Wastewater treatment

water e-journal
Online Journal of the Australian Water Association
ISSN 2206-1991
Volume 3 No 1 2018
https://doi.org/10.21139/wej.2018.007

IMPLEMENTATION OF EEI-ANAMMOX PROCESS FOR WASTEWATER TREATMENT

NITROGEN REMOVAL

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INTRODUCTION

Across Australia and in other parts of the world, nitrogen removal has become an essential process of wastewater treatment. The conventional method of nitrogen removal (the nitrification and denitrification pathway) requires substantial oxygen transfer (approximately 4.3 g of O_2 for each g of ammonia-N) and carbon (about 4 g/g of NO_3–N reduced) (Kurup 2008). In the case of low carbon, high nitrogen wastewater, the addition of an external carbon source is required during the denitrification stage to effectively convert nitrate to nitrogen gas. These escalate the cost of the conventional nitrogen removal process, and utilities and industry have been looking for alternative low-cost nitrogen removal technologies. Some of the recent innovations in nitrogen removal include the anammox process, and struvite precipitation (precipitation of ammonium and phosphate as $MgNH_4PO_4$, with the addition of magnesium salt if needed).

This paper discusses the retrofitting of the anaerobic ammonia oxidation process (anammox) by Environmental Engineers International Pty Ltd (EEI) to an existing abattoir wastewater treatment plant (WWTP) in Western Australia. Abattoir wastewater requires advanced treatment prior to discharge to the environment due to its high nitrogen content. Since the implementation of the $EEI_{anammox}$ process over a year ago, the WWTP has consistently achieved good nitrogen removal, without any extra carbon addition. The plant is monitored online for various parameters to ensure its effective operation. The WWTP has achieved over 20% savings in overall electrical power since the implementation of the anammox process.

YEAR CASE STUDY WAS IMPLEMENTED

2015 to 2016

CASE STUDY SUMMARY

The objective of the project was to implement the $EEI_{anammox}$ process to replace the existing conventional nitrification – denitrification (CND) system at Dardanup Butchering Company (DBC) in Western Australia. The goal being to avoid the use of methanol and to reduce the power costs. EEI installed an advanced monitoring and control system to ensure that the oxidation of ammonia was limited to nitrite and to achieve nitrogen removal through the anammox process. The WWTP was a pond based system and was operated in an SBR mode. No external anammox bacterial consortium was added to the WWTP, however, the operation ensured that the anammox process was gradually implemented as the main TN removal process.

The plant was in full operation during the implementation. The anammox bacteria were found to cope with the changes in the process. Unlike the European case studies, the WWTP has achieved over 95% TN reduction even during the winter months when the temperature has fallen below 15°C. We have observed that in warmer periods, the $\mathrm{EEI}_{\mathrm{anammox}}$ process required careful intervention to prevent excess nitrate formation. During the full operation of the $\mathrm{EEI}_{\mathrm{anammox}}$ process, the WWTP achieved energy savings of over 20% and has not required the addition of an external carbon source.

Figure 1B. The aerated pond wastewater treatment system at DBC during the ammonia oxidation phase

CASE STUDY DETAIL

The specific issue

DBC is a multi-species abattoir, which produces up to 0.5 MLD of wastewater. The original treatment system consisted of an anaerobic reactor, and an aerated pond (Figure 1A & 1B) to treat an influent BOD of 2,000 – 3,000 mg/L and a total nitrogen (TN) of 350 to 450 mg/L. The EEI-ANRUP system that was in operation at the WWTP employed the Modified Ludzack-Ettinger process, and had effectively removed nitrogen to <45mg/L without any external carbon addition for over three years. The treatment pond was operated as an SBR system, however, on weekends when no wastewater was produced, the plant was operated as an extended aeration system.

The changes in the slaughtering operations in the abattoir resulted in a low BOD of 900 – 1,200mg/L, affecting the BOD:TN ratio. This restricted the denitrification without an external electron donor to treat the TN to the required value of <45 mg/L. The plant was adding methanol generated as a by-product from a biodiesel plant for this purpose, costing $109,000/year. However, due to the biodiesel plant closing down, the cost of methanol significantly increased to over two-fold, thus encouraging the facility to find alternative solutions.

Figure 1A. The aerated pond wastewater treatment system at DBC during the anammox phase

Approach

DBC considered two options, struvite precipitation and the $\mathrm{EEI}_{\mathrm{anammox}}$ process. Struvite was initially considered, as the final product would be a fertiliser, with simultaneous removal of phosphorus and ammonium N. The laboratory studies carried out at the University of Queensland for DBC did not result in struvite formation from the actual wastewater samples. Further to this, EEI was approached by DBC to implement the anammox process for nitrogen removal, with a view that the process would reduce the chemical and power costs of the WWTP.

Summary of activities and their implementation

The anammox process has recently been receiving interest from the Australian water industry due to the various benefits it offers. The advantages of the anammox process when compared with the conventional nitrogen removal process include a lower oxygen requirement, lower sludge production, and no carbon source requirement (Kurup 2008). These benefits translate into a substantial reduction in the operating cost of the WWTP.

In addition, as the aeration system operating period will be reduced, the maintenance required for the aeration system will be lowered and an improvement of the life span of the system can be expected.

Figure 2 presents the overall processes of both the conventional nitrification – denitrification (CND) pathway of nitrogen removal and the anammox pathway. In the CND process, ammonia is initially oxidised to nitrite, which is then oxidised to nitrate, and the nitrate is denitrified in the presence of an electron donor (methanol or similar organic matter).

The overall equation of the CND process can be represented as:

$2NH_4^+ + 4O_2 \rightarrow 4H^+ + 2H_2O + 2NO_3^-$ | **Equation 1**

$2NO_3^- + 12H^- + 10e^- \rightarrow N_2 + 6H_2O$ | **Equation 2**

If methanol is used as the electron donor or the carbon source, the Equation 2 will become

$2NO_3^- + 5/3\ CH_3OH \rightarrow 5/3\ CO_2 + N_2 + 7/3\ H_2O + 2OH^-$ | **Equation 3**

The anammox reaction can be stated as:

$NH_4^+ + 1.32NO_2^- + 0.066HCO_3^- + 0.13H^+ \rightarrow 1.02N_2 + 0.256NO_3^- + 0.66CH_2O_{0.5}\ N_{0.15} + 2.03H_2O$ | **Equation 4**

Nitrogen removal by anammox bacteria requires only about 1.42 gO/gN removed and zero organics consumption, allowing N removal wastewater treatment plants to become energy self-sufficient (Ekama, 2015).

Despite the benefits associated with the anammox process, the rate of adoption is still low. The lack of information on the implementation strategy, specific operating conditions requirements, and the impression that the process requires significant capital cost are some examples of the reasons why the adoption rate is still low. Anammox bacteria have a very slow growth rate, with a doubling time ranging from nine days to two weeks. The anammox bacteria are also sensitive to sudden changes in environmental or process conditions. The operational control required for the anammox is still unclear to the water industry.

Several studies on the application of the anammox process have been conducted by research organisations with varying success. However, these studies have only been performed in a laboratory or a pilot scale operation. For example, the pilot plant trial (4.7 m^3 capacity) of the anammox process to treat sludge dewatering effluent at the Bolivar WWTP in South Australia has shown promising results. However, a full-scale application of the anammox process in a WWTP has not been reported in Australia.

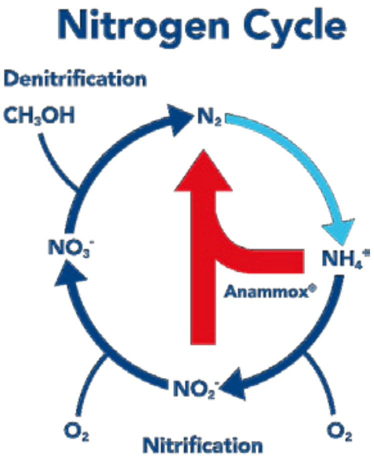

Figure 2. Nitrogen removal process in wastewater treatment (blue indicates conventional, red indicates the anammox process) (Ref: Meng 2012)

To understand the optimal process conditions for sustained performance of the anammox process for the system, EEI carried out laboratory trials and developed a process model. The findings of operating a laboratory scale reactor were then applied in the full-scale implementation.

In order to implement the EEI$_{anammox}$ process and to monitor its efficiency in nitrogen removal, EEI proposed to upgrade the existing sensors and control system at the WWTP. However, the installation of the required sensors and control system was delayed for 18 months. The EEI$_{anammox}$ process was nevertheless implemented with the available sensors such as DO, pH, ammonia and nitrate probes, and by enabling the human machine interface to optimise the process in real time. The EEI$_{anammox}$ process was implemented simultaneously with the CND system. Some cycles of the SBR were on the anammox mode, however, if the nitrate concentration was in excess, the denitrification mode was carried out in the SBR with methanol addition. This had become essential to ensure that the total nitrogen value did not exceed the maximum annual average application rate permitted by the regulatory body (45 mg/L of TN).

In order to introduce and completely implement the EEI$_{anammox}$ process, no addition of anammox bacteria from external sources was carried out. This is mainly because there are no working WWTPs in Western Australia with the anammox process for nitrogen removal. Considering this constraint, we assumed that the inherent anammox bacteria in the WWTP as part of the CND could be the source bacteria and with the right operational procedure, the bacterial biomass could be developed over a period of time. As a result of this, the system could eventually be completely based on the anammox process for nitrogen removal.

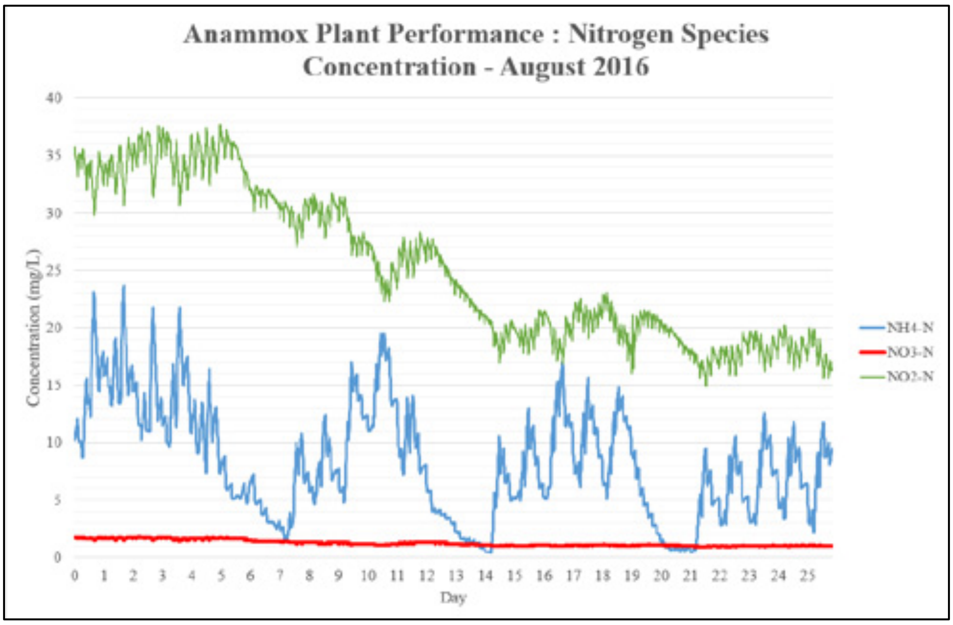

Figure 3 . Performance of the EEI$_{anammox}$ system in August 2016

Regular sampling and off-site testing were conducted for total nitrogen, NH_4-N, NO_3-N and TSS to evaluate the effectiveness of the process and to validate or recalibrate the probes. An indirect measurement of MLSS was carried out using sludge volume index, and recirculation quantity of the activated sludge was based on this data. Due to the slow growth rate of the anammox bacteria, and the WWTP being a suspended growth activated sludge system with no attached or floating media at all, the implementation of the EEI$_{anammox}$ process was challenging. Over a period of 6 months, the total nitrogen was reduced to a range of 25 to 85 mg/L.

The upgrade of the monitoring and control system was completed in February 2016. The reactor's COD, TSS and nitrite could now be monitored in addition to the original measurable parameters. The availability of information on the nitrogen speciation was found to be crucial as it allowed operators to understand the real-time condition of the reactor. By knowing the distributions of nitrogen species within the mixed liquor, the aeration period can be optimised to allow the anammox process. The TSS information is used to estimate the availability of biomass within the reactor to ensure that the optimum biomass concentration is achieved. By having better control of the reactor, we could ensure that both the consistency and performance of the EEI$_{anammox}$ process were improved.

The real-time online remote control system, and the monitoring probes of nitrogen species along with other parameters have helped the full implementation of the EEI$_{anammox}$ process. Operation of the process has resulted in methanol addition being discontinued.

Summary of outcomes and measurable impacts

One of the notable outcomes of the project is that we could demystify the myth surrounding the implementation of the anammox process in an operating wastewater treatment plant. This project has shown that the plant could be operated in both CND and anammox mode, and gradually the operation time of the anammox process could be increased and eventually, the plant could be operated fully on the anammox mode.

The second outcome of the project is that we have proved that the implementation of the EEI$_{anammox}$ process does not require pure anammox bacteria to be added to the aeration basin. Even with the addition of anammox sludge, the start-up of the full anammox process at the WWTP of Waterboard Hollandse Delta Rotterdam, The Netherlands took 3.5 years (Ni and Shang, 2013). Our experience is that within about 12 months, we could completely switch over to full anammox mode. We consider that the addition of anammox sludge is not mandatory.

If a nearby WWTP operates the anammox process for nitrogen removal, it may be advantageous to utilise the biomass from the plant to commission the process in another plant. However, it is not required and neither economical.

The plant's operation and performance data is collected at 10-minute intervals. This enables the operator to evaluate the performance and make any changes to the operation of the system in real time. With respect to the performance of the anammox process, the ammonia-N varied from 1-25mg/L, the nitrite-N from 2 to 18mg/L and the nitrate-N was kept under 5mg/L. As part of the assessment of the tolerance of each nitrogen species, the nitrite was peaked to over 55 mg/L. The plant has consistently kept the nitrogen levels as a sum of ammonia, nitrate and nitrite in the range of 10 to 40mg/L since June 2016, apart from the extreme tolerance testing period.

Figure 3 presents the performance of the system for August 2016 and Figure 4 presents that of a working and weekend day (8/9/2016 and 4/9/2016).

The overall performance, and performance during the winter and summer periods are presented in Figures 5 to 7. The gap of data in Figure 7 is due to the monitoring system being taken off line for regular maintenance service. It can be seen that the plant has consistently performed during these periods apart from the extreme tolerance testing periods.

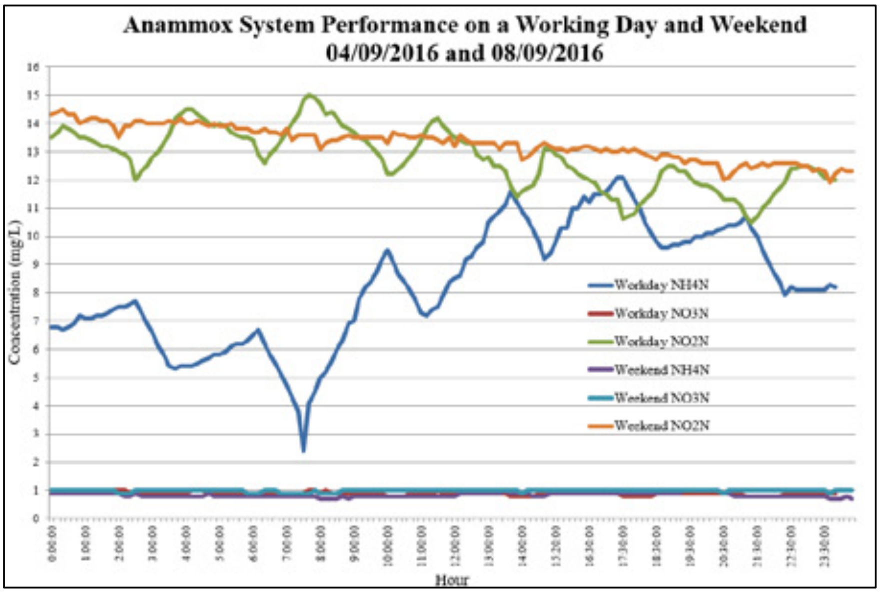

Figure 4. Performance of the $\text{EEI}_{\text{anammox}}$ system at DBC WWTP on a week day and weekend

The extent to which the outcomes are sustainable

The plant now requires no methanol addition, which otherwise would have cost the operator about $200,000 per annum. In addition, the aeration cost (without considering the mixing cost) could be gradually reduced from $25,000 per annum (for CND) to less than $5,000 per annum with the complete operation of the anammox process. The overall power cost has been reduced by 20% including the mixing energy as shown in Figure 8.

The nitrogen removal efficiency is over 90%. The $\text{EEI}_{\text{anammox}}$ process performed efficiently during winter periods when the temperature was below 15°C. The lessons learnt from this project of retrofitting the anammox process to an existing WWTP will be applicable to other plants.

The cost of the implementation of the system is substantially lower, and the main requirement is a good online real-time monitoring and control system. For the case of DBC, the payback period has been found to be less than 18 months.

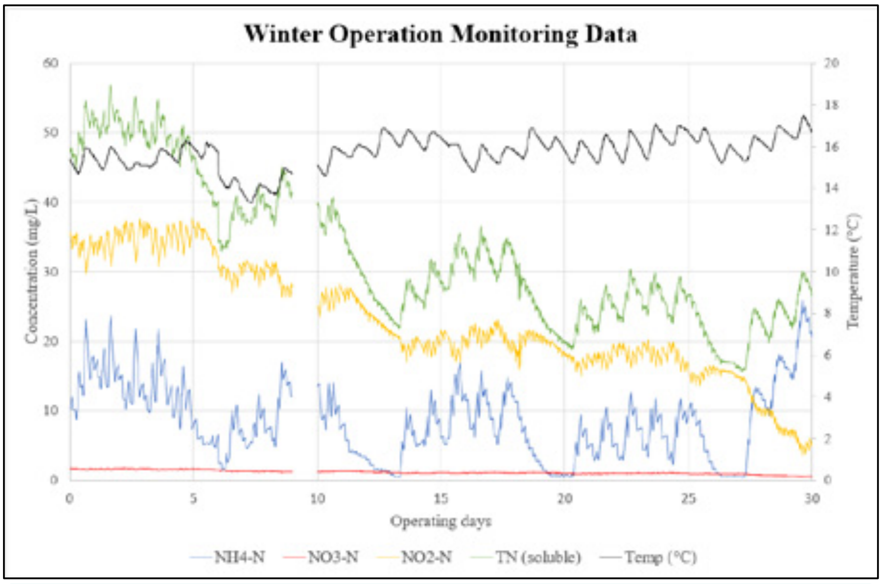

Figure 5. Performance of the $\text{EEI}_{\text{anammox}}$ process during winter at DBC WWTP

Important lessons learnt and critical success factors.

It has been concluded that the anammox process could be implemented in an existing wastewater treatment plant without the need for significant capital investment or operational cost. There is no requirement to import or apply pure anammox culture to retrofit the anammox process to an existing operating full-scale WWTP. With the right control, the process start-up time can be reduced substantially to within a few months.

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Dr Raj Kurup is an internationally reputed environmental engineer and project manager. Raj was awarded the title of one of Australia's Most Innovative Engineers in the consulting category by Engineers Australia for 2017. Raj was also selected by the Australian Water Association as the WA Water Professional of the Year 2017. Raj has over 25 years of professional experience in various facets of water and wastewater engineering. Raj has authored over 60 publications, including highly cited peer reviewed journal papers, refereed conference papers, books, and book chapters. Raj's qualifications include a PhD in wastewater treatment from Murdoch University, a Master of Engineering Science (Research) in environmental engineering from UWA, a Master of Engineering in environmental science & technology from UNESCO-IHE Delft, The Netherlands, and a Bachelor of Engineering in Civil Engineering from the College of Engineering Trivandrum, India.

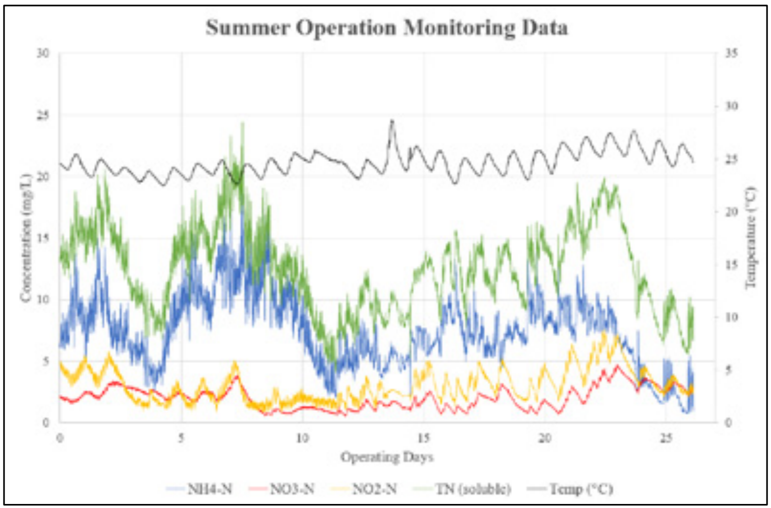

Figure 6. Summer Operating data of the EEI$_{anammox}$ process at DBC WWTP

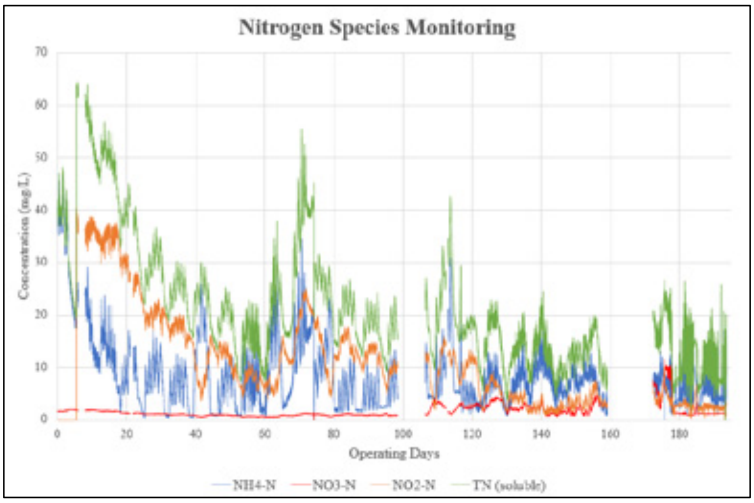

Figure 7. Overall Operating data of the EEI$_{anammox}$ process at DBC WWTP

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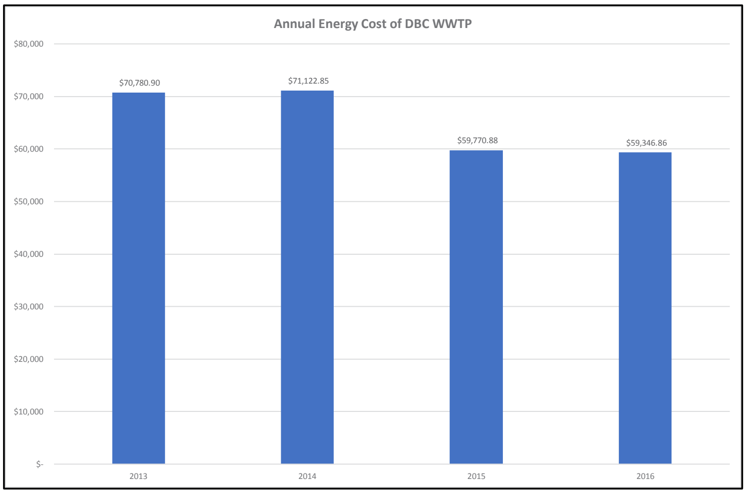

Figure 8. Annual energy cost of the EEI $_{anammox}$ system installed at DBC WWTP