

LAYING GROUNDWORK FOR NZ PDNA: NEXT-GENERATION WASTEWATER TREATMENT

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ABSTRACT

Partial Denitrification-Anammox (PdNA) is a nutrient removal and intensification process, which is becoming a well accepted mainstream wastewater treatment technology in the US, EU, and Asia. PdNA process, when implemented as an additional secondary or tertiary process, has been shown to be a robust, resilient nutrient removal strategy which can meet lower effluent nitrogen concentrations while reducing OPEX. As the New Zealand wastewater industry is broadly reducing nutrient discharge limits, PdNA has the potential to be a key intensification process to meet the required treatment outcomes with reduced chemical and power consumption.

This paper is intended to help bring awareness to the benefits of PdNA and assist in making it a viable technology in NZ. The paper summarises the PdNA process, benefits of the process, historic barriers of PdNA, pilot work at the Totara WWTP in Palmerston North, and a future full-scale installation at the Tokoroa WWTP in South Waikato District Council.

INTRODUCTION

As New Zealand's wastewater regulations change and nutrient discharge limits become more stringent, the NZ industry has adapted to this change by implementing newer technologies and intensification processes such as Membrane Aerated Biofilm Reactor (MABR), densification via inDENSE®, mobile carriers, etc. However, noticeably absent from the New Zealand wastewater industry are anammox based nitrogen removal processes which "shortcut" the nitrogen removal process. Despite the discovery of anammox bacteria in 1995, and the first full scale anammox processes being constructed and commissioned in 2002 (Driessen et al, 2012), this technology is yet to be adopted in New Zealand.

Several shortcut nitrogen removal processes have been discovered, tested, and/or implemented over the past 30 years. Figure 1 provides a comparison of conventional nitrification-denitrification (N/dN) reactions and common anammox pathways (Wagner, 2024)

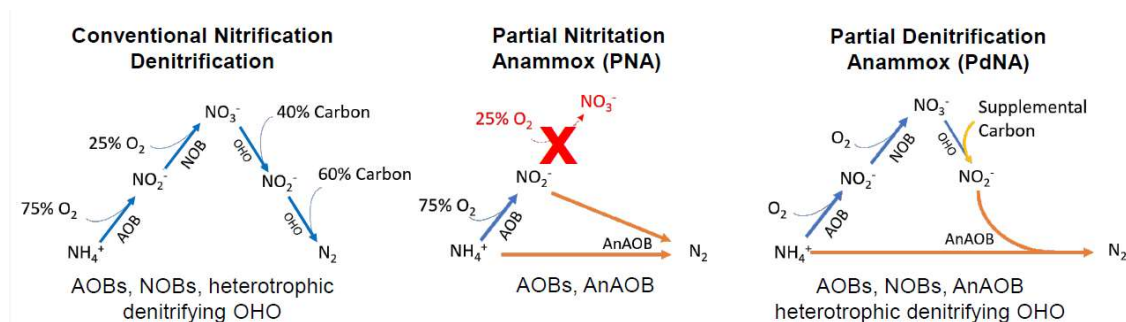


Figure 1: Nitrogen Removal Pathways – Conventional and Anammox Based (Wagner, 2024)

A barrier for New Zealand wastewater industry for short cut nitrogen processes utilising anammox is border biosecurity, which does not allow for bacteria populations to be imported into the country. This obstacle was overcome by Watercare in 2018 when they produced a lab grown anammox population in a bench scale Partial Nitrification Anammox (PNA) or deammonification process for anaerobically digested centrate (Perez-Garcia et al, 2018).

PNA VS PDNA

PNA relies on the partial nitrification of total ammoniacal nitrogen (TAN) into NO₂-N by ammonia oxidizing bacteria (AOB). Residual TAN and NO₂-N are then converted to N₂ gas and NO₃-N (to a lesser extent) by the anammox bacteria. PNA has been successfully implemented in sidestream treatment of anaerobic digestate and industrial wastewater treatment worldwide for over 20 years. However, its application to mainstream municipal wastewater treatment is still very limited.

The PdNA process requires that a portion of the TAN has been oxidized to NO₃-N. The NO₃-N is then partially denitrified into NO₂-N. The resulting NO₂-N and residual TAN are then converted to N₂ gas and NO₃-N (to a lesser extent) by the anammox bacteria.

While PNA is the more commonly implemented of the anammox processes (albeit in sidestream treatment of anaerobic digestate), PdNA has become a process of global focus as it is proving to be a relatively robust and consistent mainstream anammox process. The PNA process is a more obvious choice in sidestream treatment of anaerobic digestate centrate/filtrate as the process can rely on various factors such as high temperature, high residual ammonia, low COD:N, etc. to enable AOB's to outcompete NOB's, which is essential to the PNA process. As a result of this, there are limited successful examples of PNA for mainstream treatment. This is not the case for PdNA which does not rely on NOB out-selection (Fofana et al., 2022).

In contrast the PdNA process has been implemented as a mainstream tertiary system for nutrient removal at relatively large WWTP's. While the nutrient removal pathway for PdNA is not as direct as PNA the stability of this process makes it more suitable for mainstream treatment. It is also more efficient than conventional N/dN process, resulting in significant OPEX savings. The benefits of mainstream PdNA compared to conventional N/dN process include the following:

- Accommodates for higher effluent ammonia discharged into tertiary treatment system allowing for:
 - Higher secondary treatment capacity
 - Lower aeration power consumption
 - Lower alkalinity consumption
 - Lower N₂O emissions
- Decreased exogenous carbon demand

Utilities (list is not exhaustive) have successfully implemented mainstream PdNA at the following WWTP's:

Table 1: WWTP's with PdNA processes (Wagner, 2024)

Plant	Utility/Municipality	Capacity ¹	Process	Impact
York River	Hampton Roads Sanitation District	25 MGD	Denite Filter	OPEX Savings = ~1M USD/y 35% capacity increase
Blue Plains	DC Water	400 MGD	IFAS	Methanol Savings = 35-40%
Noman Cole	Fairfax County, VA	80 MGD	Tertiary MBBR	MeOH Savings = 20-30% Aeration Energy = 5-10% OPEX Savings = ~\$200-400k USD/y
James River	Hampton Roads Sanitation District	20 MGD	IFAS	COD savings = 45-75%

1. Annual Average

PILOT METHODOLOGY

Several of New Zealand's WWTPs will face more stringent nutrient removal requirements either through the new national wastewater discharge standards or through new resource consents, Lutra saw the potential that PdNA could have a significant impact on the NZ wastewater industry. As a result, Lutra piloted PdNA (among other study objectives) using its two stage MBBR pilot system at the Totara WWTP at Palmerston North City Council (PNCC).

Lutra's two stage MBBR pilot was operated at the Totara WWTP at PNCC in a multiphase pilot trial. The pilot was positioned on the outlet of Oxidation Pond 2 as shown in Figure 2 below. The two-stage MBBR pilot includes an aerobic reactor for nitrification followed by an anoxic reactor with exogenous carbon dosing to achieve denitrification.

For the PdNA phase of the pilot trial, the pilot system was dosed with a sodium acetate solution acting as exogenous carbon source for denitrification. The pilot system has minimal automation and is limited to motor speed control on most equipment. The pilot was operated as follows:

- Wastewater samples were collected and analysed for nitrogen species, alkalinity, and COD either onsite with Hach TNT kits and DR 3900 or through CEL laboratories.
- Based on results, operational adjustments were made to pilot feed flow, aeration rates, or COD dosing as follows:
 - Secondary effluent feed pump has a built in VSD allowing for flow control based on a dial setting.
 - Aeration blower is constant speed with a bleed valve and back pressure valve providing minimal flow control.
 - Exogeneous COD dosing allows for speed control with an operator adjusted speed dial.
- COD was dosed at a reduced COD:N ratio to prevent full denitrification.
- Feed flow was set to achieve a specific TAN:NO₃-N ratio in the feed to the anoxic reactor to provide an additional selective pressure to prevent full denitrification.



Figure 2: Totara Rd. Wastewater Treatment Plant in Palmerston North

The pilot was operated in the PdNA phase from November 2024 to April 2025. The objectives of the PdNA phase of the pilot included the following:

- Primary - Gain understanding around the resilience and sensitivity of the partial denitrification process.
- Secondary - Establish anammox population.

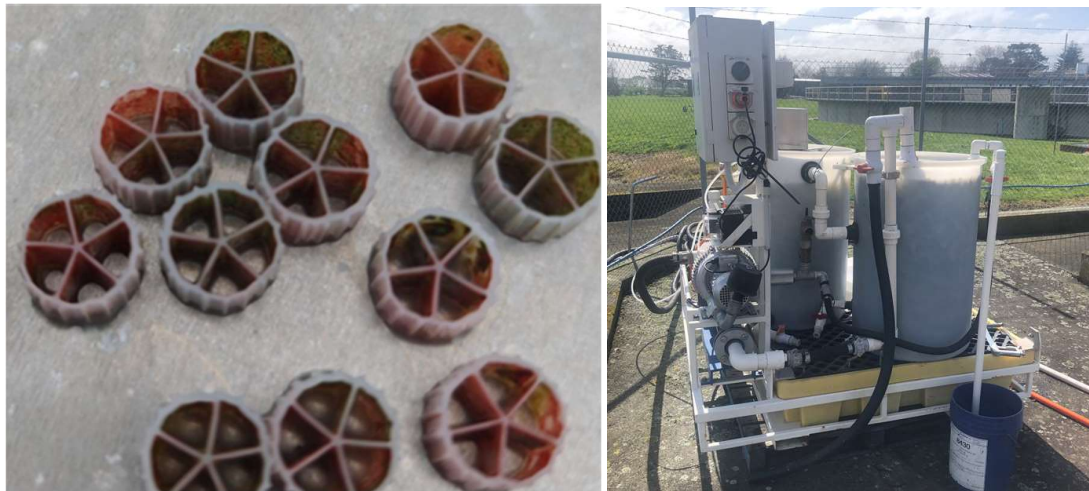


Figure 3: Denitrification media biofilm during PdNA trial (left), pilot system (right)

PdNA efficiency was tracked based on equation 1 (Bachmann et. al, 2025). NH_4^+ assimilation was estimated based on NH_4^+ decrease during times of full conventional denitrification.

$$\text{PdN}\% = \frac{\text{NO}_2 \text{ out} + 1.32 * (\text{NH}_4^+ \text{ in} - \text{NH}_4^+ \text{ out} - \text{NH}_4^+ \text{ assim})}{\text{NO}_3 \text{ in} - \text{NO}_3 \text{ out} + \text{NO}_2 \text{ in} + 0.26 * (\text{NH}_4^+ \text{ in} - \text{NH}_4^+ \text{ out} - \text{NH}_4^+ \text{ assim})} \quad (1)$$

DISCUSSION

$\text{NO}_2\text{-N}$ concentrations across the duration of the pilot study are presented below in Figure 4.

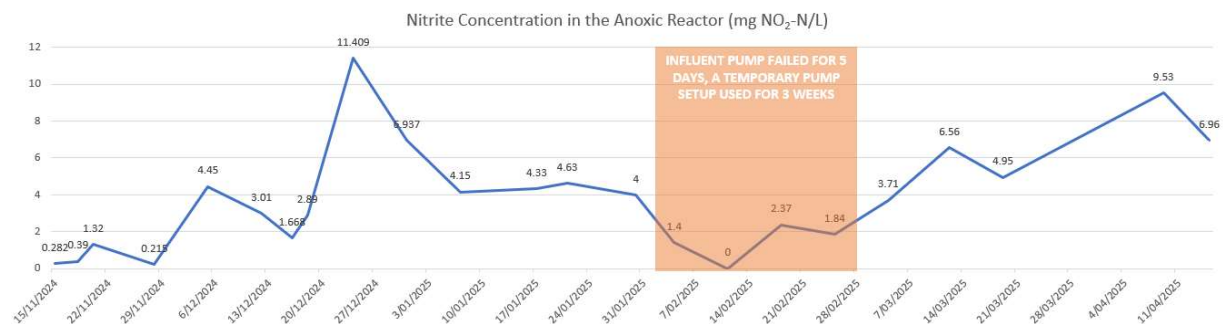


Figure 4: Observed $\text{NO}_2\text{-N}$ concentrations in post-anoxic MBBR reactor using sodium acetate as carbon source during PdNA pilot trial

The pilot demonstrated that maintaining a high $\text{NO}_2\text{-N}$ residual via partial-denitrification is possible and even relatively robust considering the limited automation and process control. Lutra's international experience in sidestream PNA supports that once the anammox population has been established, the nitrification step is the more sensitive and challenging step in the process to manage. This step often requires complex process control or load management. It is expected that maintaining partial denitrification (e.g. $\text{NO}_2\text{-N}$ production while preventing full denitrification) is similarly the key to a successful PdNA implementation.

The pilot was unable to develop an anammox population producing any observable treatment impact. While red/iron-coloured bacteria as observed are usually associated with anammox bacteria, it has been observed before in conventional denitrification processes and is not considered a sign of appreciable anammox growth during the pilot study.

Literature reviews and anecdotal information from other utilities showed that anammox seeding is not required for the establishment of PdNA, and an anammox population can be developed in 3-4 months (WRF, 2022). This was further demonstrated at the James River WWTP in a purpose built IFAS PdNA

system (Bachmann et. al, 2025). Critical pilot system equipment started to fail at the 3-month mark, making operation and performance inconsistent. Following 5 months, the pilot electrical system completely failed and prematurely ended the pilot study. The project team postulate that the lack of anammox growth in the pilot could be due to pilot operational downtime, poor environmental control resulting in sub-optimal growth conditions, or long HRT of upstream ponds causing poor seeding potential rather than a fatal flaw in the technology or anything inhibitory in the system.

FULL SCALE POTENTIAL

The PdNA process was identified as a potential further intensification process for the Tokoroa WWTP in South Waikato District Council. The Tokoroa WWTP is a biofilm plant with trickling filters, submerged aerated filter (SAF) by Smith & Loveless known as the FAST system, followed by filtration. Three sand filter cells were converted into post-denitrification MBBR reactors with the intention to use methanol as the exogenous carbon source to meet provide 85-90% nitrate removal to meet future TN limits. Due to challenges with the methanol supply chain and safety certification, the exogenous carbon source was shifted from methanol to ethanol. This shift provided an opportunity to reinvestigate the project drivers due to the inherent differences between using methanol and ethanol as exogenous carbon sources.

Methanol is a common exogenous carbon source globally due to its low cost, however, due to factors such as limited supply chain and safety systems, its use is uncommon in NZ. Acetic acid is a more common carbon source, and ethanol is also available as a byproduct from local industry. Acetic acid and ethanol are advantageous as carbon sources as they result in a higher surface area removal rate (SARR) in fixed film denitrifying processes. More simply, less biofilm and media surface are required to remove the same pollutant load for ethanol than is required for methanol. This difference in SARR between carbon sources is demonstrated in Figure 5.

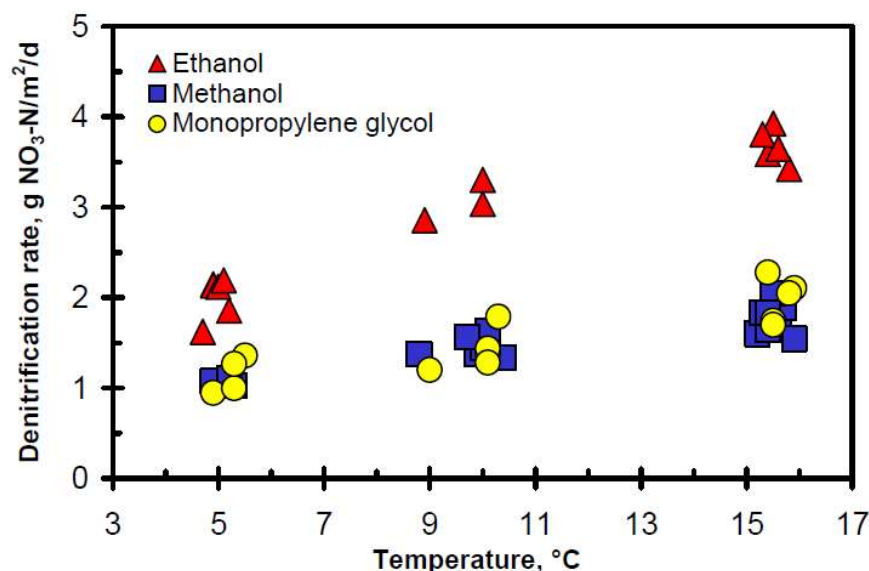


Figure 5: Impact of carbon type and temperature on SARR in post-denitrification MBBR (Rusten et al, 1996)

As a result of the increased SARR due to the switch from methanol to ethanol as the carbon source, the Tokoroa WWTP MBBR has excess denitrification capacity allowing for the implementation of a PdNA into the first reactor followed by conventional post-denitrification. It should be noted that due to serendipitous reactor quantity, sizing and media fill, the denitrification capacity for two ethanol fed MBBR reactors and three methanol fed MBBR reactors is the essentially same – resulting in little to no compliance risk.

Prior to making the decision to accommodate modifications to enable PdNA operation at the Tokoroa WWTP, a high-level assessment of cost vs savings was prepared looking at only the ethanol savings and not including potential aeration power savings. The assessment is summarised in Table 2.

Table 2: Simplified PdNA Business Case for Tokoroa WWTP MBBR

Parameter	Unit	Value
Average PdNA SARR due to Anammox	g N/m ² /d	0.8
PdNA NO ₃ -N removal	kg/d	23.0
PdNA NH ₄ -N removal	kg/d	17.4
Ethanol reduction	%	15-20%
Potential ethanol savings per annum	NZD	75-130k
Additional implementation cost*	NZD	50k

*Instrumentation, piping, controls implementation, etc.

CONCLUSIONS

Through this research, pilot work, and full scale work, we have the following conclusions:

- PdNA can be used as a mainstream wastewater treatment process to reduce the effluent nitrogen concentrations in NZ, especially those relying on expensive carbon dosing for the traditional post-denitrification process.
- PdNA allows for the reuse of existing assets (trickling filters, ponds etc.) for upstream secondary treatment providing BOD removal and partial nitrification. Depending on design, it can be a compact process which can be added to the end of existing processes.
- The partial denitrification part of the PdNA process has been proven viable and resilient in a two-stage MBBR pilot system for the pond effluent at the Totara WWTP, Palmerston North.
- PdNA is in the process of being implemented at full scale with minimal modifications required for the post-denitrification process at the Tokoroa WWTP.

RECOMMENDATIONS

With further research, piloting, and full scale work, PdNA should be considered and pursued as a process which can be implemented across the NZ wastewater industry to meet discharge nitrogen requirements. By leveraging off of international experience and further developing NZ experience, the PdNA process can become a regular technology and treatment process used to meet NZ treatment outcomes.

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NOMENCLATURE OR GLOSSARY

Acronym	Meaning
AOB	<i>Ammonia Oxidizing Bacteria</i>
COD	<i>Chemical Oxygen Demand</i>
IFAS	<i>Integrated Fixed Film Activated Sludge</i>
MABR	<i>Membrane Aerated Biofilm Reactor</i>
MBBR	<i>Moving Bed Biofilm Reactor</i>
N/dN	<i>Nitrification-Denitrification</i>
NOB	<i>Nitrite Oxidizing Bacteria</i>
PdNA	<i>Partial Denitrification Anammox</i>
PNA	<i>Partial Nitrification Anammox</i>
SARR	<i>Surface Area Removal Rate</i>
TAN	<i>Total Ammoniacal Nitrogen</i>

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