CONTROL AND OPTIMISATION OF A HIGH STRENGTH NITROGEN INDUSTRIAL WASTEWATER BNR PLANT

D.D. Irvine and A. Khan
Pattle Delamore Partners Limited, Auckland, New Zealand

ABSTRACT

Meat rendering plants produce very high strength nitrogenous wastewater that requires intensive monitoring and control to ensure adequate nitrogen removal. A North Island based rendering plant that produces meat & bone meal, tallow and blood products, with raw wastewater nitrogen concentrations of 730 mg/L, found that its biological nitrogen removal (BNR) part of the wastewater treatment plant was operating poorly, generating a lot of odour and was not meeting the discharge consent compliance limits.

A rigorous troubleshooting programme was initiated to identify the cause of the treatment deterioration. Processes were recognised early during the troubleshooting phase and substantial process train changes were initially implemented to prevent further overloading, stop odours and to allow the BNR plant to recover quickly without compromising the processing ability of the rendering plant.

Following the initial plant reconfiguration, a period of close monitoring was undertaken to identify any potential areas for further system improvements. It was identified that the variable nature of weekly and seasonal processing was resulting in highly variable operating conditions. Alkalinity and carbon level entering the BNR system were marginal for the nitrogen requirements and that a reduction in either parameter was resulting in a rapid decrease in nitrogen removal. Key improvements made to the system included better management of weekly load variations on the BNR system, the inclusion of supplementary carbon to maintain nitrogen removal during seasonal processing fluctuations and an additional system reconfiguration of the BNR system to provide for effluent polishing.

The overall changes to the treatment system have resulted in more consistent loads on the BNR system, enabling consistent nitrogen removal, from an influent nitrogen concentration of 730 mg.NH_4-N/L to below 50 mg.NH_4-N/L and 80 mg.NO_3-N/L. All system upgrades were implemented without significant capital expenditure.

KEYWORDS

Biological nitrogen removal, industrial wastewater treatment, rendering.

1 INTRODUCTION

Meat rendering is considered a value-added process for the meat industry, receiving and processing generally non-edible by-products into tallow, blood meal and meat & bone meal (MBM). Meat rendering can be undertaken either in a high temperature rendering (HTR) or in a low temperature rendering (LTR) plant. While there is no free water in the HTR method, the resulting meal is deep-fried in hot fat and the tallow that is produced is generally of poor quality. LTR plants operate at lower temperature range with and without direct heating. The LTR plants generally produce good-quality MBM and generate tallow with good colour. However, the LTR process produces higher contaminant loading in the resultant wastewater, but produces less air pollutants (gases and odours), less ash content in meal and results in an easier phase separation than HTR. The resultant wastewater from LTR plants is characteristically high strength, with particularly high levels of nitrogen and biochemical oxygen demand (BOD), which associated with high protein content and high levels of fats, oil and grease. Depending on the disposal method, rendering plant wastewater requires a high level of treatment to reduce contaminant levels in the wastewater to meet discharge consent limits.

A North Island based LTR rendering plant that produces MBM, tallow and blood products, was encountering operational problems in July 2009 with the biological nitrogen removal (BNR) part of its on-site wastewater treatment plant resulting in non-compliance of the discharge of its treated wastewater. The operational problems also contributed to the generation of objectionable odours. Although its wastewater treatment system was managed with external professional assistance at the time of the operational problems, the meat rendering plant owner sought independent advice to assist in reducing the odour and to manage its compliance. The rendering plant faced the risk of enforcement action from the regional council because of the continued non-compliance in relation to odour generated from the wastewater treatment plant as well as for exceeding the compliance limits in the final discharge.

With the assistance of the rendering plant staff, a comprehensive troubleshooting investigation was conducted to investigate the cause of the poor BNR system performance. Once the causes and process limitations were identified and resolved, the treatment system was initially reconfigured and then optimised to progress towards a level of controlled operation that would ensure compliance with the discharge consent limits on an ongoing basis.

2 THE WASTEWATER TREATMENT SYSTEM AND ITS DETERIORATION

2.1 WASTEWATER CHARACTERISTICS

The variable nature of seasonal and daily processing at the rendering plant results in highly variable wastewater flows and loads. Table 1 shows the general nature of average and peak characteristics of the wastewater that was received into the biological treatment plant after it has been pre-treated in a dissolved air flotation (DAF) unit.

Table 1: Rendering Plant Pre-treated Wastewater Characteristics

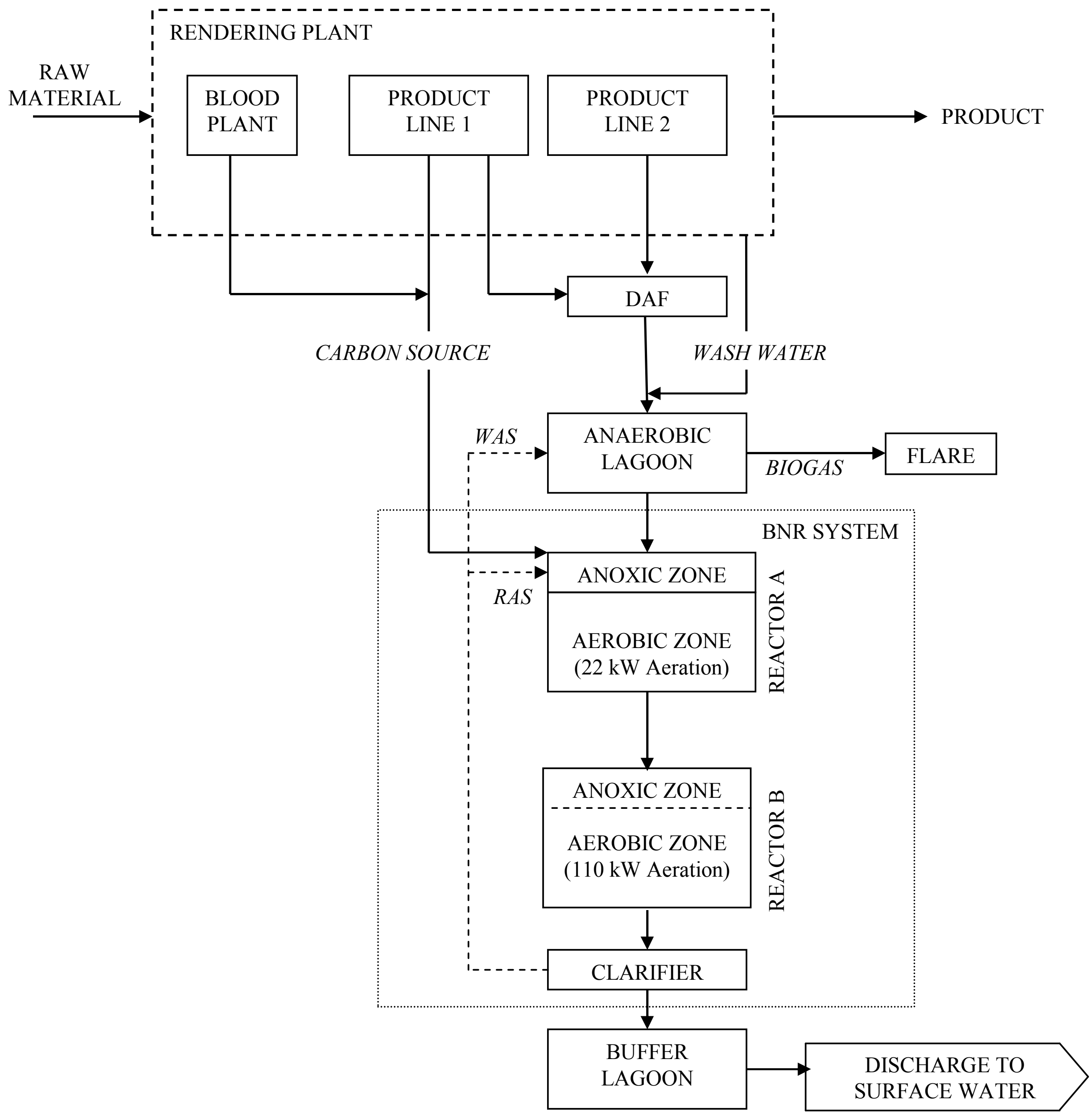
Parameter	**Average**	**Peak**
Daily Flow (m^3/d)	560	930
Biochemical Oxygen Demand (mg/L)	7,300	18,600
Total Kjeldahl Nitrogen (mg/L)	600	730

Since the rendering plant is heavily influenced by the supply of raw material from the red-meat industry, seasonal production variations meant that the wastewater flows and loads can vary significantly, with peak flows and loads occurring during the summer/autumn period and low flows and loads being experienced during the winter and early spring months.

2.2 THE WASTEWATER TREATMENT SYSTEM

The wastewater treatment system utilised at the rendering plant is characteristic of many rendering wastewater treatment systems around New Zealand, that discharge directly into the receiving environment. The treatment system incorporates primary screening, physico-chemical treatment in a dissolved air flotation (DAF) tank, prior to biological treatment in an anaerobic lagoon and biological nitrogen removal (BNR) in an activated sludge treatment system. The BNR plant at this site consists of two activated sludge reactors in series with anoxic selectors at the beginning of each reactor. Figure 1 details the wastewater treatment system prior to the process deterioration.

Figure 1: Wastewater Treatment System prior to BNR Process Deterioration



Nitrogen removal is generally the key constraint when treating rendering plant wastewater. The BNR system as shown in Figure 1 utilises a combination of separate and simultaneous nitrification and denitrification processes. However, due to the high concentrations of nitrogen present in rendering plant wastewater, a high level of system control and operation is required to ensure that efficient nitrogen removal is maintained at all times.

The classical microbial process of nitrification combined with heterotrophic denitrification is the most widely used method of nitrogen control in wastewater treatment. For this biological process to function efficiently, autotrophic bacteria must oxidise ammoniacal nitrogen into nitrite and then to nitrate, and heterotrophic bacteria convert oxidised nitrogen in to nitrogen gas in the presence of biologically available carbon. While it is possible that some other biological processes may short circuit the nitrogen removal process, through direct utilisation of ammoniacal nitrogen in the presence of nitrite, this is not entirely realised in this BNR plant because of the considerable dependency on carbon to sustain the classical nitrogen removal process.

The BNR system configuration, prior to the process train upgrade, had the anaerobically treated effluent entering a small tank reactor (400 m^3) with an initial anoxic zone followed by an aerobic zone (Reactor A). The discharge from Reactor A entered a large lagoon reactor (3,000 m^3) with a small anoxic zone and a large aerobic zone (Reactor B). The discharge from Reactor B entered the clarifier for solids separation. The recycled activated sludge (RAS) from the clarifier was returned to Reactor A. The waste activated sludge (WAS) was wasted to the anaerobic lagoon.

Reactor A was operated on dissolved oxygen (DO) control. Biologically available carbon in the anaerobically treated effluent entering the anoxic zone was utilised to denitrify oxidised nitrogen in the RAS and the internally recycled mixed liquor. The DO concentration in the aerobic zone was maintained at low levels to promote simultaneous nitrification/denitrification. The carbon to nitrogen ratios in the anaerobic effluent were generally insufficient to maintain efficient denitrification alone so a high carbon wastewater source was bypassed around the anaerobic lagoon and discharged directly to the Reactor A.

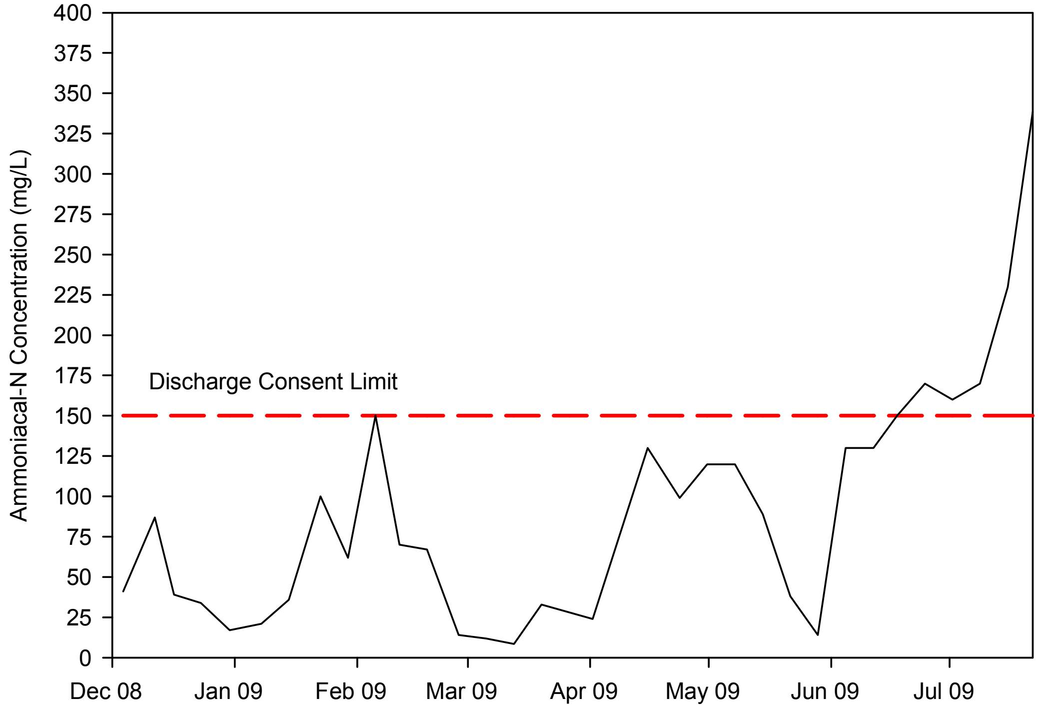
Reactor B was operated on pH control. While this lagoon reactor contained a pre-anoxic zone separated by a suspended curtain, the measured redox potential in this zone was higher than that considered to be representative of anoxic conditions. This reactor operated more like a completely mixed simultaneous nitrification/denitrification reactor rather than a stepped denitrification/nitrification reactor.

2.3 THE BNR SYSTEM PROCESS DETERIORATION

The wastewater treatment system began encountering operational difficulties in early to mid 2009. While Reactor A had traditionally been an odorous area, as a result of anaerobic effluent arriving in the anoxic zone, the frequency and intensity of the objectionable odour had started to increase during autumn and winter. The concern was raised by the rendering plant staff during the winter, as the level of odour arising in Reactor A was inconsistent with the low amount of raw material being processed at the rendering plant during that period. The frequency, intensity and duration of objectionable odour events were of significant concerns because of the location of the plant.

In addition to objectionable odour production from Reactor A, ammoniacal nitrogen levels in the final treated effluent were increasing beyond the compliance limits on a regular basis, as detailed in Figure 2.

Figure 2: Treated Wastewater Ammoniacal-N Concentrations Pre-Failure



The intensity of the odour generation from Reactor A prompted the rendering plant to seek immediate specialist assistance from Pattle Delamore Partners Ltd (PDP), in late July 2009, separate to their then wastewater treatment advisor.

3 SYSTEM INVESTIGATIONS AND REMEDIAL ACTION

An immediate site visit was carried out to address the odour issues from the BNR system. Follow up visits were then conducted to investigate the process failure points within the treatment system and to identify the likely problems in the plant that were resulting in the high ammoniacal nitrogen levels in the treated wastewater.

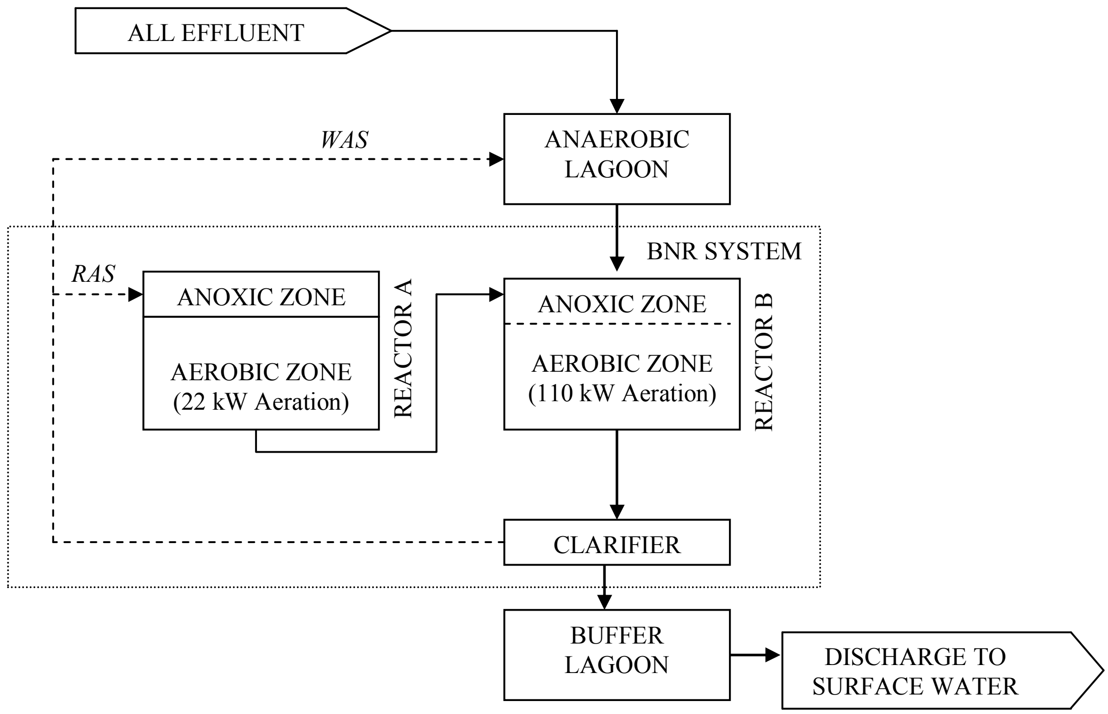
3.1 INVESTIGATING AND STOPPING THE ODOUR

Due to the close proximity of residential housing to the rendering plant, the immediate issue to be addressed was the odour generation from Reactor A. It was clearly evident from the intensity of the odour that Reactor A was being overloaded by the incoming anaerobic effluent, beyond the process aeration capacity available in the reactor.

The initial steps were to turn off the aeration supply in Reactor A as the diffused aeration was assisting in the air stripping of the odour generating compounds, increasing the adverse odour effect. Following this, the anaerobic effluent was diverted to Reactor B, while the RAS was continually pumped into Reactor A. After a period of 2-3 hours, aeration of Reactor A was re-started, when the tank had been sufficiently diluted to prevent further air stripping of odour generating compounds. With no anaerobic effluent entering Reactor A, the two BNR reactors were run in parallel.

The “technical fix” configuration for immediate recovery of Reactor A is shown in Figure 3.

Figure 3: BNR System Reconfiguration Immediately after Process Failure



The effect of this modification was a drop in odour levels within an hour of the re-configuration, even when Reactor B faced a substantial increase in wastewater load. Because the actions taken to prevent the odours did not significantly improve the system performance, in terms of nitrogen removal, further follow-up investigations were required to establish the cause of the BNR system process failure.

3.2 ADDRESSING THE BNR SYSTEM PROCESS DETERIORATION

Following the diversion of the flows from Reactor A, to overcome the odour issues, a rigorous investigation of the wastewater treatment system was conducted to identify the process constraints that were resulting in the ongoing ammoniacal nitrogen non-compliances in the final discharge. The investigation included:

1. Identification of the sources of wastewater that by-passed the DAF plant and their direct entry into the biological treatment plant, and confirmation of the treatment process train and its mode of operation.

2. Assessment of the historical flows and loads of major wastewater sources in an attempt to identify if shock loads were occurring from the rendering plant in the weeks preceding the treatment deterioration;

3. Assessment of the performance of each major treatment component within the wastewater treatment system, including the anaerobic lagoon and both BNR reactors.

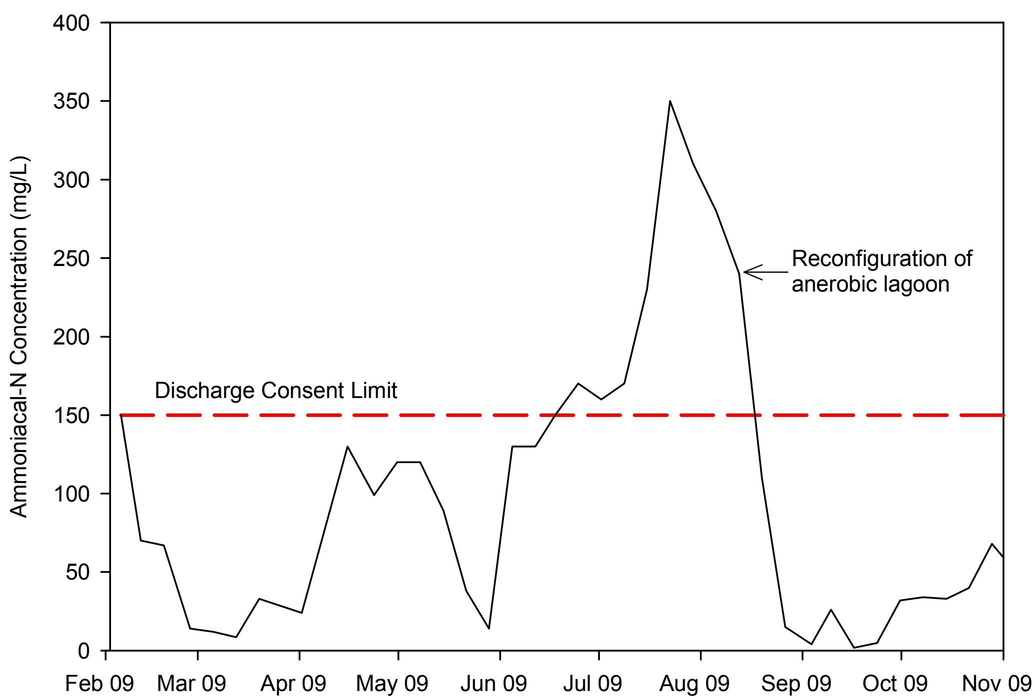
From raw wastewater monitoring results and discussions with the plant operators, it was concluded that irregular shock loading of the wastewater treatment system was unlikely to be the cause of the progressive degradation in treatment performance of the BNR system. Although some incidences of large contaminant loads were infrequently experienced at the wastewater treatment plant, due to rendering plant operational difficulties, this did not entirely explain the continued progression to process failure.

A full system investigation was conducted to assess the wastewater loads on the plant and the capacity of each treatment component and its expected performance. Based on historical monitoring data it was clearly evident that the anaerobic lagoon was providing insufficient removal of organic load received into the lagoon, with as little as 50% removal of BOD. The high BOD load in the anaerobic pond effluent was in turn overloading the aeration capacity of the BNR system and significantly impeding biological nitrification.

The investigation was then focused on the anaerobic lagoon and its operation. With the assistance of the rendering plant staff, some short circuiting of the wastewater flows within the anaerobic lagoon was identified. An upgrade of the anaerobic lagoon had occurred in the previous two years, which had included the installation of a floating cover and gas flare system, and the installation of a series of inlet manifolds along the base of the lagoon. A new self priming discharge pump was also installed and initially operated on level control. Since the upgrade of the lagoon, the inlet manifolds experienced frequent blocking, requiring regular cleaning. However, when the manifold system experienced excessive blockage, the incoming wastewater would overflow into a by-pass pipe and enter the lagoon via three inlet pipes that had historically been the lagoon inlet. One of the inlet pipes, however, was situated in close proximity to the new lagoon outlet, resulting in the short circuiting of the anaerobic lagoon.

To overcome the blockages and short circuiting, the manifold system was decommissioned. The original inlet pipes were re-commissioned with the inlet nearest to the anaerobic lagoon discharge pump blocked off. The isolation of the short-circuiting in the anaerobic lagoon substantially improved BOD removal in the anaerobic lagoon, with more than 80% BOD removal, and a rapid improvement in nitrification was experienced. This resulted in a rapid reduction of the ammoniacal nitrogen levels in the treated effluent, to well below the compliance limit, as shown in Figure 4.

Figure 4: Treated Wastewater Ammoniacal-N Levels post-Anaerobic Lagoon Upgrade



4 TREATMENT SYSTEM OPTIMISATION

While the initial amendments to the wastewater treatment plant had reduced odour levels and improved nitrogen removal, to maintain compliance with the instantaneous ammoniacal-N concentration consent limit, there was continued non-compliance of the average mass limits. The rendering plant is also required to maintain compliance with 26 week average load limits for ammoniacal-N and total nitrogen. It was, therefore, important that the BNR system was optimised to maintain low treated effluent loads of ammoniacal-N and total nitrogen in order to reduce the average load to below the consent limit as soon as possible.

From historical data it was identified that the performance of the BNR system was highly variable and while some of this could be attributed to the anaerobic lagoon short circuiting, it was suspected that the variable flows and loads of the rendering plant wastewater were also contributing to the variable performance of the BNR.

A period of ongoing system observation was undertaken in an attempt to identify the areas where the BNR system could be optimised. An ion selective electrode (ISE) meter was installed in the main reactor to observe the ammoniacal nitrogen levels, rather than relying on historical laboratory results that were up to two weeks out of date. This continuous field monitoring was key to observing the responses of the BNR system to variations in rendering plant processing and BNR plant operation.

Following a period of three months operation, the key areas that were identified for BNR system optimisation were:

- Wastewater flow and load balancing;
- Maintenance of carbon to nitrogen ratios within the BNR reactors;
- Method of final effluent polishing;

The system observations and respective optimisation upgrades are detailed in the following sections.

4.1 WASTEWATER FLOW AND LOAD BALANCING

The wastewater flows from the rendering plant vary considerably, with rendering generally starting at midday on Monday, once the raw material has been delivered to site, and operating through until Saturday afternoon. This results in a high flow and load on the treatment system during week days and no load on the wastewater plant over Sunday and Monday. Reactor B had a limited amount of aeration, at 110 kW, and it was important that this capacity was not exceeded as ammoniacal nitrogen level could be expected to rise quickly in this reactor.

The discharge from the anaerobic lagoon had relied on level control using an ultrasonic level sensor on the floating cover. This method of level control was realised to be a problem as infrequent foaming under the cover resulted in the cover rising to a level too close to the ultrasonic levels sensor, whereby shutting down the discharge pump. This was deemed as an operational risk and this automatic control system was not operated in favour of manual adjustment of the pumped discharge rate. The manual control of the anaerobic lagoon discharge rate had the negative affect that if it was identified that the level was creeping up, the operators tended to over adjust the pumping rate from the anaerobic lagoon, exceeding the maximum capacity of the BNR system. It was also identified that manual control of the discharge left the system vulnerable to human error and potential for anaerobic lagoon overtopping.

In an attempt to limit the maximum load on the BNR plant, a pressure transducer was installed to identify the level in the anaerobic lagoon and control the discharge pump rate. The discharge pump rate from the lagoon was then limited to the maximum capacity of the BNR system. A high level overflow pipe was also installed to minimise the potential for pond overtopping.

The controlled discharge from the anaerobic lagoon has allowed for a constant supply of effluent to the BNR part of the treatment plant and has provided the security in the anaerobic lagoon to manage the lagoon levels.

4.2 MAINTENANCE OF THE CARBON TO NITROGEN RATIO

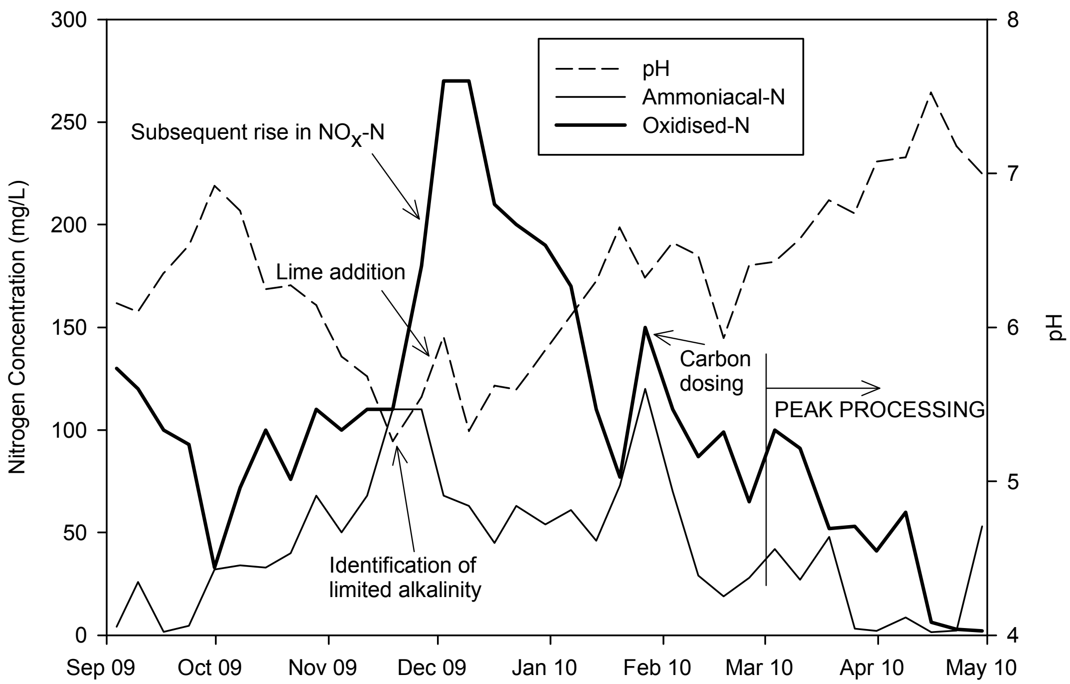
Monitoring indicated that the anaerobic lagoon effluent contained marginal alkalinity for complete nitrification and that it was essential for the majority of the resultant oxidised nitrogen to be denitrified in order to return enough alkalinity to complete nitrification of a large amount of incoming ammoniacal-N.

Aeration within Reactor B had historically been operated on pH control. During the initial optimisation programme, DO control of the aerators was utilised. This worked very effectively for a period of time, however, when processing at the rendering plant changed, as a result of seasonal product variations, it was found that the pH of the reactor was dropping as low as 5.2 pH units and nitrification was being inhibited, which resulted in the ammoniacal nitrogen levels increasing.

Additional alkalinity was added to the reactor, in the form of burnt lime, to maintain alkalinity and nitrification rates. The laboratory results obtained following alkalinity augmentation showed that denitrification was not keeping up with the uninhibited nitrification rate and that nitrate-N levels were increasing.

Monitoring of the anaerobic effluent indicated that characteristically the BOD:N ratios in the effluent were between 1:1 and 2:1, well short of the generally accepted minimum BOD:N ratio for nitrogen removal of 3 to 3.5 (Henze *et al.* 2002). It was noted that previously, under normal operation, supplementary carbon was supplied at an uncontrolled rate from several identified internal carbon sources, that were available from the rendering plant. Seasonal variations in rendering plant operation resulted in a limited supply of the supplementary carbon source waste stream, which was identified as the cause of the impaired nitrogen removal, potentially contributing to historical events of poor nitrogen removal. The depletion of available carbon for denitrification and the impact of the alkalinity augmentation during the BNR plant optimisation is demonstrated in Figure 5.

Figure 5: BNR Plant Performance during Low Carbon Conditions



Following the observation of elevated nitrate, an ISE nitrate meter was installed. This enabled the total inorganic nitrogen content (excluding nitrite, which had generally been at low concentrations) in the BNR reactor to be observed in real time and process adjustments made quickly.

In order to ensure that sustainable nitrogen removal was accomplished, a suitable external carbon supply was secured and added to the BNR Reactor B at controlled rates when required. Reactor B was changed back to pH control of aeration and the pH was maintained between 6.0 and 6.7 pH units, based on the optimum pH zone for nitrification and denitrification [Henze et al., 2002] for the reactor ammoniacal-N concentrations received from the anaerobic lagoon. Daily carbon dosing decisions were then made based on anticipated rendering plant processing rates, and the ammoniacal-N and nitrate-N content in the discharge from Reactor B. While carbon dosing was conducted during times of reduced processing, once peak processing season started carbon dosing was no longer required.

Dosing of externally supplied carbon during the period of reduced rendering plant operation, had an improved effect on the performance of the BNR plant (as shown in Figure 5). The nitrate-N levels were able to be maintained at acceptable levels and alkalinity augmentation was not required to maintain nitrification. Carbon dosing from an external supply was able to be maintained at controlled minimum supply levels until the rendering plant production levels had increased to a level that internal carbon supply from specific wastewater sources provided for sufficient nitrogen removal.

Two key findings from this period of system optimisation were:

1. The actual carbon requirements for nitrogen removal were close to the optimum level for denitrification at 3.5.BOD:1.TN (Henze et al., 2002). This indicates that a higher efficiency factor is being achieved than would be expected for a simultaneous nitrification/denitrification system.

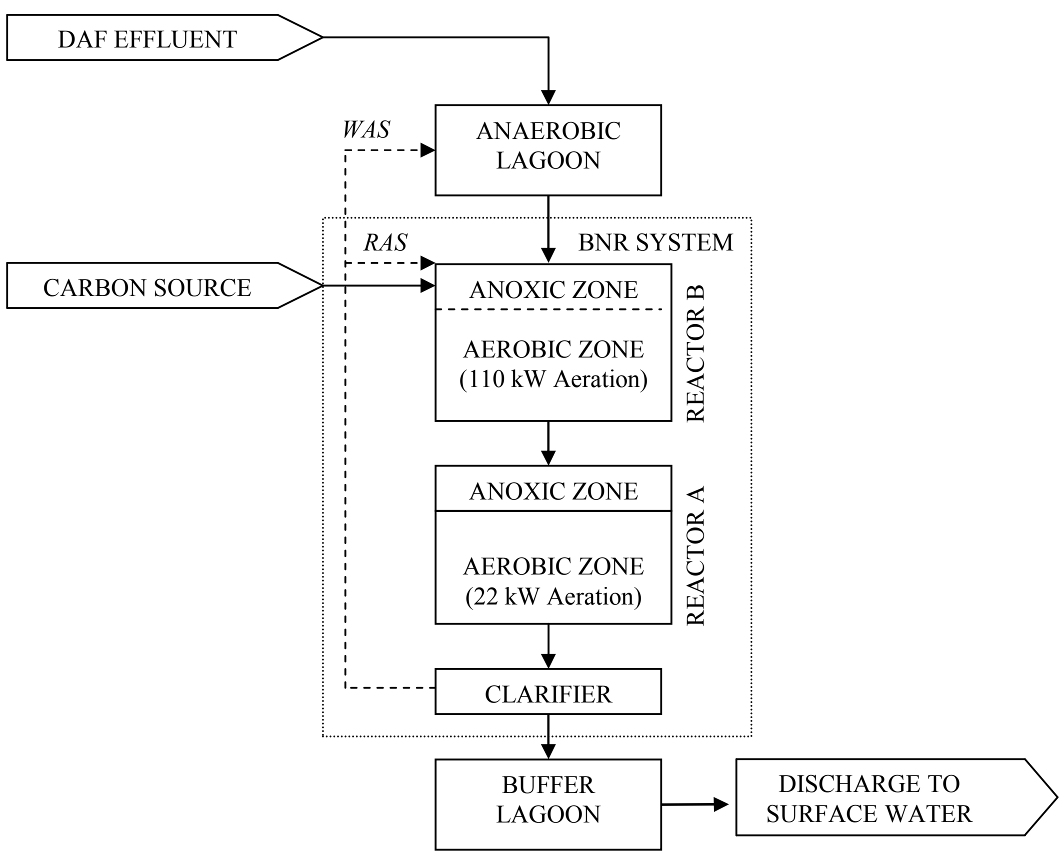
2. In this case, pH control of aeration in BNR reactor B provides for better maintenance of nitrification and denitrification. It enables the optimum pH zone for nitrification and denitrification to be maintained, without excessive removal of alkalinity.

3. The use of ISE nitrogen field instruments, to monitor the real-time ammoniacal-N and nitrate-N levels, are an effective tool for the identification of the actual carbon dosing requirements in the BNR. The field ISE meters are ideal for control of a BNR at an industrial site, where there is limited wastewater expertise to conduct more involved analysis of incoming wastewater characteristics.

4.3 FINAL EFFLUENT POLISHING

The post-failure reconfiguration of the BNR reactors, as a result of the odour emissions from Reactor A, meant the BNR reactors were operating in parallel for a period of time. While sufficient nitrogen removal was being maintained, much of the wastewater was not being treated in Reactor A and effluent polishing of all wastewater was not being realised. The BNR system was then reconfigured to provide for Reactor A to be operated in series, following Reactor B, without any internal/external supply of carbon into Reactor A. The optimised configuration of the BNR system is shown in Figure 6.

Figure 6: Optimised Reconfiguration of BNR System



The reconfigured system has the process trains reversed from the pre-optimisation system where the larger Reactor B receives all the anaerobically treated effluent and Reactor A is now utilised for polishing prior to discharge. This configuration provides the rendering plant with a large amount of security as the there is lesser potential for shock loading the of larger BNR reactor.

Ongoing operation of the reconfigured system identified that the Reactor B was consistently capable of removing the majority of the nitrogen from the wastewater, with effluent ammoniacal-N concentrations of approximately 50 mg/L and nitrate-N levels of 80 mg/L during peak rendering plant processing.

Optimisation of further nitrate-N removal within Reactor A was then investigated, with addition of supplementary carbon sources into the anoxic zone of the reactor. Initially, waste streams from within the rendering plant were investigated and then the external carbon source was trialled. On both occasions it was found that only very minor amounts of each carbon source could be added before rising sludge occurred as a result of delayed denitrification response in the clarifier. It was concluded that the residence time within the reactor was not long enough to utilise residual carbon from the supplied carbon. The reactor was then operated with no additional carbon source, in favour of forcing denitrification from carbon released by endogenous decay. Although other more readily available carbon sources could have been utilised, the denitrification provided from endogenous decay proved to be sufficient, consistently removing an additional 30 to 40 g/m^3 of nitrogen.

The key outcome of this component of the system optimisation was that the larger, Reactor B was capable of achieving similar nitrogen removal rates as the parallel system and that by operating the reactors in series, with Reactor A following Reactor B, additional nitrogen removal was enabled as well as providing better settleability of the solids in the clarifier. The major benefit of the optimisation programme was that excellent nitrogen removal rates, of over 90% removal, were achieved without any major plant upgrades or capital expenditure.

5 CONCLUSIONS

Faced with continuing problems of a non-complying discharge and release of objectionable odour, the rendering plant sought specialist assistance to control the odour and progress its wastewater treatment plant towards compliance.

A comprehensive troubleshooting programme was initiated and the existing BNR plant was switched from an immediate "technical fix" to alleviate odour issues and then optimised, with a process reconfiguration to improve nitrogen removal. Over a period of several weeks after reconfiguration and optimisation, the rendering plant achieved compliance with its discharge limits. With over 90% nitrogen removal, continued compliance with the discharge consent nitrogen limits have been maintained without the need for major plant construction or upgrade works.

During the period of system observation and optimisation, the key operational findings were:

1. Effective nitrogen removal could be maintained with low carbon to nitrogen ratios;

2. The use of pH control of aeration proved to be a more effective method for maintaining nitrogen removal and preventing stripping of alkalinity; and

3. The use of ISE nitrogen field meters are an effective tool for maintaining BNR operation in an industrial setting.

ACKNOWLEDGEMENTS

The authors take this opportunity to thank the rendering plant company for their assistance on this project and allowing the use of the monitoring data for this paper.

REFERENCES

Henze M, Harremoes P, Cour Jansen J. la, & Arvin, E. (2002). *Wastewater Treatment: Biological and Chemical Processes,* 3rd *Ed.*. Environmental Science and Engineering/Environmental Engineering.