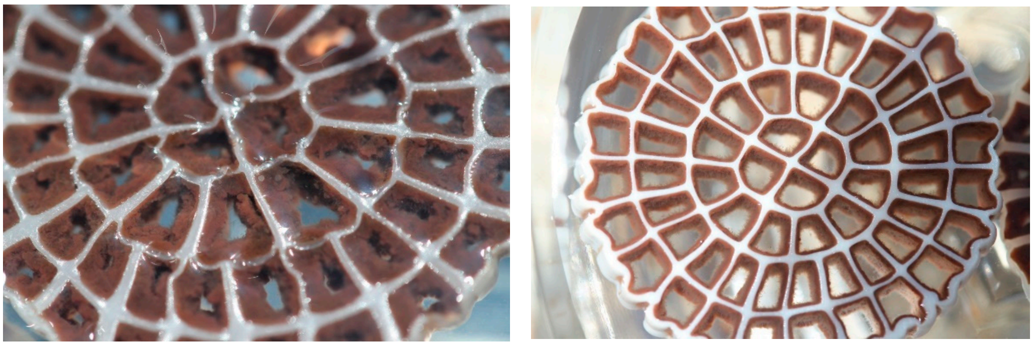

Figure 3. Photo of AnoxK^{TM}5 carriers 1 year after start-up (**left**: "seed" carrier, **right**: "virgin" carrier).

2.3. Egan, IL: Robust Performance under Variable Flow

The Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) installed the ANITA Mox system at its Egan Water Reclamation Plant in Schaumburg, IL. Existing, unused dissolved air flotation (DAF) thickening tanks were converted into one equalisation tank and four identical, parallel ANITA Mox reactors. Centrate design flow is 860 m^3/d with a NH_4 load of 940 kgN/d at a concentration of 1100 mg/L. The minimum design temperature is 27.5 °C without any heating device.

The process started in August 2016 with 10% of seed media coming from the James River plant. Experiences during the startup phase are summarised in [10] and include extended periods (10 months) of limited centrate availability due to maintenance/revamping work on the sludge line and alkalinity limitation. Egan reactors each receive similar flow through gravitational distribution via the weir box. Minor adjustments in aeration setpoints between the reactors are sufficient to keep them operating with similar performance.

As shown in Figure 4, after the 10 months of limited centrate availability, the ANITA Mox reached the design load in less than 3 months. A 90-day performance test was performed from April to June 2018. The average NH_4 load during that period was 75% of design load but with periods reaching 120% of design load based on centrate availability. The limited size of the centrate equalisation tank did not allow the process to be fed continuously during weekends when centrifuges were off, meaning that during the weekdays, the load and flow were often higher than design values [11]. Despite this large flow variation, average NH_4 and TIN removal efficiency were 89% and 81%, respectively with some fluctuation observed between the low load periods (higher removal efficiency >90%) and the high load periods often exceeding the design load (lower removal efficiency around 80%). Average NH_4 levels in the centrate and in the ANITA Mox outlet were 1230 mgN/L and 140 mgN/L, respectively.

2.4. Denver, CO: Largest ANITA Mox to Date

The Metropolitan Water Reclamation District (MWRD) in Denver, CO USA, installed the largest ANITA Mox plant to date at its Robert W. Hite Water Reclamation Facility (850 MLD) by converting an existing return activated sludge (RAS) reaeration basin into two parallel ANITA Mox MBBR reactors (Figure 5). The centrate design flow is 3400 m^3/d with a NH_4 load of 4000 kgN/d at a concentration of 1200 mgN/L. The process started in August 2017 with 5% of seed media coming from US and Europe ANITA Mox plants. As seen in Figure 6, it took only 13 weeks to reach the full design load, while starting with only 5% of seed media.

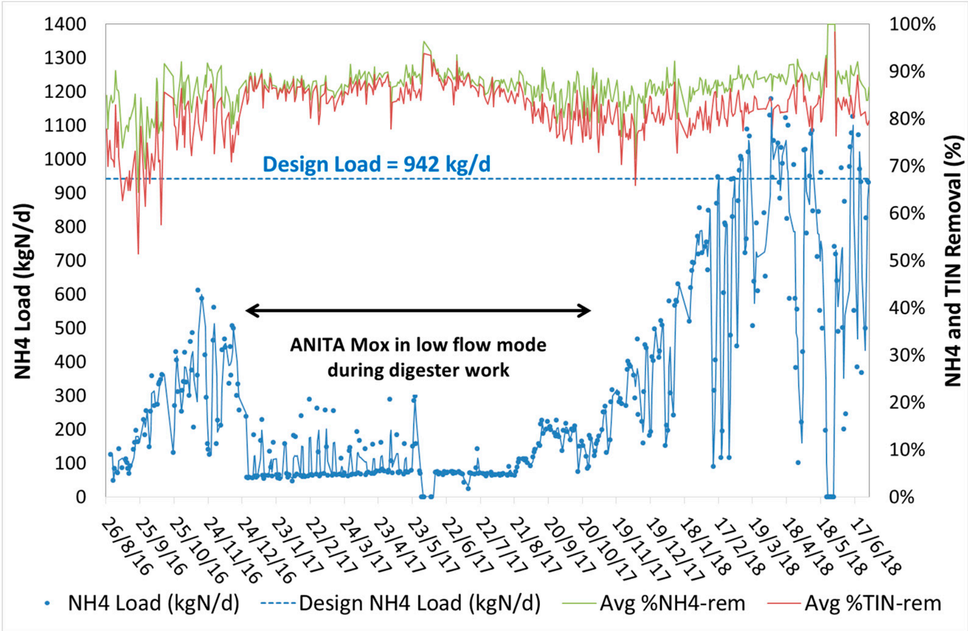

Figure 4. NH_4 load, NH_4, and TIN removal efficiency.

Figure 5. Photo of the ANITA Mox reactor in Denver retrofitted into an existing RAS reaeration tank.

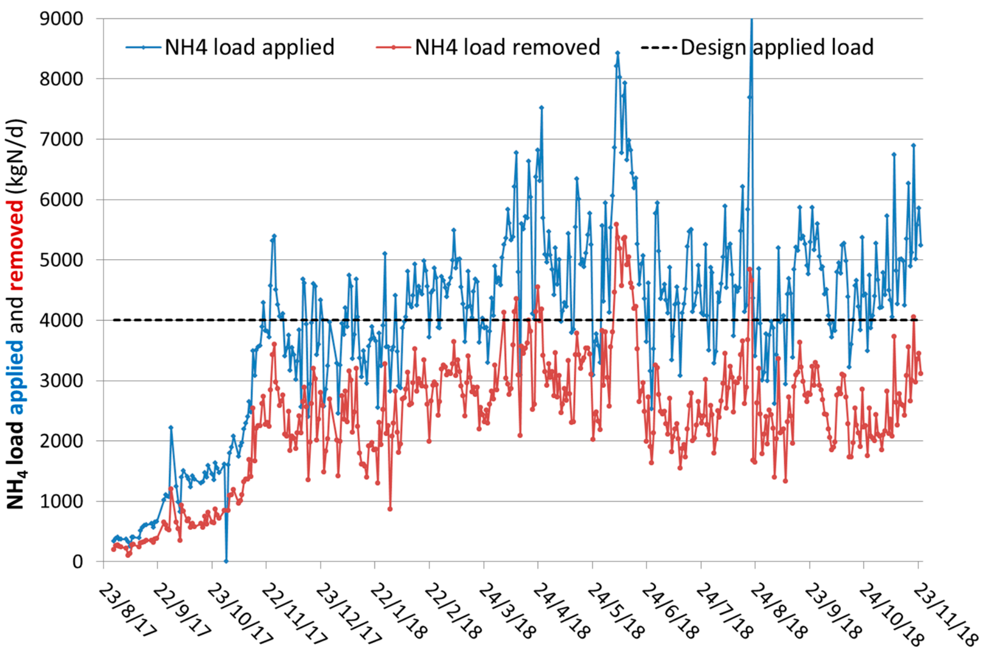

Figure 6. NH_4 load applied and removed (in kgN/d) at Denver since start-up of the ANITA Mox.

Experiences during this startup include instances of loading over design, variable flow, high polymer residual, and high TSS spikes. The ANITA Mox was very resilient to all of these disturbances thanks to the robustness of the MBBR system and its complete anammox biofilm retention feature. The goal of MWRD is to load the ANITA Mox to its maximum capacity (consistently above design load by 20–50%) targeting a residual NH_4 level between 200 and 300 mgN/L. It results in a lower NH_4 removal efficiency (65–75% instead of >85%) but allows them not to dose any extra alkalinity despite being limited in their centrate. Then, the ANITA Mox outlet is polished in remaining RAS reaeration basins.

2.5. Brisbane: 1st Anammox Plant in Australia

The Anammox journey in Australia began in 2014 for Queensland Urban Utilities (QUU) and Veolia at QUU innovation centre located at Luggage Point WWTP in Brisbane. Starting with only 10 L of homegrown Anammox seed media provided by the University of Queensland, QUU and Veolia decided to carefully grow these precious bacteria, as biomass importation from overseas is not allowed to Australia, in order to have sufficient biomass to perform a 6 m^3 pilot trial. After several years of piloting, Urban Utilities decided to move to a full-scale sidestream anammox process for the Luggage point WWTP. The decision was based on the following required outcomes for Urban Utilities:

- Reduce OPEX cost associated with nitrogen removal in their WWTP (methanol to reach TN < 5 mg/L).
- Reduce the cost of delivery by retrofitting existing infrastructure.
- Be a leader in implementation of new technology in Australia with positive environmental outcomes.

ANITA™ Mox technology was selected as the media-based process, since it allowed easy retrofit into existing process tanks, and also, the process had proved itself to be very stable in extreme fluctuation of centrate feed conditions and quality during the pilot trial period: including power outage, feed stoppages, polymer overdose, high TSS in feed.

To proceed with this implementation at full scale, a larger amount of seed media was needed than available in the 6 m^3 pilot plant. To grow this seed media, QUU installed a small 12 m^3 biofarm tank at their innovation centre in 2017, and Veolia later installed a larger 50 m^3 biofarm tank in 2019 (Figure 7). The enrichment process took approximately 8 months to establish the seed required for the full-scale treatment process. In parallel, Urban Utilities and Veolia embarked on the process of upgrading four unused process tanks at the Luggage Point WWTP to accommodate the new full-scale sidestream deammonification process.

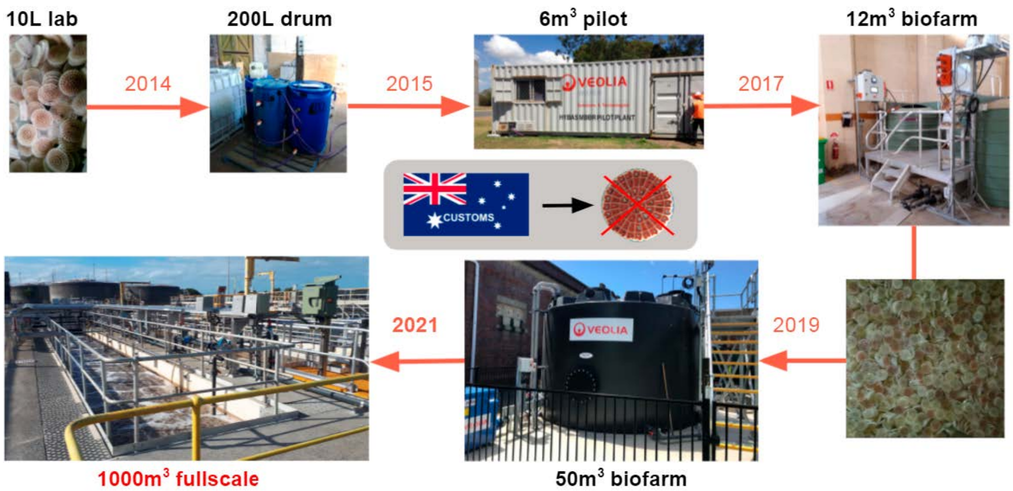

Figure 7. Scale-up journey to grow anammox bacteria locally for 1st ANITA Mox in Australia.

At the time of writing this paper (April 2021), the new sidestream tanks have been successfully retrofitted and commissioned with the seed media from the 50 m^3 biofarm, treating approximately 60% of the design flow. Once fully operational, the ANITA Mox sidestream process at Luggage point will be treating up to 1000 m^3/d of centrate with a design load of 975 kgN/d. Urban Utilities and Veolia will be operating these tanks as a biofarm as well as an integral part of the treatment process at Luggage Point. This means anammox seed in sufficient quantities will be easily available for other Australian Utilities considering ANITA Mox for their own WWTP upgrades.

3. Lessons Learned from Treating THP Centrate

When THP is introduced into the sludge treatment process, not only ammonia and soluble COD concentration increase, but also intermediate inhibitory compounds that typically require dilution of the centrate to maintain high removal performance. For this application, the IFAS configuration of ANITA™ Mox (Figure 8) has proven to be more robust than the MBBR configuration due to the buffering capacity of the heterotrophs and the increased amount of AOB in the mixed liquor suspended solids (MLSS), whereas the anammox bacteria are safely retained on the media [12,13]. Today, there are seven ANITA Mox units treating THP centrate: Växjö (Sweden), Grindsted (Denmark), FiveFords (UK), Toulouse (France) that are in operation, Osberstown (Ireland) under commissioning, and Ljubjlana (Slovenia) and Piscataway (US) that are under construction.

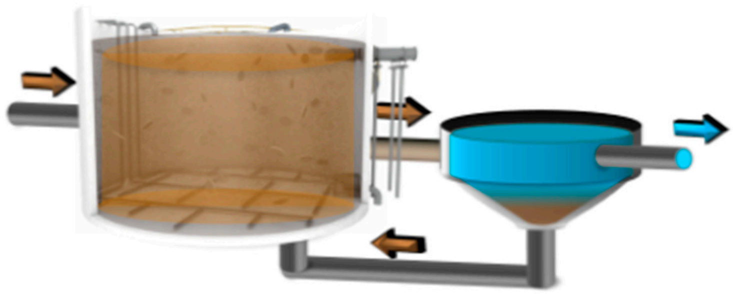

Figure 8. IFAS ANITA Mox configuration.

3.1. Växjö (Sweden): 1st Anammox THP Fullscale Plant

In 2011, Sundet WWTP located in Växjö, Sweden, installed the ANITA Mox process for sidestream management. The facility has a capacity of 95,000 population equivalent (PE) with an average daily flow of 20,000 m^3/d and discharges to nutrient-sensitive lakes around Växjö. At the time of initial startup, the system was processing filtrate from conventional anaerobically digested biosolids, native to the facility. The ANITA Mox system, operated in the MBBR configuration, was retrofitted within an existing SBR reactor. The existing fine bubble diffusers were retained in the reactor and the tank was filled with 45% of AnoxK™5 media.

In 2014–2015, the facility installed a THP upstream of the existing digesters in anticipation of an increasing solids load to the digesters in the form of source-separated household food waste and an increasing sludge volume from the existing plant. With the addition of THP, the plant is able to handle the increasing amounts of sludge and food waste using the existing digesters without the need for new digesters. In spite of higher strength filtrate, the ANITA Mox system was still able to treat all of the filtrate produced with the addition of dilution water; however, there were concerns regarding the stability of the process and the volume of dilution water being used why it was decided to upgrade to an IFAS configuration. An external stainless-steel settler was installed in May 2018, allowing the process to be operated as an IFAS. At design flows, the overflow velocity of the clarifier is 1.5 m/h. The ANITA Mox system was designed to treat an initial NH_4 load of 320 kgN/d, with the ability to treat up to 300 m^3/d of filtrate at 1400 mg N/L (corresponding to 430 kgN/d). The system should provide NH_4 and TN removal efficiency greater than 75% and 65% respectively.

Prior to THP, the MBBR ANITA Mox was receiving an average NH_4 load of 140 kgN/d and the performance of the system was, on average, 90% NH_4 and 83% TN removal. The ratio of NO_3 produced to NH_4 removed was typically less than 11% and averaged 8%, overall (Figure 9).

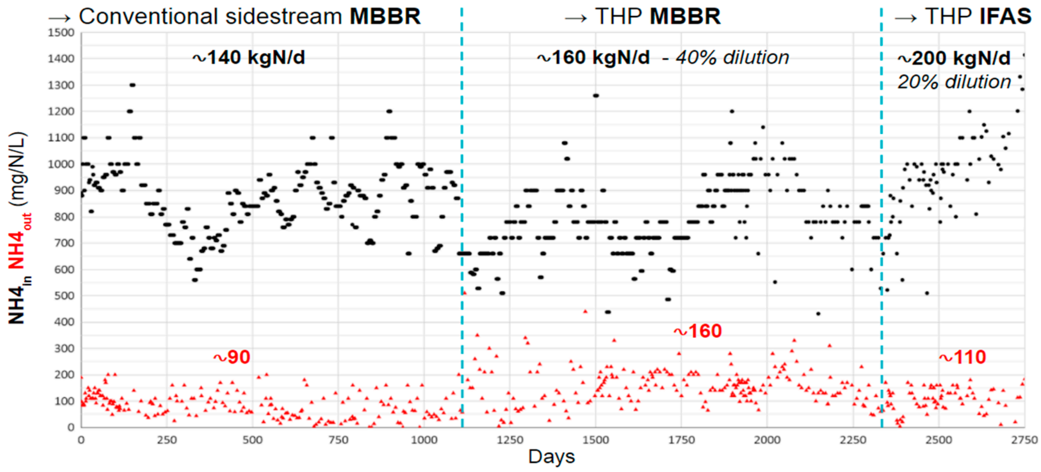

Figure 9. NH_4 concentration in the inlet and outlet of the ANITA Mox in Växjö.

After the installation of the THP process, and before the conversion of the ANITA Mox from MBBR to IFAS, the filtrate required dilution to minimise the inhibitory effects of recalcitrant COD and N compounds generated by the THP. The average ratio of dilution water to total flow during that period was 40%. The average influent NH_4 was 900 mgN/L and the NH_4 load was 160 kgN/d. The performance of the MBBR system was 85% NH_4 and 77% TN removal (Figure 9).

After converting the ANITA Mox to its IFAS configuration, the NH_4 load to the system increased to an average of 200 kgN/d, and the plant was able to treat the filtrate with less dilution water (20% on average), resulting in NH_4 concentration up to 1300 mgN/L. Results from operation in the IFAS configuration shows NH_4 and TN removal of 89% and 83%, with only 6% NO_3 production (Figure 9).

3.2. *Wrexham (UK): 1st IFAS ANITA Mox for THP*

Welsh Water decided to install a sludge treatment platform next to their FiveFords WWTP in Wrexham, UK. This new THP + AD sludge platform receives sludge from all over the region. To reduce the NH_4 load returned to the nearby WWTP, an IFAS ANITA Mox was included in the overall sludge upgrade work by Mott MacDonald Bentley (MMB). The sludge platform is designed to treat 53 tDS/d producing a NH_4 load in the final centrate of 850 kgN/d with a design flow of 425 m^3/d and a concentration of 2000 mgN/L. The ANITA Mox IFAS system at Wrexham was the 1st deammonification plant built by MMB (Figure 10). The process was initially supposed to be started up using existing conventional AD centrate while the new THP unit was getting constructed and then gradually increase the THP fraction in the centrate. Due to a change of construction planning, the ANITA Mox was started after the THP upgrade works using full-strength THP centrate straight from the beginning. Therefore, the quantity of seed media was increased from 10% originally to a total of 25% with a second addition occurring 3 months after the first one. This was necessary as the change in commissioning plan resulted in the centrate design load being available more rapidly than foreseen initially.

Figure 10. New IFAS ANITA Mox reactor at Wrexham (**left**: IFAS tank, **right**: clarifier).

After adjusting the IFAS operation to balance the high AOB activity in the MLSS to the growing but limited Anammox activity on the media, it was observed that the alkalinity of the centrate was often limiting, resulting in unstable and more challenging operation. Therefore, it was decided to better control the NH_4 removed and final NH_4 concentration in the outlet to avoid being alkalinity limited. The instrumentation for NH_4 on-line measurement was changed from ISE sensor to an analyser after filtration (FILTRAX and AMTAX units from HACH) to improve the accuracy of the measurement in this challenging THP matrix. Then, aeration of the ANITA Mox was controlled based on a target NH_4 value in the outlet to prevent alkalinity limitation and stabilise the operation. The drops in NH_4 removal efficiency from 85% to 80% around Day 380 and then to 75% on Day 440 observed in Figure 11 were the results of action taken to operate at a higher NH_4 level in the IFAS to save on alkalinity and avoid dosing caustic to the system.

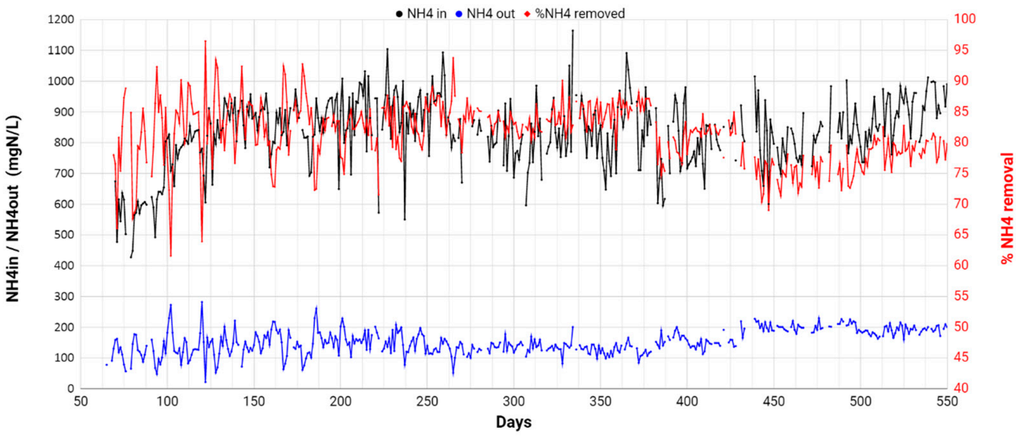

Figure 11. NH_4 level in the inlet and outlet of the ANITA Mox at Wrexham and percentage of NH_4 removed.

Despite a longer start-up time to reach full design load, the IFAS ANITA Mox at Wrexham is successfully treating all the THP centrate produced by the new sludge platform (Figure 12). The anammox activity on both the seed and initial virgin media has been monitored during the entire period through ex situ laboratory batch test and microbial analysis (quantitative polymerase chain reaction—qPCR) by Veolia Research and Innovation team in Paris and AnoxKaldnes process experts in Sweden providing robust evidence that the biofilm colonisation by Anammox in the IFAS ANITA Mox process at Wrexham was always progressing in the right direction. This comprehensive technical and scientific support was key to overcome some of the challenges encountered during the start-up.

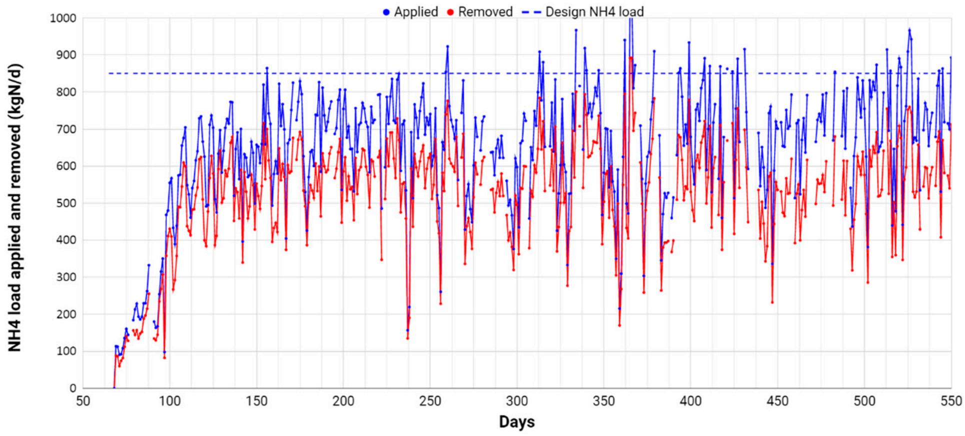

Figure 12. NH_4 load applied and removed (kgN/d) at the ANITA Mox in FiveFords.

3.3. Toulouse (France): Largest IFAS ANITA Mox

Toulouse Metropole decided to upgrade the sludge treatment line at the Ginestous WWTP (1M PE). The new sludge line is composed of BioThelys^{TM} THP, two large anaerobic digesters of 6000 m^3 each, and a MemGas^{TM} biomethane purification unit to produce 56 GWh/year that will be reinjected into the city natural gas grid. For the cost-effective removal of the NH_4 load returned to the WWTP, an IFAS ANITA Mox is treating all the centrate generated by the THP and AD. Figure 13 shows a 3D illustration of the new sludge treatment line with the IFAS ANITA Mox highlighted in red. The new sludge line is still under the final commissioning stage but is already treating all the sludge produced by the plant today, approximately 45 tDS/d for a design load of 73 tDS/d in 2035. The IFAS ANITA Mox is designed to treat a NH_4 load of 1800 kgN/d with a centrate flow of 1000 m^3/d in 2035. Today, it is already treating all the centrate produced by the THP + digester (approximately 900 m^3/d corresponding to 800–1000 kgN/d) despite having been seeded with only 8% of pre-colonised Anammox media.

Figure 13. Three-dimensional (3D) drawing of the THP + AD sludge treatment extension project in Toulouse and photo of the IFAS ANITA Mox unit.

4. Lessons Learned with Operation Control Strategy

Experiences show that the deammonification systems have some challenges during their start-up phase and their operation. Reported challenges are mainly due to the slow growth rate of the anammox bacteria, the complex interactions between different groups of microorganisms, and these microorganisms being sensitive to inhibition [14]. There is a need for a safe operation strategy to overcome such challenges. Known operation strategies require reliable on-line sensors and acute attention from the operator. When the operation strategy mostly relies on the operator's attention, it is very likely to have disturbances in operation during the absence of a dedicated operator. Considering the entire operation period and the long start-up phase of such processes, a lot of man-hours are needed for process control.

The control strategy of the ANITA Mox was developed to have not only safe but also optimised operation in a less operator-dependent way. Veolia's digital offering Hubgrade Performance Plant provides process optimisation and long-term stability in operation. The Hubgrade Performance Plant is a cloud-based holistic service for real-time optimisation of the process performance. This digital solution calculates set points for blowers and feed pumps using operational data from the on-line sensors and algorithms built in the features. This allows adjustment of aeration flow into the reactor and feed flow rate to optimal levels, thus providing a state-of-the-art autopilot to optimize the whole treatment process.

Overall, the ANITA Mox operation with Hubgrade Performance Plant provides an automated real-time performance optimisation, remote monitoring of operation via a user interface, stable optimal conditions 24/7 and maximal utilisation of all the ANITA Mox benefits.

Nitrous oxide (N_2O) emissions from sidestream deammonification processes have been often linked to specific operation control strategies employed by the different technologies such as feeding regime (continuous vs. batch), aeration control (continuous vs. intermittent), and substrate concentration gradient in the reactor [15,16]. Ref. [15] reported N_2O emission from a full-scale granular sequencing batch reactor (SBR) deammonification unit at Ejby Mølle WWTP in Denmark in the range of 4–8% of incoming N-load under standard intermittent aeration control. The N_2O emission was divided by half (2–4% of N-load) when the granular SBR was operated under a new continuous aeration strategy. Similar observation was made by [16] comparing N_2O emission of a full-scale sidestream SBR operated in nitrification/denitrification (N/DN) mode at Slottshagen WWTP in Sweden to that of a deammonification MBBR unit replacing the existing SBR for reject water treatment. While the N_2O emission of the N/DN SBR was averaging 10% of incoming N-load, it was reduced to an average of 0.1–0.7% of incoming N-load for the deammonification MBBR operated under continuous feed and continuous aeration. The N_2O emission measurement campaign at the ANITA Mox MBBR at Växjö was performed in 2012 [6], and average N_2O emissions of 0.2–0.8% of incoming N-load were reported with very low N_2O emission during stable operation (0.04–0.16%) and higher emission (up to 1%) when the centrate feed was not continuous, triggering the aeration to stop in the reactor until centrate was made available again at the plant. Therefore, N_2O emission from MBBR-based ANITA Mox is significantly lower than from other sidestream deammonication systems due to its continuous feed and continuous aeration feature. Operation with the Hubgrade Performance Plant system provides further optimisation of the N_2O emission by offering more stable operation in term of feed regime and aeration control.

5. Conclusions

With more than 30 references installed over the last ten years, the Veolia experience with Anammox has been a positive and passionate journey. With consistent good performance for NH_4 and TN removal at WWTPs combined with the added benefits of reduced OPEX for the overall WWTP, ANITA Mox has proven itself as a viable, robust, and sustainable process that can be considered for the treatment of reject water from conventional AD or after THP. With biofarms now available in Europe, the US, and Australia, this unique and exciting process can be easily installed at other WWTPs. Daily operation of such anammox systems can be improved through the use of digital advanced control system providing continuous process optimisation and stability during start-up and long-term operation.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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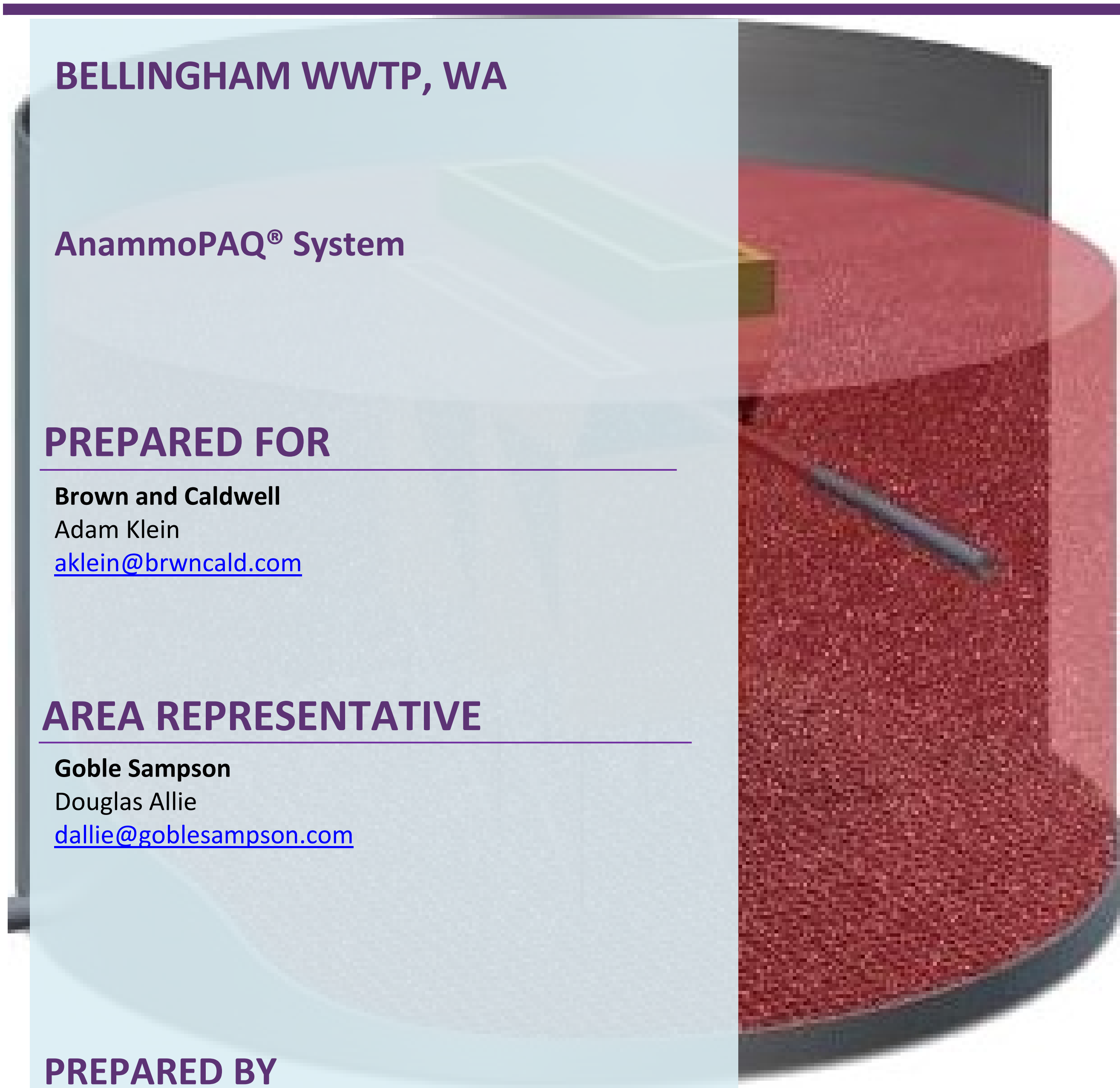
Conflicts of Interest: The authors declare no conflict of interest.

References

1. Barber, W. Thermal hydrolysis for sewage treatment: A critical review. *Water Res.* **2016**, *104*, 53–71. [CrossRef]
2. Bilyk, K.; Khunjar, W.; Latimer, R.; Galst, S.; Drummey, T.; Hanna, A.; Wankmuller, D.; Pitt, P. Lessons learned from multiple sidestream deammonification projects. In Proceedings of the WEFTEC 2017, Chicago, IL, ISA, 30 September–4 October 2017.
3. Fidgore, B.; Bowden, G.; Stinson, B.; Wett, B.; Hell, M.; Bailey, W.; Carr, J.; Der Minassian, R.; Murthy, S. Treatment of Dewatering Sidestream from a Thermal Hydrolysis-Mesophilic Anaerobic Digestion Process with a Single-Sludge Deammonification Process. In Proceedings of the WEFTEC 2011, Miami, FL, USA, 15–19 October 2011.
4. Zhang, O.; Vlaeminck SDeBarbadillo, C.; Su, C.; Al-Omari, A.; Wett, B.; Pumpel, T.; Shaw, A.; Chandran, K.; Murthy, S.; De Clippeleir, H. Supernatant organics from anaerobic digestion after thermal hydrolysis cause direct and/or diffusional activity loss for nitritation and anammox. *Water Res.* **2018**, *143*, 270–281. [CrossRef]
5. Cema, G. Comparative Study on Different Anammox Systems. Ph.D. Thesis, KTH Stockholm, Stockholm, Sweden, 2009.
6. Christensson, M.; Ekström, S.; Andersson Chan, A.; Le Vaillant, E.; Lemaire, R. Experience from Start-up of the first ANITA Mox plants. *Water Sci. Technol.* **2013**, *67*, 2677–2684. [CrossRef]
7. Lemaire, R.; Thesing, G.; Christensson, M.; Zhao, H.; Liviano, I. Experience from Start-Up and Operation of Deammonification MBBR Plants, and Testing of a New Deammonification IFAS Configuration. In Proceedings of the WEFTEC 2013, Chicago, IL, USA, 5–9 October 2013.
8. Klaus, S.; Nifong, A.; Nelson, A.; Rutherford, B.; Baumler, R.; Bott, C. Recommendations and Lessons Learned from the Startup of the First two Fullscale Sidestream Deammonification Processes in North America: DEMON and ANITA mox. In Proceedings of theWEFTEC 2015, Chicago, IL, USA, 26–30 September 2015.
9. Bilyk, K.; Khunjar, W.; Pace, G.; Worley-Morse, T.; Cocker, C.; Lobdell, S.; Taylor, R.; Gasper, B.; Pitt, P. Lessons learned about deammonification from design, startup, and operation of an ANITA Mox system. In Proceedings of the WEF Nutrient Symposium, Fort Lauderdale, FL, USA, 12–14 June 2017.
10. Lai, K.; Hollowed, M.; Qin, C.; Storino, L.; Wawczak, B.; Brand, M.; Thesing, G. Start-up of Sidestream Deammonification at MWRDGC's John E. Egan Water Reclamation Plant. In Proceedings of the WEFTEC 2017, Chicago, IL, USA, 30 September–4 October 2017.
11. Hollowed, M.; Thesing, G.; Liang, S. Tale of Two Cities: Operation of Sidestream ANITA Mox. In Proceedings of the WEF Nutrient Removal and Recovery Conference, Raleigh, NC, USA, 18–21 June 2018.
12. Lemaire, R.; Veuillet, F.; Bausseron, A.; Chastrusse SMonnier, R.; Christensson, M.; Zhao HThomson, C.; Ochoa, J. ANITA Mox deammonification process for COD-rich and THP reject water. In Proceedings of the WEFTEC 2015, Chicago, IL, USA, 26–30 September 2015.
13. Hollowed, M.; Lemaire, R.; Graveleau, L.; Veuillet, F.; Christensson, M.; Nussbaum, B.; Zhao, H. IFAS ANITA™Mox Deammonification Process for Treating THP Reject Water: From Lab/Pilot Scale Development to Full Scale Implementation. In Proceedings of the WEF Nutrient Removal and Recovery Conference, Minneapolis, MN, USA, 23–25 July 2019.
14. Lackner, S.; Gilbert, M.E.; Vlaeminck, S.E.; Joss, A.; Horn, H.; van Loosdrecht, M.C.M. Full-scale partial nitritation/anammox experiences—An application survey. *Water Res.* **2014**, *55*, 292–303. [CrossRef]
15. Uri, N.; Eriksen, S.; Nielsen, P.; Andersen, M.; Hafner, S.; Li, Z.; Chandran, K. Continuous aeration control to reduce N_2O emissions in a full-scale sidestream deammonification reactor. In Proceedings of the WEFTEC 2017, Chicago, IL, USA, 30 September–4 October 2017.
16. Kanders, L.; Yang, J.J.; Baresel, C.; Zambrano, J. Full-scale comparison of N_2O emissions from SBR N/DN operation versus one-stage deammonification MBBR treating reject water—And optimization with pH set-point. *Water Sci. Technol.* **2019**, *79*, 1616–1625. [CrossRef] [PubMed]

PROPOSAL LETTER

PROPOSAL # 210727-1-MG-R0
AUGUST 2, 2021



BELLINGHAM WWTP, WA

AnammoPAQ® System

PREPARED FOR

Brown and Caldwell
Adam Klein
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AREA REPRESENTATIVE

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PREPARED BY

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Ovivo USA, LLC
2300 Greenhill Dr. Bldg. #1
Round Rock, Texas, 78664, USA

AUGUST 2, 2021

Attn: Adam Klein
Brown and Caldwell

Re: Bellingham WWTP, WA
Ovivo AnammoPAQ® System
Proposal No. 210727-1-MG-R0

Dear Mr. Klein,

With regard to your recent request for the Bellingham WWTP, WA Ovivo USA, LLC is pleased to submit this preliminary proposal for its AnammoPAQ® system. The system design is based on the influent high nitrogen stream at the Bellingham WWTP, WA having a design flow of 0.077 MGD to achieve approximately 85% Ammonia-N removal at a design temperature of 28 °C. The system will also be able to treat the Max 2-week scenario flow of 0.106 MGD to achieve 85% Ammonia-N removal.

Note that given the wide variation in flows and loads, our recommendation is to have slightly lower loading rated, two (2) reactors, each capable of treating the Average load of 1,020 lbsN/d but still capable of treating 1400 lbsN/d at peak loading. It is however recommended to have both reactors online during the one or two occasions annually when the loading rate reaches 1,400 lbsN/d. Notably both reactors together still have enough capacity to treat the Less Likely condition of 1,930 lbsN/d.

It is assumed that the dewatering will occur 24 hours a day and 7 days a week with AnammoPAQ® system operation 7 days a week. It is also assumed enough equalization will be provided (by others) and all equipment in the equalization tank including feed pumps will be by others.

We have endeavored to provide complete information in this proposal. However, if you have any questions or need additional information, please feel free to contact Doug, our regional sales representative, or me directly.

Sincerely,

Mudit Gangal
Product Manager
Biosolids Management and Resource Recovery
Ovivo USA, LLC
2300 Green Hill, Round Rock, Texas 78664
P: 512-834-6042 **C:** 512-590-0391 **F:** 512-834-6039

INTRODUCTION

The Bellingham WWTP, WA is in the process of evaluating technologies for treatment of its high Nitrogen content side-stream to reduce the Ammonia-N load to help meet its effluent permits in an efficient manner. The design flows and loads required to be treated by using the AnammoPAQ® treatment process to reduce the Ammonia-N concentration in the effluent stream being discharged to more acceptable limits are provided in Table 1 below.

BASIS OF DESIGN

The AnammoPAQ® system design and performance are based on the design information provided by Brown & Caldwell. Table 1 summarizes the parameters used for developing the proposed solution.

Table 1: Design Parameters

Treatment Parameter	Units	Influent Start-up	Influent Average	Influent Max-2 week	Influent Max-2 week (BNR)	Treated Effluent
Equalized Design Flow	MGD	0.052	0.0635	0.077	0.106	
Design Temperature	°C	28	28	28	28	
sCOD	mg/l	150	150	150	150	
BOD	mg/l	< 100	< 100	< 100	< 100	
TSS[1]	mg/l	500	500	500	500	
NH_3-N	mg/l	1,864	1,924	2,180	2,182	< 280 Start-up < 290 Average < 330 Max 2-week < 330 Max 2-week (BNR)
TKN[1]	mg/l	1,864	1,924	2,180	2,182	
Alkalinity	mg/l	5,000	5,000	5,000	5,000	
PO_4-P[3]	mg/l	200	200	200	200	

[1] Assumed
[2] Ammonia in effluent based on pre-dilution basis.
[3] Assumed to be removed up to < 75 mg/l

The design is based on the following assumption(s):
The influent flows are produced seven (7) days a week, twenty-four (24) hours a day.

The Bellingham WWTP, WA AnammoPAQ® system was designed using extensive modeling and experience from Ovivo's pilot and full-scale installations. The modeling assists in process selection and determining the optimal volumes for treatment and the overall process operating parameters.

OVIVO-PAQUES ANAMMOPAQ® EXPERIENCE

The Ovivo-Paques AnammoPAQ® system currently has over 62 operating nitrogen removal deammonification systems worldwide. Further, Ovivo's AnammoPAQ® installation base cumulatively treats globally Nitrogen loads in excess of 300,000 lbs N/d, which is second to none. This is estimated to be around 80% of all Ammonia-N load currently treated in engineered systems utilizing anammox bacteria worldwide.

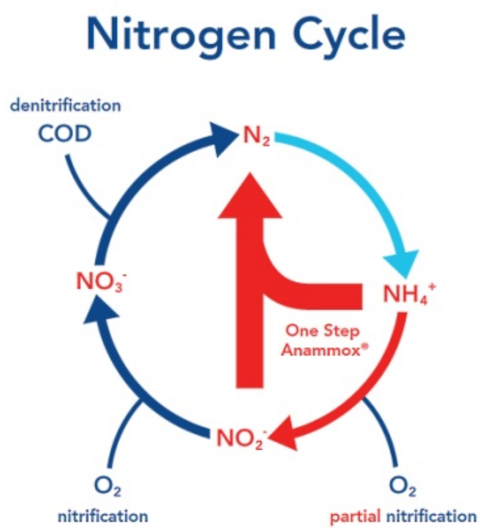
Figure:1 Modular AnammoPAQ® setup at Rendac, The Netherland (13,000 lds N/day)

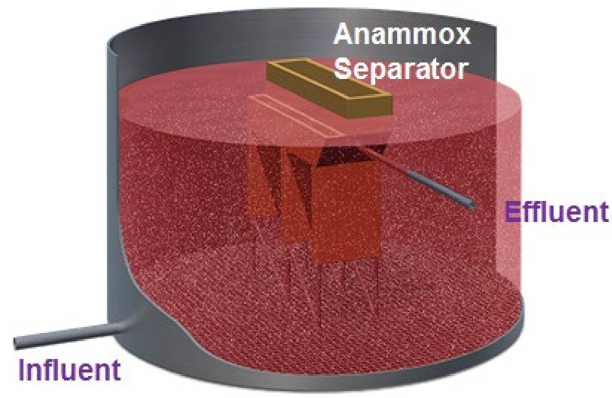
TREATMENT APPROACH

In the AnammoPAQ® reactor, ammonium is converted to nitrogen gas. The reaction is executed by two different bacteria, which coexist in the reactor. Ammonium oxidizing bacteria (AOB) oxidize about half of the ammonium to nitrite. Anammox bacteria then convert the remaining ammonium and nitrite, into nitrogen gas. The overall reaction of the one step AnammoPAQ® reactor is:

$$NH_4^+ + 0.85O_2 \rightarrow 0.45N_2 + 0.1NO_3^- + 1.1H^+$$

The deammonification conversion thus is an elegant shortcut in the natural nitrogen cycle. A key feature of the AnammoPAQ® system is that ammonium is removed from the reject water stream in one treatment step without the use of external carbon sources and with minimal energy input.





The AnammoPAQ® reactor is a continuously fed and aerated tank, equipped with Ovivo's patented biomass retention system. The aeration provides for rapid mixing of the influent with the reactor content, intense contact with the biomass and oxygen supply to drive the conversion. This process is based on granular biomass. The aeration is controlled in order to selectively convert ammonium to nitrogen gas. Around 10% of the ammonium is converted into nitrate. The treated wastewater leaves the reactor via the biomass retention system at the top of the reactor.

The granular biomass is separated from the cleaned wastewater, assuring high biomass content in the reactor. Together with the dense conversion properties typical for granular biomass, the high biomass content provides for high loading/conversion rates and therefore a small reactor volume.

AnammoPAQ® PROCESS ADVANTAGES

Main benefits of implementing the AnammoPAQ® system for Nitrogen removal are the significant savings on operational costs and environmental impact compared to conventional and alternative deammonification systems. These include:

- Aeration Energy Savings (over 60%)
- Elimination of external Carbon source (100% saving)
- Reduction in sludge production (up to 90%)
- Compact footprint
- High Loading Rates
- Reduction in CO2 emission
- Limited chemical consumption
- Fast start up due to inoculation with granular biomass
- Robust process: Tolerant to presence of toxic chemicals
- Ability to handle high suspended solids in influent

Anammox Granular Biomass

AnammoPAQ® PROCESS DESIGN

The system for the Bellingham WWTP, WA has been designed using proprietary models to perform process selection and to determine essential operating parameters.

A summary of the AnammoPAQ® system design is provided in Table 2. This table demonstrates the volumes required to achieve desired effluent Ammonia-N reduction, and provides associated process design details.

Table 2. Design Summary		
Treatment Parameter	Unit	Design
Equalized Design Flow	MGD	0.077
Total No. of AnammoPAQ® Reactors	#	2
Volume of AnammoPAQ® Reactors Required (each)	gallons	68,000
AnammoPAQ® Reactor Length	ft	21.3’
AnammoPAQ® Reactor Width	ft	21.3’
AnammoPAQ® Reactor SWD	ft	20’
Air Flow for AnammoPAQ® Reactors	scfm	750

* 0.0312 MGD Dilution water recommended for AnammoPAQ®

In addition to our System, Ovivo offers a mobile-based platform (Water Expert) allowing to reserve workforce's expertise by uploading media and procedures, access itemized OEM operator manuals for all of your Ovivo Installations, create and update service logs, maintenance schedules, performance alerts.

The Water Expert platform is unique in the industry and allows the end user to any new content in addition to getting instant access to expert support and monitor equipment performance with live data readings with any cellphone, tablet or PC. See the link below for additional information:
https://www.youtube.com/watch?v=qWvU6fjlypY&feature=youtu.be

SCOPE

SCOPE OF SUPPLY

The following table outlines the Ovivo AnammoPAQ® system scope of supply for the proposed project.

Scope of Supply		
Item	Qty	Description
1	2	AnammoPAQ® reactor <u>internals</u> (suitable for each 68,000-Gal tank – tank by others) • Type 10 Settler and support construction • Fine Bubble aeration system with fine bubble diffusers, basin piping for c/w drop legs, flanged diffuser pipes, mounting brackets and connection fasteners • Piping for aeration, influent, effluent, biomass sampling
2	2 (1+1)	Process Air Blowers for AnammoPAQ®; Capacity: 750 scfm each
3	Lot	Anammox granular biomass
4	Lot	Controls and Instrumentation (NH_4^+, NO_3^-, NO_2^-, DO, pH, T)
5	2	Sets of O&M Manuals
6	2	Sets of Detailed Shop Drawings
7	1	One (1) year subscription to WaterExpert™ System
8	20	Service Days, to inspect equipment installation, test all supplied components, assist in start-up and train plant personnel.

ITEMS BY OTHERS

The following items are specifically not by Ovivo. They may or may not be required.

Items Not Included	
Air Main Piping and all accessories including valves, bolts gaskets and connectors for attaching to drop pipes	Yard Hydrants
Chemical Feed Systems for alkalinity correction, magnesium oxide, nutrients, methanol and defoamer	Mixers
Chemicals for operation: Including methanol, nutrients, alkaline solution, defoamer	Motor Control Center (MCC)
Cleanouts	Non-potable water supply
Concrete	Overflow structures including baffles and weir plates
Drains	Power
Dryers	Dilution Water
Engines/Generators	Pre-treatment systems for deammonification system (e.g. influent TSS removal system, Phosphorus removal system and COD removal system)
Equalization Tank and equipment therein	Sludge handling and disposal
Foam control	Support Platforms
Hoses /Bibs	Tanks (and modifications to tankage – existing or new)
Influent/Feed Pumps	Transformers
Interconnecting Piping	Valves – Manual and Automatic
Laboratory	Variable Frequency Drives for blowers and pumps
Ladders (caged or other types) and Handrails	Ventilation
Lighting	Walkways/Roofing/Stairs/Gratings/Handrails
Liquid sampling and analytical work	Wireways/Wiring
Local control panels for blowers etc.	Yard Piping

ADDITIONAL ITEMS BY INSTALLING CONTRACTOR

1 Obtain necessary construction permits and licenses, construction drawings (including interconnecting piping drawings) field office space, telephone service, and temporary electrical service.

2 All site preparation, grading, locating foundation placement, excavation for foundation, underground piping, conduits and drains.

3 Demolition and/or removal of any existing structures, equipment or facilities required for construction and installation of the AnammoPAQ® system.

4 Installation of all foundation - supply and installation of all embedded or underground piping, conduits and drains.

5 All backfill, compaction, finish grading, earthwork and final paving.

6 Receiving (preparation of receiving reports), unloading, storage, maintenance preservation and protection of all equipment and materials supplied by Ovivo.

7 Installation of all equipment and materials supplied by Ovivo.

8 Supply, fabrication, installation, cleaning, pickling and/or passivation of all interconnecting steel piping components.

9 Provide and install all embedded pipe sections and valves for tank drains and reactor inlets and elbows.

10 All cutting, welding, fitting and finishing for all field fabricated piping.

11 Supply and installation of all flange gaskets and bolts for all piping components.

12 Supply and installation of all pipe supports and wall penetrations.

13 Install and provide all motor control centers, motor starters, panels, field wiring, wireways, supports and transformers.

14 Install all control panels and instrumentation as supplied by Ovivo, as applicable.

15 Supply and install all electrical power and control wiring and conduit to the equipment served plus interconnection between the Ovivo equipment as required, including wire, cable, junction boxes, fittings, conduit, cable trays, safety disconnect switches, circuit breakers, etc.

16 Supply and install all insulation, supports, drains, gauges, hold down clamps, condensate drain systems, flanges, flex pipe joints, expansion joints, boots, gaskets, adhesives, fasteners, safety signs, and any specialty items such as traps.

17 All labor, materials, supplies and utilities as required for start-up including laboratory facilities and analytical work.

18 Provide all chemicals required for plant operation and all chemicals, lubricants, glycol, oils or grease and other supplies thereafter.

19 Install all anchor bolts and mounting hardware supplied by Ovivo; and supply and install all anchor bolts and mounting hardware not specifically supplied by Ovivo.

20 Provide all nameplates, safety signs and labels.

21 Provide all additional support beams and/or slabs.

22 Provide and install all manual valves.

23 Provide and install all piping required to interconnect to the Ovivo's equipment.

24 The Contractor shall coordinate the installation and timing of interface points such as piping and electrical with the Ovivo Supplier.

All other necessary equipment and services not otherwise listed as specifically supplied by Ovivo.

BUDGET PRICE

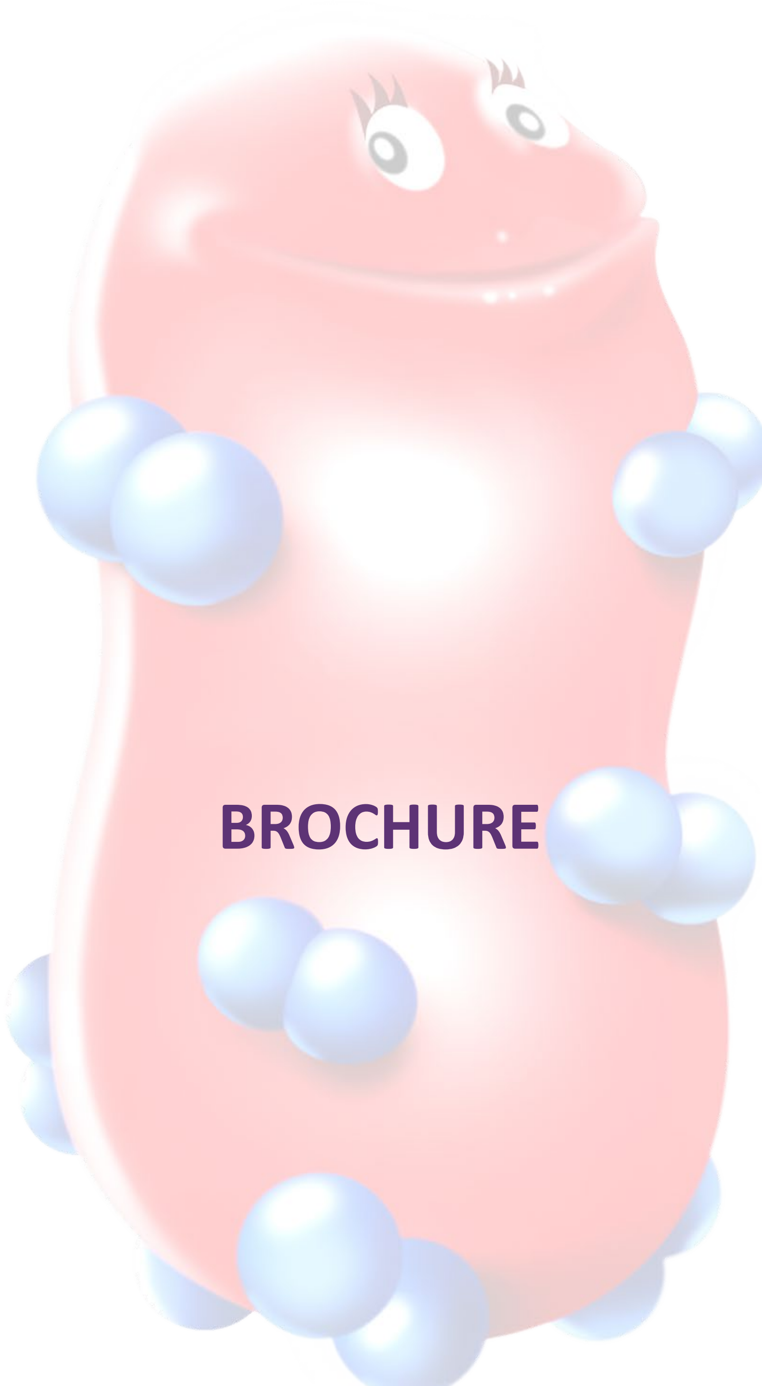
Our current budget estimate price for the AnammoPAQ® system, as described in this proposal is:

Description	Price
AnammoPAQ® system as described above	**As Advised by Rep**

NOTES –

1. Our Price and Payment Terms are based on Ovivo's standard terms and conditions, which can be provided upon request.
2. This price will be valid for thirty (30) days.
3. All prices are excluding Washington state sales and use taxes and any federal taxes which shall be the sole responsibility of the Client. No additional duties will have to be paid for the equipment supplied by Ovivo.
4. Pricing is subject to the London Metal exchange index for stainless steel rolled coil calculated from the original proposal date and is in accordance with the Scope of Supply and terms of this proposal and any changes may require the price to be adjusted.

Shipping Terms
FOB Shipping Point, Full Freight Allowed



BROCHURE

OVIVO-PAQUES
AnammoPAQ® PROCESS

SUSTAINABLE NITROGEN REMOVAL

HOW WE CREATE VALUE

Cost-effective nitrogen removal from digester sidestreams (with or without THP) using Anammox

Compared to conventional nitrification and denitrification:

- 60% energy savings compared
- 100% reduction in supplemental organic carbon
- 90% reduction in sludge production
- 90% reduction in footprint
- 85% reduction in CO_2 emissions

Quick startup time with potential for full process optimization within 3 weeks

THE CHALLENGE

- Despite representing 1% to 3% of the flow to the mainstream, typical anaerobic digester sidestream contains 10% to 30% of the nitrogen load, with concentrations often in excess of 1,000 mg/L ammonia-N
- Sludge pre-treatment with THP can double the ammonia-N concentrations in the sidestream
- Stringent BNR limits on main stream
- Conventional nitrification and denitrification requires significant aeration energy and supplemental carbon

THE OVIVO SOLUTION

The AnammoPAQ® process is an elegant shortcut in the natural nitrogen cycle. The process utilizes Anammox bacteria which directly convert ammonium (NH_4^+) and nitrite (NO_2^-) into nitrogen gas. Paques B.V. developed the original process for commercial purposes in cooperation with Delft University of Technology and the University of Nijmegen. Since the first full-scale plant started up in 2002 (treatment of sidestream from sludge digestion), many other plants have been installed and are running successfully.

The AnammoPAQ® ADVANTAGE

- Proven technology with 15+ years operational experience
- 65+ AnammoPAQ® references worldwide including North America
- Largest single unit can handle 10 metric tons of nitrogen/day (equivalent to sidestream from a 250 MGD municipal plant)!
- Robust system, handling high loading variations
- Up to 60% saving on operational costs
- Savings on excess sludge production
- No addition of organic carbon source (methanol) required
- Production of valuable Anammox biomass
- High loading rates leading to compact footprint
- Lowest O&M amongst competing systems

ovivowater.com

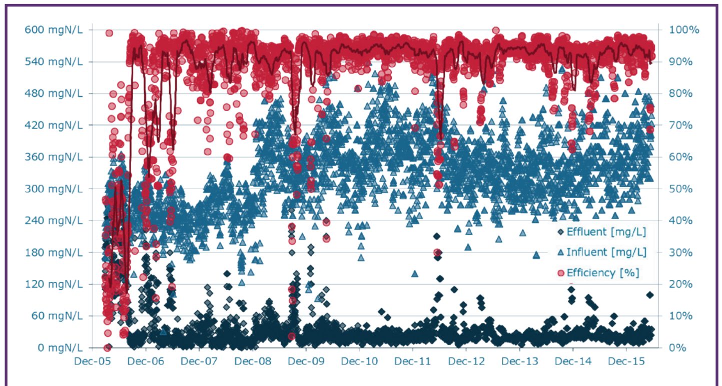
info@ovivowater.com

OPERATING PRINCIPLE

AnammoPAQ® technology is a continuous flow reactor system in which nitritation and anammox conversion occur simultaneously in a single process unit. Anammox (anaerobic ammonium oxidation) conversion is an elegant short-cut in the natural nitrogen cycle where ammonium and nitrite are converted to nitrogen gas. As the Anammox process involves removal of ammonium over nitrite (NO_2^-) rather than nitrate (NO_3^-), 63% less oxygen (O_2) is required while eliminating the need for an external carbon source altogether. Optimal process control ensures retention of AOBs and Anammox bacteria while eliminating NOBs, leading to stable & robust operation.

$$NH_4^+ + 1\tfrac{1}{2}\,O_2 \rightarrow NO_2^- + H_2O + 2H^+$$

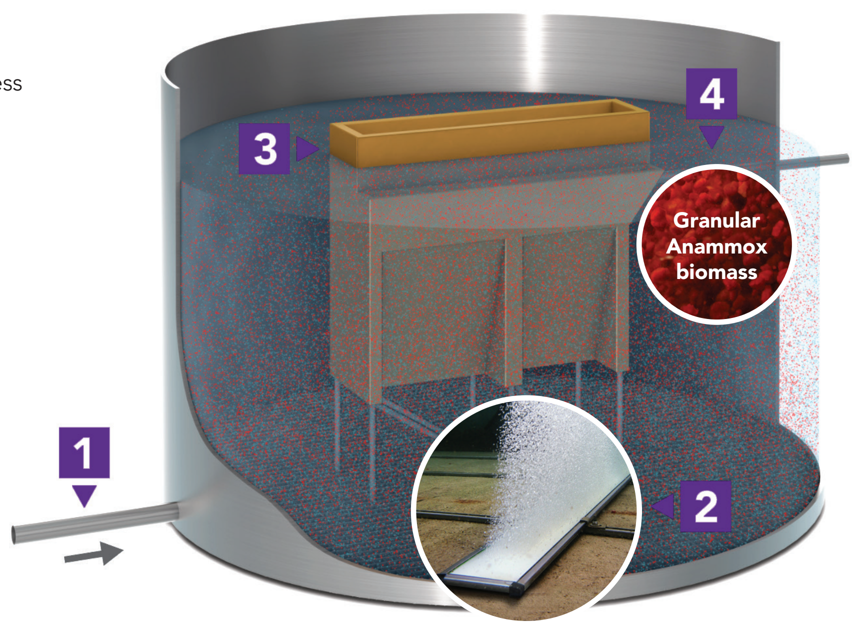
$$NH_4^+ + NO_2^- \rightarrow N_2 + 2H_2O$$



The Olburgen WWTP in Netherlands, with the Ovivo AnammoPAQ® process has reached stable & continuous 92% ammonium and 85% total nitrogen removal average for over 10 years

HOW IT WORKS

1. Ammonia-rich influent
2. Aerators for mixing and ammonia removal process
3. AnammoPAQ® separator for biomass retention
4. Effluent exits the reactor



CONTACT
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From: Douglas Allie <dallie@goblesampson.com>
Sent: Tuesday, August 03, 2021 12:05 PM
To: Adam Klein <aklein@brwncald.com>
Subject: RE: Anammox at Bellingham

Adam,

As promised, please see attached our proposal for AnammoPAQ system for Bellingham WWTP, WA. The budget price of the system is $2,600,000.

What is the timeline on this project from design to bid?

Doug Allie
GOBLE SAMPSON