Nitrogen removal

Nitrogen present in meat processing wastewater are termed a "nutrient", since they are essential elements for life. They largely derive from proteins dissolved into wastewater from meat tissue, blood (nitrogen), paunch liquid and stockyards.

Nitrogen is stringently regulated in Australia. Regulatory limits vary widely throughout Australia. For river discharge, they are usually negotiated on a site-specific basis taking the limiting nutrient of the river system and the catchment. In many parts of Australia, direct river discharge is not an option. Similarly, discharges to land irrigation depend on the receiving environment. The cost of wastewater discharged to sewer is generally dependent on (amongst other characteristics) the nutrient load.

These limits define the levels that the wastewater treatment plant must reliably achieve and to some extent which treatment technologies are most appropriate.

Table 1: Typical regulatory limits for nitrogen

Receiving environment	Nitrogen
Sewer	$NH_3 \leq 50$ mg/L TN ≤ 100 mg/L
River discharge	$NH_3 \leq 1$ mg/L TN ≤ 50 - 100 mg/L (site specific) Also, typically load based limits
Land irrigation (soil & crop specific)	TN: 250 – 500 kg/ha/yr load based limits

Technologies for reducing nitrogen

A range of technologies exist for reducing nitrogen concentrations in meat processing wastewater.

Table 2: Technologies for nitrogen removal

Technology	Process	Mode	Typical N removal	Status	In Australian meat plants
SBR	Bacterial	Intermittent	> 80%	Proven	> 5
BNR	Bacterial	Continuous	> 80%	Proven	> 4
Aerated Pond	Bacterial	Continuous	~ 65%	proven	1
Anaerobic Ammonium Removal (Anammox)	Bacterial	Continuous/ intermittent	> 80%	emerging	In trials
Dosed DAF	Chemical	Continuous	~ 50%	proven	many
Struvite	Crystallisation	Continuous	Low	emerging	none

The first three technologies in this table use bacterial biological nitrogen removal activated sludge processes. Biological nitrogen removal technology is preferred for river discharge and land irrigation where nitrogen limits are strict. Biological nitrogen removal can be harnessed in a range of reactor types including:

- Continuous Biological Nutrient Reactors;
- Sequencing Batch Reactors; and
- Aerated ponds which are a less intensive form of continuous BNR systems.

Dosed DAF technology is commonly used for sewer discharge. Anaerobic Ammonium Removal (AAR) technology and struvite are emerging technologies which have not been proven at large scale in meat plants.

The Activated Sludge Biological Nutrient Removal (BNR) process

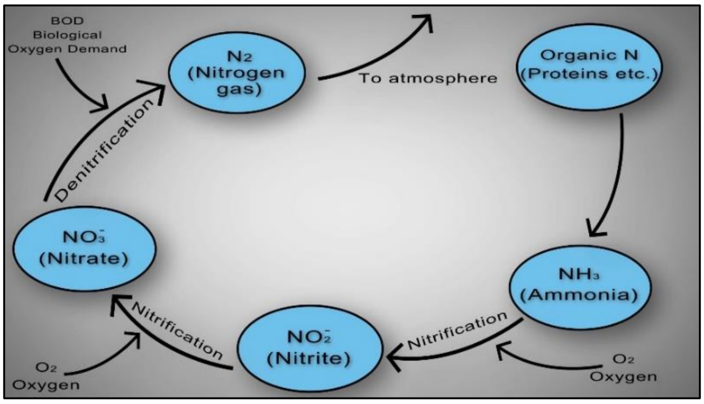
An Activated Sludge Biological Nutrient Removal process achieves nitrogen removal in a two-step process.

Step 1 is the nitrification process and is a multi-step reaction.

- Ammonia rich water from upstream CALs or anaerobic lagoons is converted to nitrite by ammonia oxidising bacteria.
- Nitrite is further oxidised to nitrate by nitrite oxidising bacteria.

Nitrification only changes the form of dissolved nitrogen in the wastewater, but it is an essential first step for removal. The nitrification process must occur in an aerated zone where oxygen is available. COD and BOD levels are kept as low as possible.

Step 2 is the de-nitrification process where nitrate is reduced to nitrogen gas (N_2) by de-nitrifying bacteria. The N_2 escapes the wastewater into the atmosphere. This step removes the nitrogen from the wastewater. The denitrification process occurs in the absence of oxygen and requires high levels of biodegradable COD.



The environment required for each step is radically different. The two technologies provide these two different environments in different ways. Provided the appropriate environment is present, the relevant bacterial will perform the reactions needed to reduce nitrogen levels.

In **Continuous BNR processes**, nitrification and denitrification are performed in different parts of the reactor. An example is the Biolac process where although the denitrification zones are not separated by walls from the nitrification zones, there are distinct areas allocated for each reaction. This requires the constant circulation of flow between zones to complete the reaction.

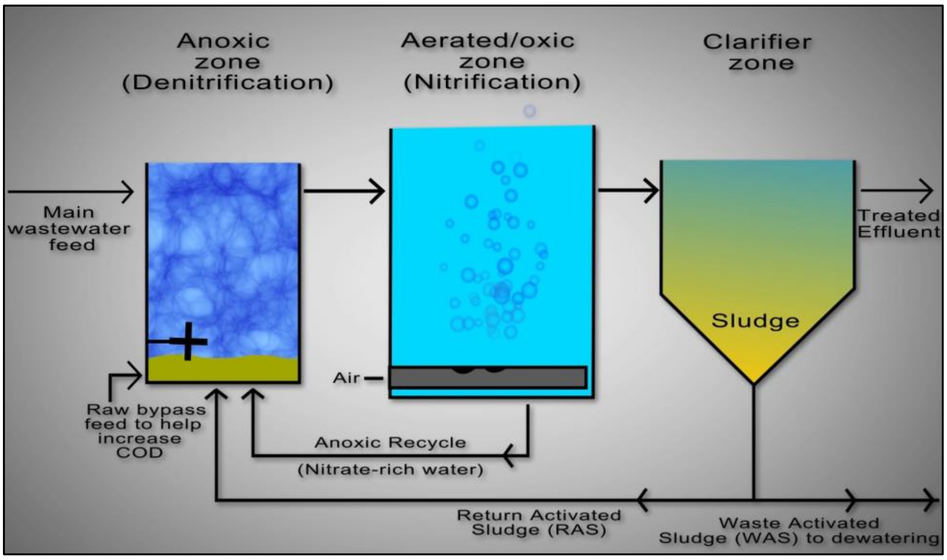
Image: Teys, Beenleigh

In **Sequence Batch BNR processes**, nitrification and denitrification occur in the same reactor space, but at different times in the cycle. For example, the aeration system turns on for the nitrification part of the cycle, then switches off during the denitrification period. This saves the need for pumping large volumes of liquid around or for separate structures such as clarifiers.

Image: JBS, Dinmore

Continuous Activated Sludge BNR systems

The main components of a modern Continuous Activated Sludge BNR systems include:



The anoxic (denitrification) basin or zone

This basin or zone continually receives several streams including the main feed of ammonia-rich wastewater from the upstream CAL or anaerobic pond. This is a large volume stream containing the bulk of the new nitrogen load to the system. Unfortunately, the COD content of this stream is usually insufficient to provide all the COD needed for the denitrifying bacteria so additional COD is added. This can be an external carbon source such as ethanol or methanol, but this is expensive. Most systems divert a portion of the raw primary-treated wastewater to the anoxic basin to supply the carbon needed. Since this stream bypasses the upstream CAL, it is often termed the raw bypass. For some systems, this can be as high as 25% of the total wastewater flow.

The Return Activated Sludge is usually pumped out of the base of the clarifier and back to the anoxic zone. This ensures fast rates of treatment.

The denitrifying bacteria also require nitrate which is not present in the raw wastewater feed and must be supplied from the downstream aerated basin. In the anoxic basin, denitrifying bacteria catalyse the conversion of nitrate to nitrogen gas and consume COD in the process. The loss of nitrogen gas to the atmosphere removes it from the wastewater.

In the Biolac process, the upstream aerated zone provides the nitrate-rich water for the downstream anoxic zone so there is no separate recycle stream. The basin is usually mixed in a manner to minimise the presence of oxygen, for example with submerged mixers.
Image: Teys, Beenleigh

The oxic (nitrification) basin or zone

The wastewater continually flows out of the anoxic basin or zone into the aerated basin or zone which maintains high dissolved oxygen concentrations.

- This supports two important reactions. Firstly, COD removal. Heterotrophic bacteria consume any remaining biodegradable COD aerobically to form new cells and CO_2. These excess cells must be continually removed as Waste Activated Sludge.
- Secondly nitrification occurs in the presence of the high dissolved oxygen and low COD levels where nitrifying bacteria in the flocs convert the ammonia to nitrate. The acid released by the nitrification process is neutralised by the alkalinity generated by both the upstream CAL or anaerobic pond and denitrification.

Clarifier

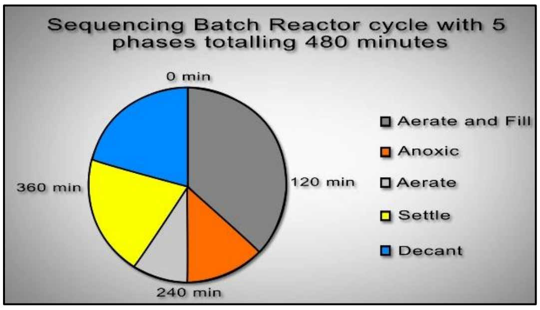
The contents of the aerated basin flow continually into the clarifier. In the clarifier, the bacterial floc settles out of the water column in the still environment provided. The treated effluent overflows the clarifier usually through some kind of weir system and should contain low total suspended solid levels, typically less than 20 - 50 mg/L.

Clarifier weir
Image: Teys, Beenleigh

The settled sludge is pumped out of the base of the clarifier and split into the sludge to be recycled and sludge to be pumped to the dewatering plant for disposal. In red meat processing wastewater treatment plants the dewatering device is typically a belt filter press or decanter centrifuge. The sludge stream is injected with a suitable polymer which promotes large, stable flocs for dewatering. The mixture is pumped to the dewatering device which removes large quantities of water from it and generates a dewatered sludge cake. Ideally this cake should have a consistency somewhat like wet cardboard. The filtrate is returned to the head of the system. The sludge cake is disposed to an appropriate waste management facility such as composting or landfill.

Sequence Batch Reactor BNR

Sequencing Batch Reactors undertake the activated sludge process in batches. Rather than performing the anoxic, aerated and settling processes in different specialised tanks each with their own equipment, in the sequencing batch reactors all stages are performed in one tank or pond, but at different times. Note that the same biological processes are used. Only the reactor is different. In a sequence batch reactor a time-based control strategy is employed. This strategy is built around a "cycle" consisting of a number of "phases".



SBR Cycle with 5 phases totalling 480 minutes

Each of these phases establishes the environment conducive to the process required by controlling the entry/exit of streams and operation of equipment. This is automated using PLC control. Once the Sequencing Batch Reactor has completed a cycle, the cycle clock resets to zero and the sequencing batch reactors repeats the cycle with a new batch of wastewater.

Waste Activated Sludge must still be removed during aerate & fill phase. The WAS is dewatered in exactly the same manner as for continuous biological removal plants.

Table 3: Properties of Continuous activated sludge systems and Sequencing Batch Reactors

Positives	Negatives
Continuous activated sludge BNR systems	
• Low maintenance • Relatively robust • Relatively easy to operate • High effluent quality able to meet current and anticipated future discharge requirements	• Not very flexible to changes in wastewater volume or quality. • High operating & capital costs • Large amounts of sludge production • Large volumes of wastewater are circulated. • Skilled operators are required to operate system
Sequencing Batch Reactors	
• High degree of operational flexibility (to changes in wastewater volume or quality). • Lower capital cost than continuous BNR since expensive clarifiers are not required. • High degree of automation. • Small footprint. • High effluent quality able to meet current and anticipated future discharge requirements.	• Higher level of control required compared to continuous BNR. • Batch operation means that upstream storage required if only 1 SBR. • Requires knowledgeable and experienced operators. • Equalization prior to discharge may be required due to discontinuous discharge. • Large amounts of sludge production.

Legislative and regulatory requirements

Direct regulatory requirements concerning nutrient removal will be stated in the facility's environmental protection licence, permit or approval which is issued by State Government. The main focus is usually on minimising the risk of odour and the appropriate off-site transport and disposal of the dewatered waste solids.

Operator Responsibilities

Recommended day-to-day operator responsibilities include:

Activated sludge BNR systems are extremely responsive due to their relatively short hydraulic retention times and their high bacterial concentrations (MLSS) which are typically of the order of 4 – 6,000 mg/L. Consequently, it is important that their performance is monitored daily. It is critical that any changes to system operation are made in a considered manner and in accordance with the designer's operating parameters. This is because impacts from some changes may take up to a month to surface (especially where sludge age is long).

Common responsibilities include:

Maintain MLSS Levels in the system

- ☐ Measure MLSS concentration (mg/L) daily as this defines the need for dewatering to maintain the operating MLSS and sludge age setpoint. Sample at the mixed contents of basin; during aerate & fill phase (SBR).
- ☐ Run the dewatering device to dewater the WAS. This includes checking polymer level, starting the device, ensuring the DWAS is of good consistency and dry solids and checking the filling of the DWAS transport.
- ☐ Clean dewatering area after completion.
- ☐ Check RAS pumps are operating properly. If a Continuous BNR system also check the anaerobic main stream control valve operates correctly.
- ☐ Record the WAS flow dewatered (needed to estimate sludge age).
- ☐ Calculate sludge age.

Maintain aeration system

- ☐ Maintenance (e.g. diffuser cleaning and/or replacement).
- ☐ Check Dissolved Oxygen (DO) levels in aeration & anoxic basins to ensure they are at design settings.
- ☐ Warn supervisor if DO can't be maintained.

Monitor treatment performance

- ☐ Measure sludge settleability using settleometer or measuring cylinder. Record tests as interface of sludge & clear liquid (mL/L). Critical test for identifying problems with sludge settling.
- ☐ Measure the pH, temperature & electrical conductivity (usually use a portable instrument) at the mixed contents of basin; during aerate & fill phase (SBR).
- ☐ Measure the dissolved oxygen concentration (mg/L) (usually use a portable instrument). This provides a check on the on-line DO sensors. Sample mixed contents of basin; during aerate & fill phase (SBR).
- ☐ Measure COD, TSS, pH, TN, NH_3-N, NO_x-N and TP as required. Check system performance. These may be monitored in-house using modern spectrophotometers with digestion block, or externally. Sample treated effluent.
- ☐ If on-line sensors are available to monitor these parameters, check regularly (at least daily) to monitor levels. If ammonia levels or nitrite or nitrate levels in treated effluent increase, discuss with supervisor.
- ☐ Ensure results are recorded, preferably in a spreadsheet. This data is essential for troubleshooting.
- ☐ Clean & calibrate sensors as required.
- ☐ Measure raw feed flow to BNR with installed flowmeter. This is essential for balancing carbon supply for denitrification.
- ☐ Measure total flow to BNR with installed flowmeter. This is essential for ensuring hydraulic retention time is appropriate.

Monitor sludge settling

- ☐ Sample & test settleability of sludge from aeration basin at least daily. Record results preferably in a spreadsheet. If settleability changes markedly, notify supervisor immediately.
- ☐ Check for increasing levels of scum, foam, mousse or crust on the basins. This may be a sign of bacterial bulking. Inform the supervisor to determine the course of action;
- ☐ Failure of sludge to settle is a serious problem and urgent action is needed. It usually leads to increased TSS in the final effluent.

Routine Checks

- ☐ Ensure inlet & outlet weirs, pipes & pumps are not blocked.
- ☐ Check that the clarifier overflow is of a high quality & the sludge blanket is well below the overflow weirs.
- ☐ Check any chemicals required (e.g. for P dosing) are available.

Supervisor and management responsibilities

The primary responsibilities of the supervisor include:

- ☐ Review monitoring data to observe trends with time. The best means of catching problems before they cause non-compliance with final effluent quality is to watch trends with time for influent COD and nitrogen load (daily flow x influent concentrations), DO levels during aeration, especially during summer, pH trends (heavily impacted by nitrogen reactions), sludge settling behaviour, final effluent quality with time.
- ☐ Ensure maintenance is performed and regular calibration of sensors (especially DO) is performed.
- ☐ Anticipate impacts of sustained increases or decreases in production on the operation of BNR systems. Where needed, obtain specialist advice on these impacts.

These fact sheets have been prepared by The Ecoefficiency Group Pty Ltd in association with Johns Environmental in 2017.