MAINSTREAM DEAMMONIFICATION AT THE WESTERN TREATMENT PLANT

J Watson*, J Segal*, T Yeager, N Dow**, M Duke****

* Melbourne Water Corporation; GPO Box 4342, Melbourne, VIC, Australia 3001;
Jenelle.Watson@melbournewater.com.au
** Victoria University, Melbourne, VIC, Australia

Abstract: Melbourne Water's Western Treatment Plant (WTP) is forecast to experience significant growth in flow and load over the coming decades. In order to mitigate the impacts of increased energy demand and treatment costs an extensive program has been initiated with the aim of implementing mainstream deammonification for a capital upgrade in 2020. Mainstream deammonification is a short-cut nitrogen removal process with significantly lower energy demand and carbon requirement than conventional nitrification-denitrification. Laboratory research, large-scale piloting and collaboration with Australian water utilities and universities are being undertaken over a five year period in order to prove and successfully implement this innovative technology.

Keywords: anammox; mainstream deammonification; Western Treatment Plant; nitrogen removal

Introduction

Melbourne Water's Western Treatment Plant (WTP) is located in Werribee, southwest of Melbourne. The plant is set on a 10,500 hectare site and treats approximately 490 ML per day in a lagoon-based process, making it one of the world's largest lagoon treatment plants. The site is one of Australia's most important wetlands for water-birds and is listed under the international Ramsar Convention, and also supports a 5,000 hectare on-site agricultural operation.

The treatment plant comprises 2,000 hectares of anaerobic, aerated, facultative and maturation ponds, with two activated sludge plants (ASP) integrated into two of the five lagoon systems. All wastewater entering the plant passes through two covered anaerobic lagoons which provide primary treatment as well as capturing the methane-rich biogas produced, which is used for on-site electricity generation. Typically, approximately two-thirds of the flow from the covered anaerobic lagoons is treated in the two ASPs followed by maturation ponds; the remaining third is treated in aerated and facultative ponds. All solids produced in the plant are stabilised within the lagoon system before being dried in sludge drying pans.

On average over the year the plant is near energy neutral with minimal dependence on imported electricity. Whilst the high biogas and onsite electricity production is a key contributor to the WTP's near energy self-sufficiency, the use of lower energy processes including facultative lagoon systems and sludge drying pans is perhaps the more important factor.

As Melbourne and the WTP grow the proportion of flow and load that will be treated in more energy-intensive treatment processes will rise and with this, the cost of treatment. Adopting energy efficient, innovative treatment processes, such as shortcut nitrogen removal will be essential in mitigating the rising energy demand.

A large proportion of the WTP's energy demand is mechanical aeration for nitrogen removal in order to meet the plant discharge licence and recycled water requirements. Shortcut nitrogen removal is the term given to processes that short cut the conventional nitrification – denitrification nitrogen removal process (Fig. 1). Nitrite shunt requires 25% less and deammonification (anammox) 60% less energy for aeration than nitrification – denitrification, and both processes have a lower carbon demand than the conventional process. The implementation of deammonification at full-scale has been practiced on digested sludge dewatering side-streams since the 1990s with over 100 plants operating worldwide to date. Mainstream deammonification, that is, treatment of the entire liquid stream, currently has limited full-scale applications globally due to many technical hurdles and risks.

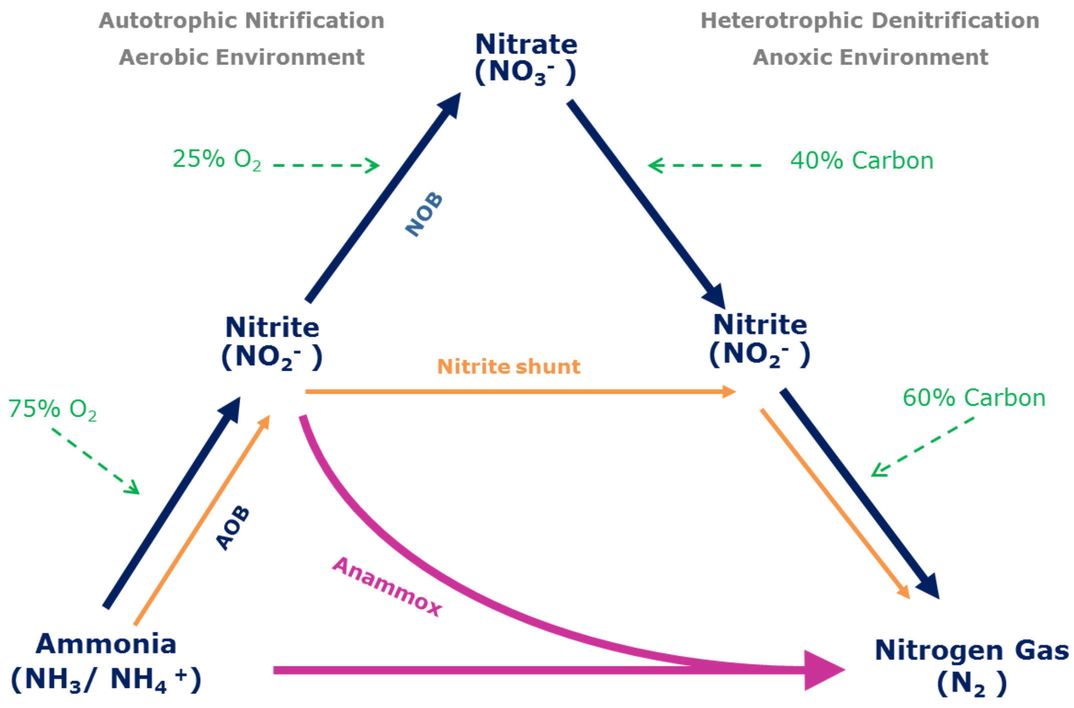

Figure 1 Nitrogen removal pathways. Blue lines represent conventional nitrification–denitrification, orange lines represent nitrite shunt, pink lines represents deammonification.

Material and Methods

In early 2014 Melbourne Water together with engineering consultants undertook a preliminary feasibility study to better understand the challenges associated with implementing mainstream deammonification as part of a capital upgrade scheduled for 2020. These include generic challenges, primarily around sustaining sufficient growth of the required microorganisms and suppressing growth of undesired organisms, as well as site-specific challenges to WTP including the impact of pre-anaerobic treatment, a feed with high variability in COD and operating in a low temperature environment.

In order to address the risks described above as well as to develop an approach to the design of a full-scale facility, a roadmap for the adoption of mainstream deammonification at the WTP was developed including key questions and challenges, decision points and external factors for consideration (Fig. 2). As part of development of an implementation plan the study identified two key steps: (a) proof of principle, and (b) proof of process.

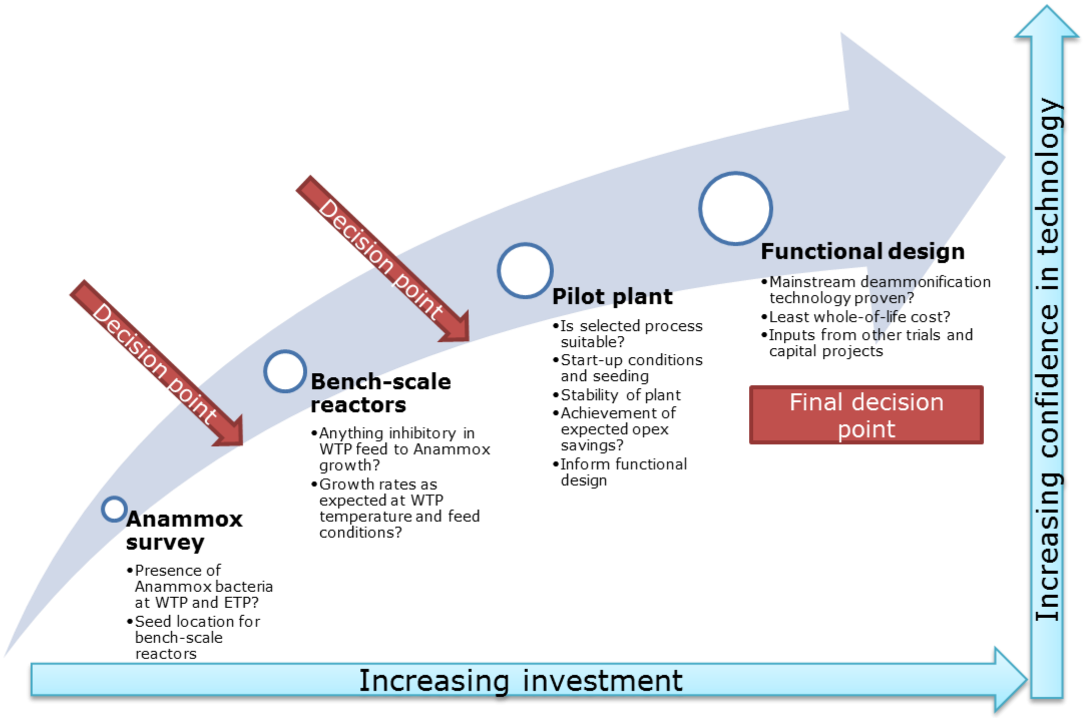

Figure 2 'Roadmap' including key decision points

In mid-2014 Melbourne Water, in conjunction with Victoria University, commenced lab trials aimed at proof of principle. Four bench-scale (2 L) anaerobic membrane bioreactors were seeded with sludge native to the WTP and fed on WTP partially-treated effluent in order to cultivate anammox biomass. The reactors were temperature-controlled and the feed was dosed with nitrite and acid in order to provide the desired stoichiometric ratio and pH for the anammox metabolism. A stirrer was used to keep biomass in suspension, nitrogen purge provided to maintain anaerobic conditions and submerged polyvinylidene fluoride (PVDF) ultrafiltration membranes used as a means of effluent extraction and biomass retention. Quantitative polymerase chain reaction (qPCR), specific activity tests and routine wastewater analyses were used to quantify the growth and performance of anammox cultures.

Upon satisfactory demonstration of bench-scale investigations, the focus of the roadmap moves to pilot-scale investigations to address issues associated with operation, performance, proof of process and addressing of scale-up engineering issues. This second phase of work involves the construction of a 130 kL/d pilot plant to be located at the WTP (construction completion end 2016). This facility will be used to trial a selected process configuration and multiple aeration control strategies over an extended period. Results will be used to confirm the process selection and refine design of a future full-scale mainstream deammonification plant.

Results and Discussion

The initial feasibility study and risk assessment identified several challenges associated with the implementation of mainstream deammonification including relatively cool process temperatures, low ammonia concentrations and the lack of a warm side-stream at WTP to provide bio-augmentation of the anammox population. Each technical risk was categorised into an importance rating to determine criticality and sequencing of trials:

1. Proof of principle

2. Proof of process
3. Design development.

Risks were then assigned to a method of resolution, targeting cost and program efficiencies (Table 1):

a. Bench-scale testing
b. Pilot plant trials
c. Literature review
d. Collaborative research projects
e. Modelling.

Table 1 Technical challenges with criticality and phase for resolution.

Issue	Importance	Phase	Status	Notes
Identification and isolation of anammox cultures at WTP	Proof of principle	Bench-scale	Resolved	Anammox identified. Further microbial characterisation (pyrosequencing) in progress.
Growth of anammox on WTP effluent	Proof of principle	Bench-scale	Resolved	Activity rates in line with those reported in literature
Substances inhibitory to anammox in anaerobic lagoon effluent	Proof of principle	Bench-scale	Resolved	No inhibition of process
Growth of anammox at low temperature (15°C)	Proof of principle	Bench-scale	Resolved	Activity rates in line with those reported in literature
Transfer of seed culture from side-stream to mainstream conditions	Design development	Collaborative research	Resolved	Positive results from research projects
Suppression of ordinary heterotrophic organisms (OHO)	Proof of process	Pilot plant	Open	End of anaerobic lagoon as feed (lower COD). Use of AS reactor to optimise for use of available carbon.
Suppression of nitrite-oxidising bacteria (NOB)	Proof of process	Pilot plant	Open	Advanced aeration control strategies, sludge age control
Growth and retention of anammox	Proof of process	Collaborative research	Resolved	Use of media (MBBR) to retain anammox culture, providing greater resilience.
Growth and retention of anammox (WTP-specific)	Proof of process	Pilot plant	Open	Design based on learnings from collaborative research projects and literature review
Impact of variable COD in feed	Proof of process	Pilot plant	Open	Pilot designed with flexibility to increase/decrease nitrite shunt contribution
Final ammonia polishing	Design development	Pilot plant	Open	Considered low risk as proven process.

Online ammonia, nitrite and nitrate control	Proof of process	Collaborative research, literature	Resolved	Proven technologies and control systems
Scale-up engineering issues	Design development	CFD modelling, pilot plant	Open	To be investigated during functional design of full-scale plant
Sludge settling characteristics	Design development	Pilot plant	Open	To be investigated following proof of process
Impact on biosolids	Design development	Pilot plant	Open	Considered low risk.
Achievable capex and opex savings at full-scale	Design development	Pilot plant	Open	To be investigated following proof of concept and during functional design of full-scale plant
Start-up of plant	Design development	Collaborative research, literature	Resolved	Expected timing understood. Investigated as part of bench-scale work. To be further explored at pilot scale.
Start-up of plant (WTP-specific)	Design development	Pilot plant	Open	To be investigated during initial seeding/start-up

The implementation plan aims to minimise investment whilst addressing the identified challenges and providing information within the constrained upgrade timeframes.

The initial lab work provided an analysis and evaluation of the levels of anammox bacteria present in sludge samples from the plant, seeking to confirm the existence of indigenous anammox cultures using qPCR. The most highly enriched samples were then selected to seed the bench-scale bioreactors for further testing.

Bench-scale trials were conducted over 18 months (Yeager, 2016). Following successful start-up of the reactors, indicated by nitrogen removal percentage and qPCR evidence of anammox growth, a temperature reduction program was started to investigate the viability of the process at winter temperatures. The temperature was lowered in a step-wise fashion to 15°C over a period of four months, and it was shown that nitrogen removal was able to be sustained (Fig. 3) though biomass growth stagnated. Lab trials further showed that the WTP sewage, which has a large industrial catchment and primary anaerobic treatment, was not inhibitory to anammox growth, and doubling times and activity rates were in line with literature.

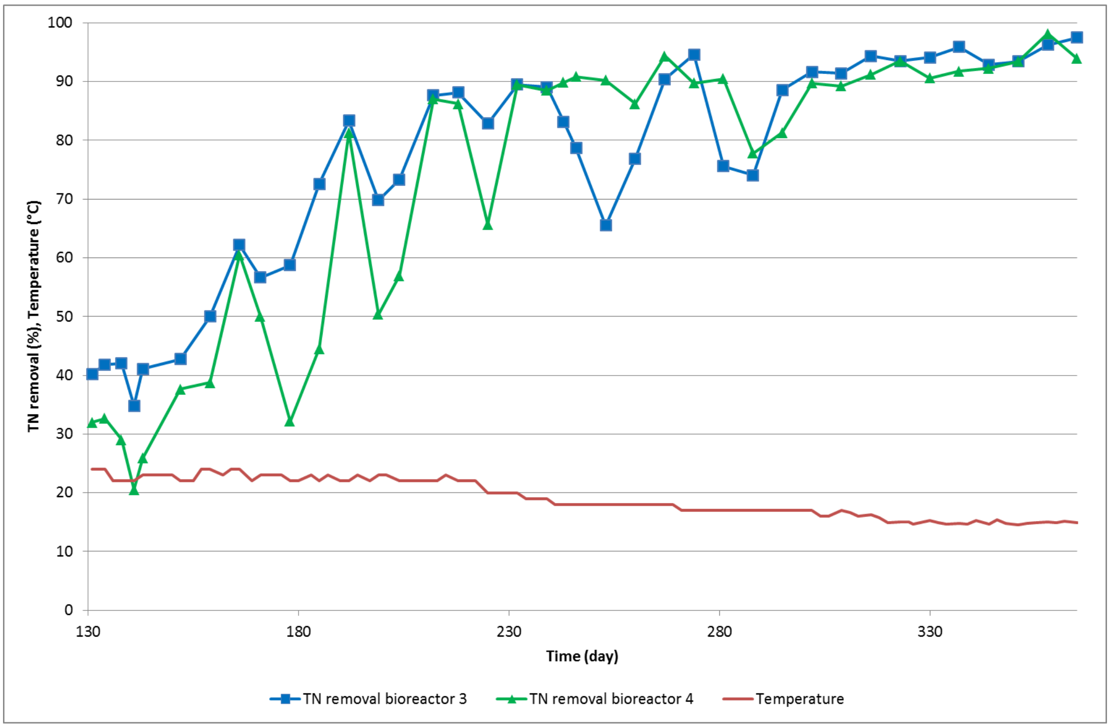

Figure 3 Bench-scale bioreactor results for total nitrogen and ammonia removal at winter temperatures.

Following successful proof of principle at lab scale, the roadmap moves to a pilot unit. Operation of bench, pilot and demonstration scale units was originally proposed, however due to the slow growth of anammox bacteria this would not be possible given the time constraints of the full-scale capital project. Ultimately a 130 kL/d unit was selected as a combined pilot/demonstration scale, which was of sufficient capacity to avoid some common pitfalls of small scale trials.

The pilot plant process proposed for WTP is a combination of activated sludge (AS) for partial nitritation (out-selection of nitrite-oxidising bacteria) and moving bed bioreactor (MBBR) technology for the deammonification processes. This process has been selected for reasons including:

(a) Highly variable COD in the feed stream can be used appropriately in the AS reactor with limited impact on anammox

(b) MBBR media provide good method of retention of slow-growing anammox.

The use of an aeration control strategy known as ammonia versus NOx (AvN) has been shown to promote the nitrite shunt pathway (Regmi et al., 2014). The pilot plant control system will allow AvN, intermittent aeration (aerobic/anoxic cycling) and several variants to be tested throughout the operation period. Similarly, provision has been made in the design and costing for future modifications to allow alternative process configurations to be tested, either as alternatives to the initial design or optimisations.

Previous piloting work (Regmi et al., 2015) has shown that the anammox MBBR can be operated as a stable nitrogen polishing process so long as the feed ammonia and nitrite concentrations can be kept at an appropriate ratio. This has led to an operating plan that involves the initial commissioning and stabilisation of the AS reactor, and only later seeding the Anammox MBBR. This will mitigate the risk of early deterioration of the anammox biomass through nitrite accumulation.

Environmental discharge licence and recycled water limits require the full-scale process to have an effluent of low ammonia and nitrite (<1 mgN/L). Allowance has been made for a provisional Nitrifying MBBR downstream of the Anammox MBBR which will provide polishing to ensure that effluent ammonia requirements are met. As it is a well-proven process, this item will only be constructed following successful proving of the main treatment train, reducing unnecessary spend in the early stages of the project.

The sequential commissioning of each process unit is an example of how costs have been phased where possible in order to minimise up-front spend (Fig. 4).

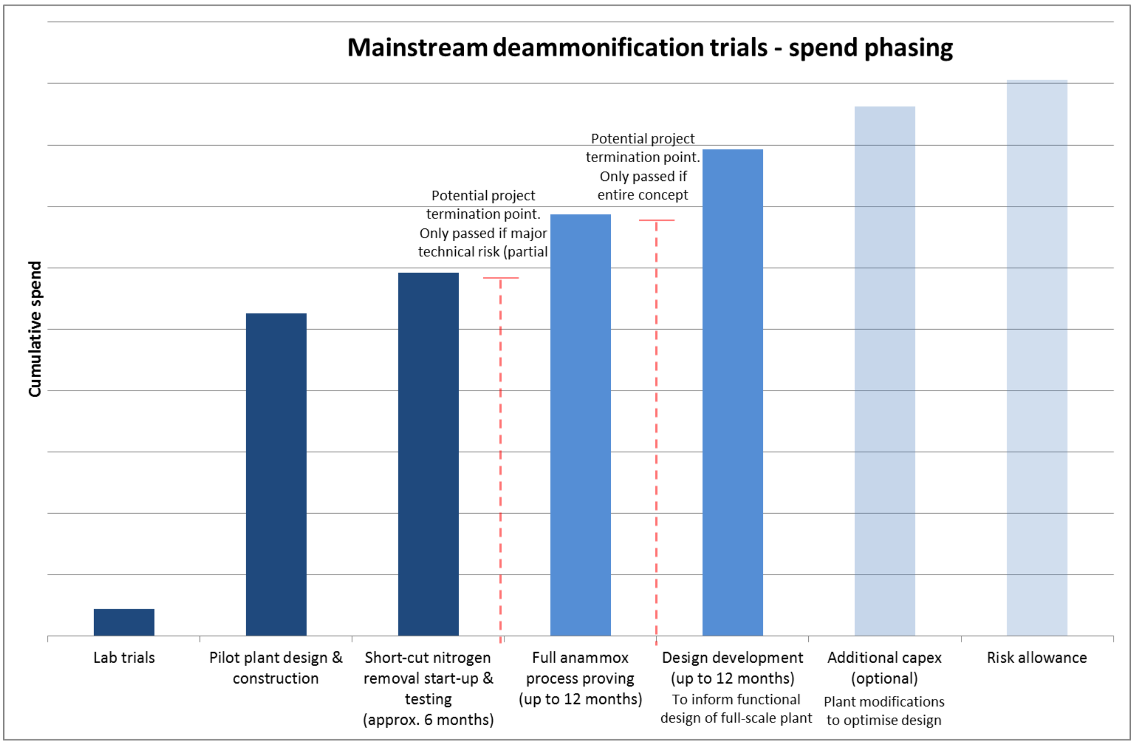

Figure 4 Phasing of costs through trial program for efficient spend.

Due to the slow growth rate of anammox the pilot plant must be inoculated with seed biomass to accelerate start-up and ensure sufficient time for trials (Strous, 1998). As there is not yet any full-scale deammonification facility in Australia, and quarantine regulations limit the importation of wastewater-derived products, it is critical that a seed culture is grown locally and well in advance of plant commissioning. This is being done through a collaboration between Melbourne Water and Queensland Urban Utilities.

Planning for the pilot plant has promoted partnerships with other water utilities and collaborations with multiple universities. These have proved extremely valuable in both direct work and learnings, but also the nurturing of a more vibrant and connected ‘anammox community’ in Australia.

Conclusion

Numerous technical hurdles were identified for implementing mainstream deammonification at WTP, including low strength wastewater, cool temperatures, lack of warm side-stream and highly variable influent. The roadmap and implementation plan aims to minimise investment whilst addressing the identified challenges and providing sufficient information within the constrained timeframes to allow for an informed decision regarding the full-scale upgrade.

Mainstream deammonification represents a significant opportunity to mitigate the increase in energy demand (and cost to treat) that would otherwise result from the forecast growth in Melbourne's population and WTP's inflow and load. Melbourne Water is actively pursuing this technology with intent to maximise the benefits through implementation as part of the next upgrade in 2020.

Successful implementation will provide not only ongoing benefits through reduced energy demands but also has the potential to defer future sludge drying and high voltage power augmentations with capital costs in excess of $100M. Further, it will set the direction for future augmentations in other areas of the plant including primary treatment and power generation from biogas.

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