**Final report**

**Anaerobic Ammonium Removal (AAR) Waste Water Treatment Facility**

Project code: P.PIP.0497

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Date published: 20 May 2021

PUBLISHED BY

Meat & Livestock Australia Limited

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NORTH SYDNEY NSW 2059

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

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# Abstract

1. The purpose of this project was to implement an Australian-first at a Red Meat Processing plant a biological treatment process that converts ammonia in wastewater to nitrogen gas. The system was successfully demonstrated at a laboratory and pilot stage however was unable to progress to commercial-scale due inability to secure an installation, operation and maintenance partner.

# Executive summary

**Background**

Anaerobic ammonium removal (AAR) nitrogen removal offers major financial benefits, particularly in terms of operating cost to the Australian red meat processing industry if it can be successfully and reliably implemented. If the AAR technology proved successful, Australian meat processing facilities would be able to upgrade their conventional Biological Nutrient Removal process as the companies either outgrow their existing systems or environmental controls tighten forcing improved nitrogen removal. The technology could prove popular with the lower operating cost (reduced electricity demand and waste solids) and lower capital cost (smaller volume units required).

**Aims/objectives**

* Develop a viable AAR process for meat processing plants.
* Demonstrate the application of existing process knowledge to show anaerobic ammonium removal (AAR) for red meat processing wastewater at both pilot and full-scale.
* Application of on-line nutrient sensor technology for the process control of the AAR process.
* Development of AAR seed material acclimatised to red meat industry wastewater.
* Build industry experience in the operation of full scale AAR treatment.

An additional delay factor was the slow development of stable covered anaerobic lagoon (CAL) treatment in the main wastewater treatment plant. Whereas this had little effect on the downstream conventional Biological Nutrient Removal and Sequenced Batch Reactor process, it impacted AAR growth in the demonstration reactor. As a result of these issues, the project successfully achieved only the first two stages of the project. Full scale use of AAR process was not attempted.

**Methodology**

**Stage 1:** Generate a seed inoculum of AAR bacteria in a purpose-built 100 litre reactor based at UQ, Brisbane. The reactor was fitted with nutrient sensors and operated with the aim of rapidly accumulating sufficient seed inoculum to start the demonstration reactor.

**Stage 2:** Design and construct a 10,000 litre demonstration reactor fitted with on-line nutrient sensors on-site at Red Meat Processor to operate on CAL-treated meat processing effluent. The key aims of this stage were to evaluate start-up strategies for the reactor, assess the performance of AAR bacteria on a mainstream meat processing wastewater feed and build sufficient mass of AAR bacteria to seed a full-scale reactor.

**Results/key findings**

The Anaerobic Ammonium Removal (AAR) process developed in this project is a viable nitrogen removal process for mainstream meat industry wastewater. The wastewater treatment train consisted of two anaerobic ponds in series followed by the single tank, sequencing batch reactor (SBR) with no additional proprietary technology such as carriers or sludge selection devices. The second anaerobic pond provided a consistently low volatile fatty acids (mg/L as acetic acid) VFA to ammonia ratio and low Total Suspended Solids (mg/L) feed stream to the AAR process. The AAR aeration strategy, with regular anoxic periods, was key to encouraging the ideal AAR microbiological population during the commissioning process.

**Recommendations**

A major challenge for adoption of AAR technology in Australia is the lack of AAR seed sludge to assist with reactor start-up. Experience both in the pilot and demonstration reactors was that the very slow growth rate of AAR bacteria makes the accumulation of a critical mass of AAR biomass excruciatingly challenging. During this start-up phase, the bacteria are highly sensitive to upsets which can set back the process by weeks. Once AAR sludge becomes more available from existing full scale plants and industry experience accumulates, this issue may become less problematic.

In Australia, there are several pilot scale AAR processes being attempted by large urban utilities, but there is yet to be a viable, full-scale operation in place. Progress has been slow, in large part due to Australia’s strict biosecurity laws that prevent the importation of viable AAR sludge from overseas. A demonstration process was implemented at Bolivar Waste Water Treatment Plant in South Australia but has since closed down. Queensland Urban Utilities have been researching Veolia’s proprietary ANITA-MOX technology at the Innovation Centre at Luggage Point Waste Water Treatment Plant in Brisbane but are also yet to implement it at full-scale. Melbourne Water is also conducting AAR trials.

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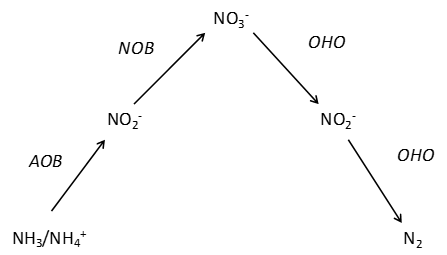
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# Background

## Nitrogen Removal – Anaerobic Ammonia Removal vs Conventional Biological Nutrient Removal

Nitrogen removal from wastewater remains a major issue for meat processing plants in Australia and continues to play a key role in the design of new wastewater treatment plants (WWTP) and the upgrade of existing plants. As there are no economically viable physical processes for the removal of nitrogen to low levels (< 50 mg/l), meat processing plants use biological processes typically known as Biological Nitrogen Removal (BNR). BNR systems involve using various nitrifying bacteria to oxidise nitrogen from ammonium (NH4+) to nitrate (NO3-) and then using denitrifying bacteria in the presence of biodegradable carbon to reduce nitrate to dinitrogen gas (N2), which diffuses into the atmosphere. This is represented in Fig. 1 below.

**Figure 1.** Nitrogen pathway in conventional BNR treatment



AOB = Ammonium Oxidising Bacteria

NOB = Nitrite (NO2-) Oxidising Bacteria

OHO = Ordinary Heterotrophic Organism (aka denitrifiers)

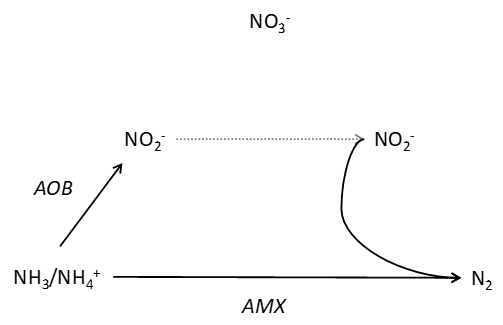
These conventional systems have worked well for meat processing facilities for the last two decades in Australia, but their edge as the leading technology for nitrogen removal from wastewater is being steadily eroded by the following:

Large increases in the unit cost of energy (particularly electricity). The oxygen necessary for the microbial oxidation of ammonia to nitrate in conventional BNR systems is provided by power hungry blowers or mechanical surface aerators.

The increasing desire of facilities to utilise the biogas generated by their Covered Anaerobic Lagoons (CALs) for power generation. Conventional BNR systems require carbon to be able to denitrify nitrate back to dinitrogen gas. This is typically in the order of 10-25% of the carbon that would have gone to the CAL, representing a similar loss in total biogas production and capture. This shortfall has to be made up with power supplied from the grid (at the new high price points).

Anaerobic Ammonium Removal (AAR) – also sometimes called anammox - is a novel process that involves the use of a number of types of bacteria to remove nitrogen from wastewater with only a fraction of oxygen (and hence power) required and virtually no carbon required. The standard AAR nitrogen pathway is shown below in Fig. 2.

**Figure 2.** Nitrogen pathway in AAR process



AMX = ANaerobic AMMonium OXidising bacteria (aka Anammox)

An AAR process is optimised to limit the production of nitrate by only providing minimal quantities of oxygen, enough to allow Ammonia Oxidising Bacteria (AOB) to oxidise the ammonium to nitrite (NO2) but limit the further oxidation of the nitrite to nitrate by the Nitrite Oxidising Bacteria (NOB). The anammox (AMX) bacteria are then able to convert ammonium and nitrite directly to dinitrogen gas without any further addition of oxygen or carbon.

For these reasons, a successful AAR process operating in lieu of a conventional BNR system would have substantial financial benefits for a processor.

In the treatment of municipal sewage, there are two types of AAR process:

* SIDESTREAM: The AAR process treats the warm (35oC), high ammonia (~ 1,000 mg/l) liquid waste from a sewage treatment plant’s (STP) anaerobic digestorwhich anaerobically digests the waste activated sludge (WAS) from the main plant’s activated sludge process (usually a conventional BNR system). This stream typically recycles 20-25% of the nitrogen load (due to digesting the WAS) back to the head of the STP if a sidestream AAR process is not present.
* MAINSTREAM: The AAR process replaces the conventional BNR system treating the entire sewage flow. This flow is typically cool (8 – 20oC) with low total nitrogen levels (~ 50 mg/l).

Anammox processes that operate on anaerobic digestate (sidestream processes) have seen significant success overseas. In contrast, mainstream processes have been more difficult to successfully implement and as yet remain relatively unproven for STPs, despite huge research and full-scale effort.

The AAR process under study in this PIP project attempts to perform mainstream treatment of all the meat processing wastewater. Unlike mainstream STP processes, however, the temperature is warmer (~30oC) and the nitrogen levels are higher (~ 300 mg/l), so that the process can be considered to be intermediate between the STP mainstream and sidestream process.

# Objectives

* Develop a viable AAR process for meat processing plants.
* Demonstrate the application of existing process knowledge to show anaerobic ammonium removal (AAR) for red meat processing wastewater at both pilot and full-scale.
* Application of on-line nutrient sensor technology for the process control of the AAR process.
* Development of AAR seed material acclimatised to red meat industry wastewater.
* Build industry experience in the operation of full scale AAR treatment.

# Methodology

## Project Approach

The project team initially planned a three staged approach as follows:

1. Stage 1: Generate a seed inoculum of AAR bacteria in a purpose-built 100 litre reactor based at UQ, Brisbane. The reactor was fitted with nutrient sensors and operated with the aim of rapidly accumulating sufficient seed inoculum to start the demonstration reactor.
2. Stage 2: Design and construct a 10,000 litre demonstration reactor fitted with on-line nutrient sensors on-site at Red Meat Processor to operate on CAL-treated meat processing effluent. The key aims of this stage were to evaluate start-up strategies for the reactor, assess the performance of AAR bacteria on a mainstream meat processing wastewater feed and build sufficient mass of AAR bacteria to seed a full-scale reactor.
3. Stage 3. Design, construct and operate a 600 kL full scale AAR reactor on site at the Meat Processing Plant.

The approach was severely challenged by the very slow-growing nature of AAR bacteria and the vulnerability of early stage AAR cultures to shocks and reactor issues. In other parts of the world these issues may be overcome by using AAR sludge from existing facilities. Unfortunately this was not possible in Australia due to biosecurity restrictions for importing sludge and the lack of full scale AAR processes.

An additional delay factor was the slow development of stable CAL treatment in the main wastewater treatment plant. Whereas this had little effect on the downstream conventional BNR SBR process, it impacted AAR growth in the demonstration reactor. As a result of these issues, the project successfully achieved only the first two stages of the project. Full scale use of AAR process was not attempted.

# Project outcomes

The following outcomes were gained from the research:

* Anaerobic Ammonium Removal (AAR) occurs successfully with mainstream meat processing wastewater using appropriately acclimated sludge.
* Even with sludge seeding from existing AAR reactors, the start-up of the reactors requires a long time to accumulate a robust critical mass of AAR bacteria. This remains the most prominent difficulty of the process. Once established however, nitrogen removal is rapid and robust. The results suggest once the reactors are well established large quantities of sludge can be used to start-up new reactors with a relatively rapid replacement of the seed sludge in the original reactor.
  + The aeration control strategy proved to be the most useful means of achieving successful AAR given the AAR bacteria’s simultaneous requirement for an anaerobic environment and aerobically generated nitrite. In practice, intermittent aeration coupled with Dissolved Oxygen (DO) control proved to be the most effective strategy in the demonstration, pilot and laboratory reactors.
  + The reactors were generally operated at 35oC in the attempt to reduce commissioning time. Laboratory scale experiments at lower temperatures found similar nitrogen removal rates, greater specific nitrogen removal rates but slower sludge growth at 25oC after six weeks of sludge acclimatisation.
  + The rate of ammonia removal was unaffected by the total ammonia concentrations in the reactor between 5 mg /L and 150 mg/L at pH 8.1. Higher total ammonia concentrations may not inhibit the AAR process if the pH is lower.
  + Nitrite production should aim to be close to zero at the start of aeration after the settle, decant and fill phases. Nitrite concentrations up to 30mg/L during the aeration phase in an established AAR system did not inhibit the nitrogen removal rate.
  + The flocculent sludge had excellent settling properties with a sludge volume index (SVI) of 100 mL/g at 30 minutes. AAR granules formed in all the reactors despite the absence of specialist equipment to promote granule formation. Sludge wasting to prevent high Total Suspended Solids (TSS) discharge was not required from any of the reactors over the research period.

The performance and suitability of two WTW nutrient sensors were an integral part of this research project.

* The WTW AmmoLyt Plus ammonia sensor provided continuous ammonium ion concentration monitoring and allowed calculation of removal rates in the pilot and demonstration reactors. It was useful for monitoring ammonia removal rates in the reactors. In general there was good agreement between the ammonium probe and off line laboratory measurements. Regular maintenance and calibration was required to ensure reliable measurements. Electrode replacement was required more often when the number of cycles per day was low (typically at reactor start-up). Installation of a cheap electrical conductivity (EC) sensor could be used to verify ammonia sensor readings as they are linearly proportional.
* The WTW Nitravis 701 IQ probe uses UV spectometry to determine nitrite and nitrate concentrations in the reactor contents. The sensor assembly is considerably larger than the other sensors used and required a purpose-built fitting to allow its suspension in the demonstration reactor. The Nitravis probe was useful during the commissioning and data gathering phases of the research project and generally reliable and required only annual maintenance. Nevertheless one of the two probes purchased for the research project did breakdown during the three years operation. We consider the high cost of the Nitravis probe is not justified for the minor contribution to the reactor control, which is more reliably and easily done using cheaper DO sensors. . The daily testing with simple strip test for nitrate and nitrite is likely to be sufficient for the system control under full scale operation*.*

The overall AAR nitrogen removal rate in meat industry wastewater is approximately four (4) times greater than conventional Biological Nutrient Removal (BNR) nitrogen removal whilst requiring 60% less aeration and producing negligible waste sludge. The estimated CAPEX for a conventional BNR system with larger covered anaerobic lagoons (CAL), Sequencing Batch Reactor (SBR) and sludge dewatering is approximately the same as an AAR system with two CALs in series and smaller AAR tank reactor. The estimate OPEX for the AAR system is 25% of the conventional BNR system mainly due to sludge disposal cost savings. The future increased cost of electricity and sludge disposal further increases the appeal of the AAR option for nitrogen removal.

# Conclusion

This project successfully demonstrated the first known application of mainstream anammox nitrogen removal from red meat industry wastewater in a single vessel, suspended biomass reactor. The demonstration scale and laboratory scale reactors both reached nitrogen removal rates of over 500 mg N/L/d at 35oC. These rates are similar to those achieved internationally in similar reactor designs treating domestic sidestream wastewater with significantly higher nitrogen feed concentration (Lackner, et al., 2014). Fluorescence in situ hybridisation (FISH) analysis and stoichiometric calculations confirmed that the AAR process was the major biochemical mechanism for nitrogen removal.

## Benefits to industry

Anaerobic ammonium removal (AAR) nitrogen removal offers major financial benefits, particularly in terms of operating cost to the Australian red meat processing industry if it can be successfully and reliably implemented.

# Future research and recommendations

In Australia, there are several pilot scale AAR processes being attempted by large urban utilities, but there is yet to be a viable, full-scale operation in place. Progress has been slow, in large part due to Australia’s strict biosecurity laws that prevent the importation of viable AAR sludge from overseas. A demonstration process was implemented at Bolivar Waste Water Treatment Plant in South Australia but has since closed down. Queensland Urban Utilities have been researching Veolia’s proprietary ANITA-MOX technology at the Innovation Centre at Luggage Point Waste Water Treatment Plant in Brisbane but are also yet to implement it at full-scale. Melbourne Water is also conducting AAR trials.

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