MANAGING CONFLICTING NEEDS IN BNR TREATMENT OF HIGH STRENGTH NITROGENOUS EFFLUENTS

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ABSTRACT

Biological nitrogen removal in wastewater is now seen as one of the essential treatment requirements prior to discharge to a receiving environment for many municipalities and industrial wastes generators. For municipal wastewaters, the level of nitrogen concentration is generally low and therefore the impact of nitrogen removal on bioprocess is not apparent.

When high strength nitrogenous effluents are subjected to biological nitrogen removal (BNR), the wastewater composition, environmental controls and the process microbiology start to impose significant constraints to the success of the BNR treatment system.

A rigorous characterisation of the incoming wastewater needs to be undertaken to determine how the nitrogen removal could be impacted by substrate concentration and the controls required to manage efficient treatment as well as ensuring that the bioflocculation of the activated sludge is maintained.

At a a case study site, operational difficulties were encountered for biological nitrogen removal. The operational controls and the process constraints resulted in poor nitrogen removal. The rate of rise of ammoniacal nitrogen concentrations within the BNR reactor was unacceptable and resulted in significant ammoniacal nitrogen excursion.

In addition bioflocculation was negatively impacted with a significant change in the cation balance. An examination of the cation balance showed a disproportionate amount of monovalent cations compared to divalent cations. The imbalance resulted in very poor solids separation in the clarifier. Remedial measures were undertaken by adding hydrated lime, but this in turn resulted in uncontrolled nitrification.

In this paper, the process fundamentals are examined to provide guidance on the BNR treatment processes for high strength nitrogenous effluents. A description of the process constraints and the methods used to manage efficient nitrogen removal is discussed.

KEYWORDS

Nitrogen, effluent, industrial, BNR, cation

1 INTRODUCTION

Nitrogen removal from wastewater is gaining importance in New Zealand with many resource consents implementing tightening nitrogen discharge limits, especially for discharges to surface water environments. Previously the key importance was given to ammonia toxicity and guideline limits have been developed for surface water (ANZECC, 2000), however, nitrate toxicity in surface water is gaining importance as well (Hickey and Martin, 2009).

Many wastewater treatment plants constructed for the treatment of high strength wastewaters have not fulfilled the requirements of their respective discharge permits. The need has arisen for the treatment plants to be retrofitted or modified at considerable expense to meet the discharge requirements and to provide more reliable performance. The need to optimise energy use is also important and hence more attention is being paid to selection of processes that conserve aeration energy use.

In the drive for better wastewater treatment and ever increasing efficiency, there is more attention being paid to the treatment of high strength nitrogenous wastewater. Wastewater treatment plants are required to meet lower ammonia effluent standards and total nitrogen limits in order to reduce nutrient levels in the receiving environment. For wastewater treatment plants, where high strength nitrogenous effluent needs to be treated, the operation and maintenance costs as well as maintaining a reliable process control are becoming critical. To design and operate a BNR wastewater treatment system, it is necessary to understand the biochemistry of the involved microbial populations and the key constraints that need to be managed in a short period of time, especially for plants receiving high nitrogen-loaded wastewater.

For BNR systems to operate efficiently and manage varying loads, a combination of the different groups of nitrogen converting micro-organisms and the optimization of the treatment process directly adapting the plant operations to wastewater composition/load, oxygen and nitrite/nitrate supply and carbon supply will improve nitrogen removal. In addition the cation balance must be controlled in such a manner that floc structure is maintained in the BNR system.

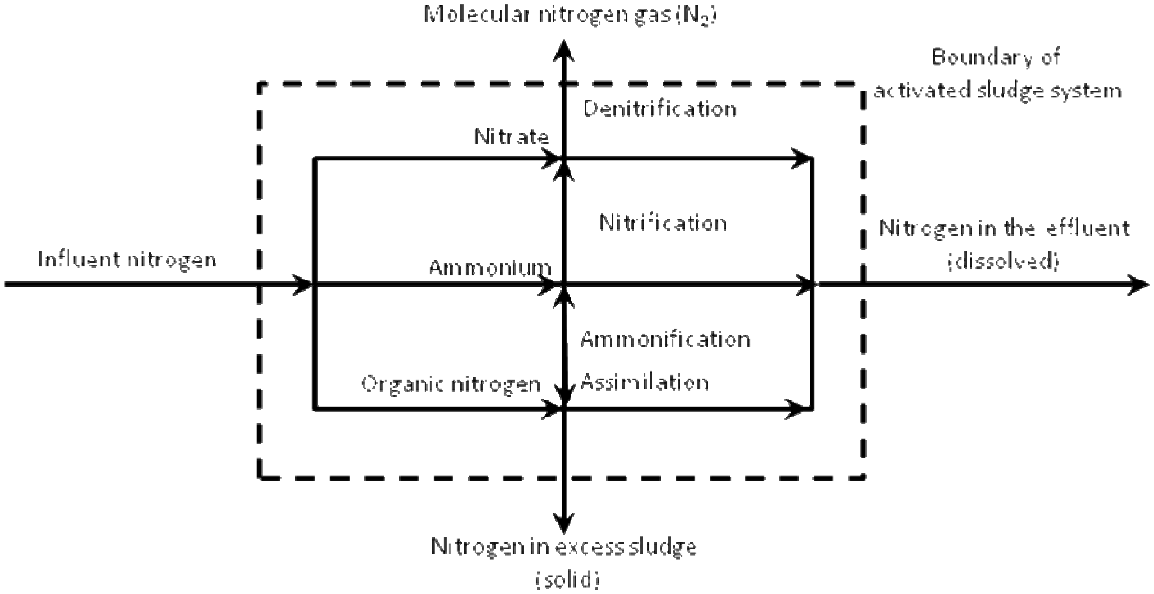
2 BIOLOGICAL NITROGEN REMOVAL PROCESSES

2.1 REACTIONS IN WASTEWATER NITROGEN

There are generally three ammonium removal processes that assist in the biological nitrogen removal processes. These include the well known aerobic ammonia and nitrite oxidisers (autotrophic bacteria) and includes the commonly known genera *Nitrobacter* and *Nitrosomonas*. The less well known anaerobic ammonia oxidisers are from a group of plantomycete bacteria (Schmidt *et al*, 2003). In order to complete the biological nitrogen removal the oxidised nitrogen is then removed by heterotrophs, through the process of denitrification. To create efficient nitrogen removal, some form of aerobic-anoxic sequencing is required (Eckenfelder and Musterman, 1995).

In the activated sludge process, several simultaneous and/or sequential reactions may occur that ultimately result in the loss of nitrogen from wastewater as nitrogen gas (lost to atmosphere) and as assimilated nitrogen (biosolids) (Gerardi, 2002). Figure 1 shows the different possibilities where the conventional ammonification, nitrification and denitrification and assimilation transformations occur (van Haandel and van der Lubbe, 2007).

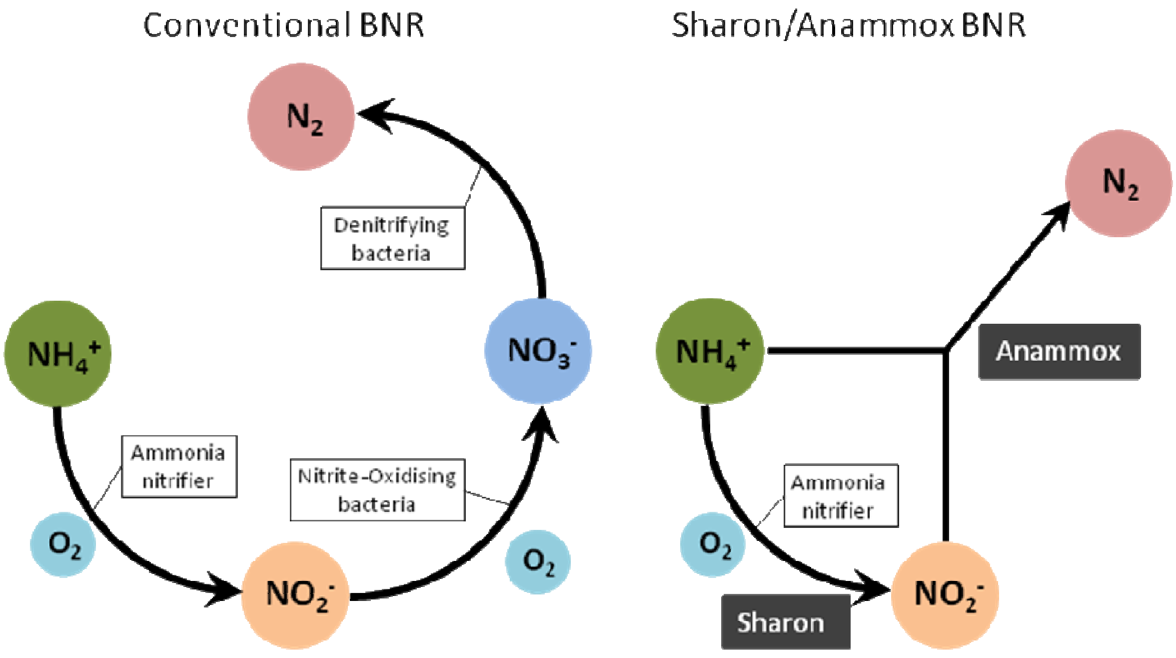
Figure 1: Forms of Nitrogen in BNR Process



One of the more recent discoveries has been anaerobic ammonium oxidation known as the Anammox process (Mulder, 1992). In this process ammonia and nitrite react to form nitrogen gas. In order to make use of the Anammox process in the wastewater a partial nitrification stage is needed (Gut and Płaza, 2003) where the ammonia is oxidised to nitrite without completing to nitrate. This partial nitrification is called nitritation and is named Sharon (Hellinga *et al*, 1998). A combination of Sharon and Anammox processes can result in significant nitrogen removal.

The principles of each type of the biological nitrogen process using the conventional nitrification, denitrification and the Anammox is shown in Figure 2.

Figure 2: Schematic Representation of Conventional and Novel BNR Process



2.2 BNR TECHNOLOGIES COMPARISON

In order to establish the suitability of the BNR technologies for high strength nitrogenous wastewaters, a comparison of the attributes of the BNR processes is given in Table 1. It is becoming apparent that if Sharon and Anammox systems can be maintained as stable systems for extended periods of time, then substantial opportunity exists that can allow existing wastewater treatment systems to be retrofitted to enable further nitrogen removal.

Table 1: Common and Novel BNR Systems Comparison

Process	**Conventional**	**Sharon**	**Anammox**
No. of Reactors	1 or more	1	1
Reactor Type	Suspended/Biofilm	Suspended	Biofilm
Oxygen Requirement	High	Low	None
pH Control	Yes	None	None
Carbon Requirement	Yes	None	None
Ammonia Loading (kg N/m^3/d)	2 - 8	0.5 – 1.5	10 - 20
Sludge Production	High	Low	Low
Nitrogen Removal (%)	95	90	90
Investment Costs	Medium	Medium	Low
Operational Costs	High	Low	Very Low

Given that novel technologies like Sharon/Anammox combination provides an opportunity to reduce nitrogen from high nitrogen-loaded wastewater, the challenge exists to operate stable systems that can be relied upon at all times.

2.3 CONSTRAINTS IN BNR TREATING HIGH STRENGTH EFFLUENTS

For BNR systems, the key constraints that high strength wastewater treatment systems face is the ability to maintain consistent pH, dissolved oxygen, substrates concentration, carbon to nitrogen ratio and avoidance of inhibiting factors. In addition the cation balance also affects the bioflocculation in the activated sludge system. Several of the constraints are discussed.

2.3.1 EFFECT OF ALKALINITY AND pH

Nitrification is an alkalinity-consuming process and when the alkalinity is exhausted a substantial reduction in pH can be experienced which in turn will inhibit the nitrification process. In practice, the neutral alkalinity of high strength nitrogenous effluent is generally lower than the value required to maintain a stable pH in the BNR process. Without the addition of alkalinity, the behaviour of the BNR process may become irregular resulting in periods with nitrification and the consequential decrease in alkalinity and pH, until a pH value is established that is inhibitory for nitrification. When nitrification ceases, then alkalinity automatically increases and the pH rises so that once again favourable conditions for nitrification are established and a new cycle of instability is initiated.

The inhibition of nitrification happens at pH = 5.8 (Henze et al, 2000). However, many practitioners suggest that nitrification needs to be maintained over pH range 7.5 to 9.0 as the relative nitrification rate rapidly drops below pH = 7.5 (Henze *et al*, 2000). For high strength nitrogenous effluents, especially from the agro-industrial discharges, the alkalinity is in short supply and generally the BNR systems are forced to run at pH values lower than 7.0.

For denitrification, literature reports a wide range of pH values where denitrification operates properly.

2.3.2 DISSOLVED OXYGEN CONCENTRATION

The nitrifying bacteria are more sensitive to low dissolved oxygen (DO) concentrations and there is a general guidance on maintaining the bulk liquid DO concentrations at above 2 mg/L to prevent oxygen limitation in the nitrification process.

However, for many high strength BNR systems, the DO concentration is reduced to low levels well below the accepted bulk liquid concentrations. Although it has been reported that a low DO concentration of around 0.2 to 0.5 mg/L may limit nitrite oxidising bacteria (Bernet and Spérandio, 2009), the condition itself allows for simultaneous nitrification-denitrification (SND) in the same reactor and offers the potential to save costs for a dedicated reactors. However, the risk of such systems is lower nitrification rates due to partial limitation of ammonia oxidising bacteria.

The operational experiences at several wastewater treatment plants treating high strength nitrogenous effluents shows that the DO levels need to be maintained at levels lower than the generally accepted bulk liquid DO concentrations of 2 mg/L to optimise nitrification.

Denitrification activity is inhibited in reversible manner under aerobic conditions. In general it has been observed that a DO concentration of more than 0.2 to 0.5 mg/L reduces the rate of denitrification significantly (Cuervo-Lopez *et al*, 2009).

2.3.3 SUBSTRATE CONCENTRATION AND INHIBITING COMPOUNDS

The nitrification process in BNR systems can be inhibited by many different substances. Any slight change in the optimum conditions can result in inhibition and can force nitrification to stop completely. The inhibition is not an acute process (as a result of toxic load), but results in the wash out of nitrifiers over a period of several weeks. As such nitrifying bacteria are not any more inhibited than other bacteria in a wastewater treatment system.

One of the more common inhibition aspects in high strength nitrogenous effluents is the concentration gradient that results in the excursion of free ammonia and free nitrous acid within the reactor. This in turn inhibits the complete nitrification at certain pH conditions.

2.3.4 CARBON SUPPLY AND LOSS OF CARBON

The presence of an electron donor to provide an energy source is essential for the reduction of nitrate. The electron donor in the denitrification process is biodegradable organic matter and supplied either from the effluent itself or from an external carbon source.

The carbon supply is critical in determining whether the nitrate/nitrite reduction pathway is via denitrification or via ammoniation of nitrite. At a high carbon to nitrogen ratio the ammoniation of nitrite may occur which in trun does not remove nitrogen. At stoichiometric value, denitrification controls the reduction pathway and therefore the nitrate/nitrite is converted to nitrogen gas (Cuervo-López *et al*, 2009). When there is a loss of carbon the denitrification process is stuck in the conventional BNR process.

2.3.5 CATION BALANCE

Although not directly related to the efficiency of BNR system, the cation balance determines the role of bioflocculation in the BNR process. The cations namely calcium and magnesium improve the floc structure, whereas high amounts of sodium, potassium are generally are detrimental to the floc structure, promoting nitrifier washout and reduction in treatment.

Increases in the salinity of the effluent in a high strength nitrogenous wastewater BNR system negatively impacts on the activity of the nitrifiers (Moussa, 2004).

3 OPERATIONAL FULL SCALE SYSTEMS MANAGEMENT

Agro-industrial wastewaters, especially from meat by-products processing (meat rendering and tanneries) generally contain high levels of nitrogen. In addition the effluents generated from these plants contain high amounts of organic matter and salts. The conventional method of treatment of effluents from meat rendering plants relies on anaerobic treatment and then activated sludge treatment. The upgrade of activated sludge treatment plant as BNR systems rely on maintaining efficient control of pH, dissolved oxygen (DO), supply of carbon, mixed liquor suspended solids (MLSS) concentrations and satisfactory cation balance.

In the case study examined, the wastewater is generated from meat rendering plant

T nitrogen load faced by the wastewater treatment plant is around 450 kg/d and the discharge limit for ammoniacal nitrogen is below 55 kg/d. The total nitrogen discharge limit is set at 75 kg/d. The incoming ammoniacal nitrogen concentrations ranges between 340 – 1,170 mg/L (average = 680 mg/L).

A summary of the operational issues arising at the case study plant related to BNR process controls, escalation of nitrite nitrogen, uncontrolled rate of rise of ammoniacal nitrogen and cation imbalances

3.1 NITROGEN TRANSFORMATIONS IN THE BNR PLANT

The performance of the BNR system showing influent ammoniacal nitrogen and the discharge ammoniacal nitrogen concentrations from January - September 2011 is shown in Figure 3. The BNR reactor is the initial reactor that receives all anaerobically treated effluent. Additional effluent that contains a large amount of metabolisable carbon is provided into the BNR reactor as well.

Although in January 2011, the ammoniacal nitrogen concentration of the influent was high, the BNR plant had handled the load effectively and the discharge out of the BNR plant had a moderate increase in the discharge concentration. Once the ammoniacal nitrogen concentration was averaging around 650 – 700 mg/L, the BNR plant showed a very good performance in terms of converting ammoniacal nitrogen into oxidised nitrogen, but subsequent removal of oxidised nitrogen was not adequate at all times. It was determined that the ammoniacal nitrogen reduction in the BNR reactor was at acceptable levels, but the oxidised nitrogen was not removed entirely. The key constraint faced in the BNR reactor was the inability to maintain a continued supply of acceptable carbon:nitrogen (C/N) ratio. The C/N ratio provided in the anaerobically treated effluent averaged at 2.4. Additional sources of carbon were identified within the processing plant and utilised in the BNR but on many occasions this was not sufficient to completely remove the oxidised nitrogen within the BNR reactor. Although the ammoniacal nitrogen removal averaged above 96%, the total inorganic nitrogen (ammoniacal + oxidised nitrogen) averaged around 83%, not sufficient to rely entirely on the first BNR reactor to remove all nitrogen. Further retrofitting of a small BNR reactor and controlled spatial separation of the denitrification and further aeration resulted in meeting the discharge standards. However, use of the second reactor provided a "stop-gap" solution.

Although the wastewater treatment plant discharge met compliance levels as subsequent treatment units were able to remove the oxidised nitrogen to the extent that low levels of nitrified effluent was discharged, the main BNR reactor struggled to maintain low levels of oxidised nitrogen. This is shown in Figure 4.

Figure 3: Nitrogen Transformation in the BNR Reactor

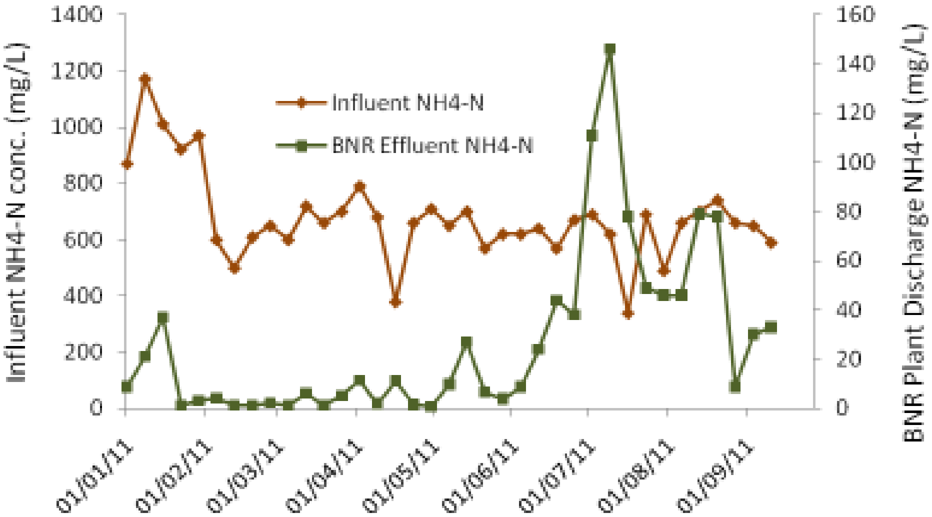
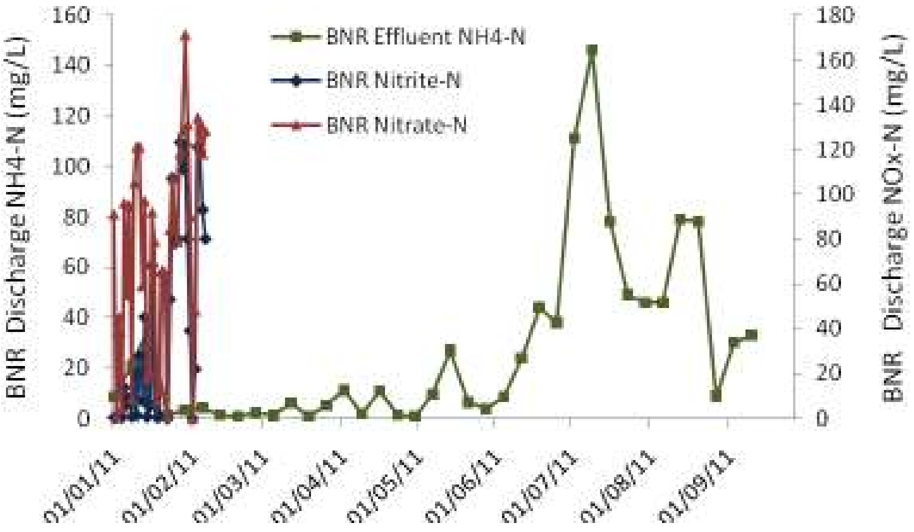


Figure 4: Nitrite/Nitrate Nitrogen Excursion in the BNR Reactor



The increase in the ammoniacal nitrogen during July 2011 was as a result of a period of very low C/N ratio in the effluent discharged into the BNR plant. The reduction in the C/N ratio was a direct result of production improvements and the optimisation of the dissolved air flotation plant to recover oils & grease. Since July 2011 the C/N ratio averaged at around 1.25 and the initial BNR response was an increase in nitrification resulting in an excursion of nitrite/nitrate production and then a sharp drop in alkalinity availability, resulting in an increase in ammoniacal nitrogen. Supplementary external supply of carbon and alkalinity was provided to assist in the reduction of nitrite/nitrate (shown in mid-August). The external supply was stopped and the BNR response in subsequent increase in nitrogen was observed. Continued stop-gap measures (external carbon and alkalinity supply) have been employed to manage the BNR nitrogen removal.

3.2 pH AND DO MANAGEMENT OF BNR PLANT

The operation of BNR reactor is managed through pH control to ensure that some alkalinity return is maintained through the promotion of simultaneous nitrification and denitrification. The pH control also is better at ensuring that nitrification does not impact on complete alkalinity destruction and escalation of dissolved oxygen concentrations when the nitrifiers stop ammonia nitrogen conversion. The dissolved oxygen level is monitored without it having significant control on the BNR aeration. As seen in Figure 5, the pH in the reactor varies and can be as low as 6.5 for extended periods of time. At this pH, the nitrification process was inhibited on some occasions and external alkalinity addition was undertaken to manage the alkalinity levels in the BNR reactor.

Figure 5: Time Series pH Response in BNR Reactor

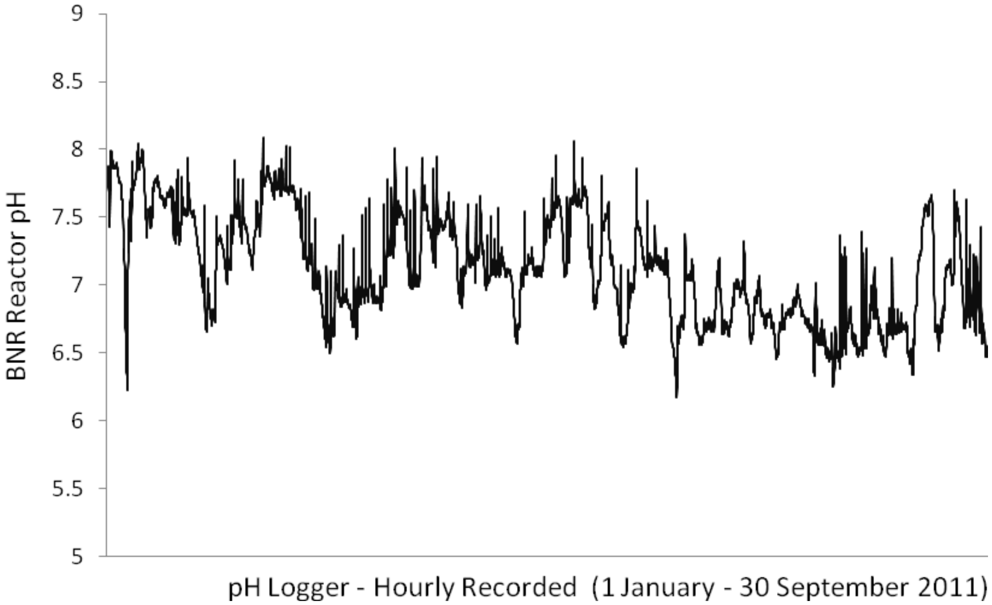
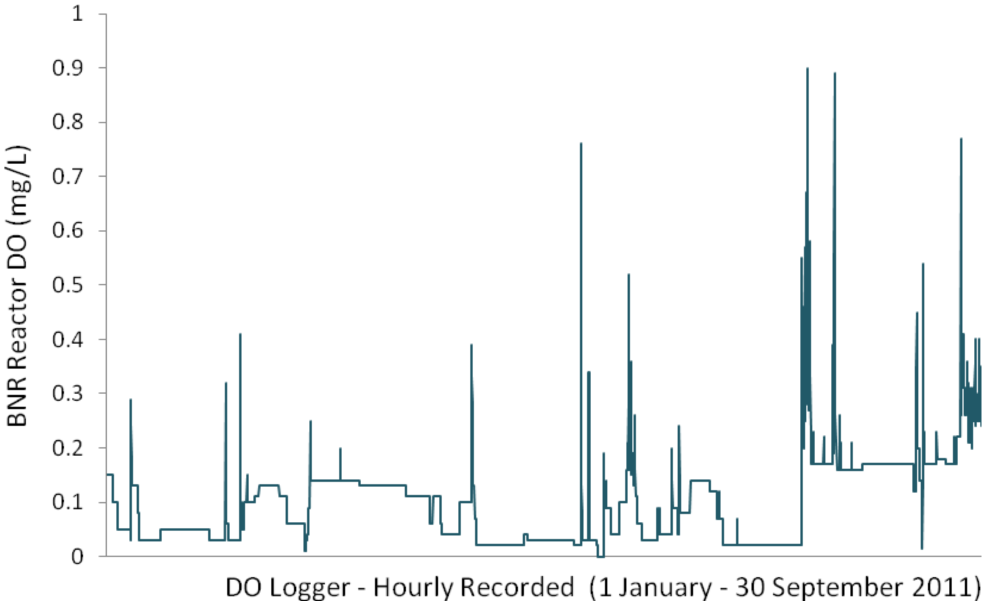


Figure 6: Time Series DO Response in BNR Reactor



The pH depression is generally managed without the addition of alkalinity as the costs of maintaining the pH in a set range close to pH 7.5 would be prohibitive. The management of pH could be also undertaken by allowing the diversion of more organic load into the BNR reactor that promotes additional denitrification. The diversion of more organic load on a continuous basis is not relied upon as the loads from the processing plant could vary within days and as such an uncontrolled increase in the organic load to the BNR could result substantially reducing the opportunity for nitrogen removal. The BNR reactor generally shows a very quick rate of rise in ammoniacal nitrogen if the organic load increases slightly into the reactor.

3.3 MANAGEMENT OF CATION BALANCE

Although not directly affecting BNR processes, the subsequent wastewater clarification can be detrimentally affected if the cation balance is not correct. The wastewater has very low levels of calcium and magnesium when compared to sodium and potassium levels. The shortage of divalent cations results in deflocculation of the activated sludge floc and poor settling in the clarifier. This is being managed by strategic addition of calcium salts by using hydrated lime. Because of the low C/N ratio, the addition of hydrated lime is managed carefully as the supply of calcium hydroxide also results in a large pool of alkalinity as a side-effect, further creating the potential for increased nitrification.

4 CONCLUSIONS

Based on the experience of two different plants operating BNR systems and receiving high nitrogen-loaded effluent, the nitrogen removal relies on the mode of operation and management of the carbon and alkalinity supply. The operation in one of the plants was complicated by the cation imbalance that resulted in poor settleability in the clarifier.

Steps were undertaken to make available a suitable internal carbon supply and augmented with strategic addition of external carbon when the nitrogen removal efficiency was compromised. Having the BNR systems under pH control resulted in external alkalinity supply infrequently.

As the processing plants have improved product recovery and reduced the organic load, the impact of nitrogen on the C/N ratio is apparent. This has resulted in changing the treatment strategies to assist in continued nitrogen removal. If there is continued shortage of carbon supply, then the novel BNR technologies like Sharon and Anammox may need to be explored further. However, for fully operational BNR plants, it is considered a risky proposition as any developmental problems during the period when Sharon/Anammox processes are established will result in non-compliance with the risk of enforcement by the regulators. Therefore, continued reliance on conventional nitrification/denitrification is undertaken at both BNR plants to ensure the nitrogen removal is managed to acceptable levels.

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