OPTIMIZING BIO-P PERFORMANCE IN BNR PROCESSES

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ABSTRACT

The enhanced biological phosphorus removal (bio-P) activated sludge process has a reputation for variable performance. The challenge with optimizing bio-P is that multiple factors influence process performance. One significant factor contributing to variability in bio-P was found to be related to microbial population dynamics involving the competitive growth of polyphosphate accumulating organisms (PAOs) and glycogen accumulating organisms (GAOs). It was found that the key factors in their competitive growth were the specific type of VFA in the influent to the bioreactor, and the pH and temperature in the bioreactor. The PAOs seem to have a competitive advantage to use propionate, whereas the GAOs have a competitive advantage to use acetate. Furthermore, PAOs have a competitive advantage at temperatures less than 20°C and at alkaline pH values in the range of 7.5 to 8.0. Therefore, in order to achieving reliable biological phosphorus removal it is necessary to control multiple factors within the optimum range, including providing an adequate supply of propionate, or an alternative substrate such as molasses that can be readily fermented to propionate. This paper consolidates experiences gained from many biological nutrient removal (BNR) plants including Noosa STP, in combination with supporting evidence from a literature review, to provide guidance to operators to optimize bio-P processes.

KEY WORDS

Biological phosphorus removal; acetate; propionate; polyphosphate accumulating organisms (PAO); glycogen accumulation organisms (GAO).

1.0 INTRODUCTION

The enhanced biological phosphorus removal (bio-P) activated sludge process has a reputation for variable performance. Unfortunately this proved to be the case when the Noosa Sewage Treatment Plant (STP) was commissioned in Nov 1997, and for several years afterwards (Fig. 2). The challenge with optimizing bio-P is that multiple factors influence process performance and the key requirements are listed below:

- Influent sewage COD characteristics, particularly the quantity and type of volatile fatty acids (VFA).
- Need for an anaerobic zone that is free of nitrate and oxygen inputs.
- Minimizing the recycle of P released during sludge stabilization and dewatering.
- Sufficient population of polyphosphate accumulating organisms (PAO) and minimizing growth of competing glycogen accumulation organisms (GAO).
- Ensuring bioreactor pH remains in the slightly alkaline range.
- Sufficient aeration capacity to maintain suitable dissolved oxygen (DO) levels in the aeration zone during peak diurnal loads.
- Bioreactor temperature is also important, although the operator typically has no practical control of this variable.

This paper synthesizes the outcomes of a research and optimization program that was carried out at Noosa STP with the findings of a literature review (refer to Thomas, 2008), which identified the cause of the variability in biological phosphorus removal and subsequently lead to improved operating performance.

It was previously reported that excessive growth of GAOs caused variability in bio-P performance and it was hypothesized that the growth of GAOs could be minimized, and the growth of PAOs encouraged, by supplying propionate to the bioreactor (Thomas *et al*, 2003). Long-term results demonstrate that reliable bio-P can be achieved in full-scale operating STPs without dosing ferric or alum.

2.0 NOOSA STP PROCESS DESCRIPTION

Noosa STP is located 150 km north of Brisbane in a sub-tropical area of Australia and serves a population of about 50,000 EP and treats an average dry weather flow of 10 ML/d. It is located in a popular tourism beach resort area and the influent sewage has a predominantly domestic character. The effluent quality requirements are as follows:

- Total nitrogen < 5 mg/L (50 percentile).
- Total phosphorus < 1 mg/L (50 percentile).
- Faecal coliforms < 10 cfu/100 mL (50 percentile).

The BNR bioreactors were operated in a 5-stage Bardenpho configuration (anaerobic-anoxic-aerobic-anoxic-aerobic) with a sludge age of 10 days. The mixed liquor temperature ranged from 20 to 28°C. Molasses was dosed into either the fermenter, or directly into the anaerobic zone of the bioreactors. No alum or ferric were added to the process, although lime was used for treatment of the sludge dewatering filtrate.

3.0 RESULTS

3.1 Importance of Propionate

Early bio-P research highlighted the importance of readily biodegradable, soluble COD and VFA as substrate for PAOs. When diurnal profiles of influent sewage VFA and phosphate, and effluent phosphate were monitored at Noosa WWTP, the sensitivity of bio-P performance to VFA was apparent (Figure 1). The ratio of VFA:P in the influent showed a sudden decrease at peak flows, which coincided with break-through of un-removed phosphate at the outlet of the bioreactors. However, the duration of phosphate break-through peak did not match the duration of the low VFA:P ratio, and these results may have also been influenced by bioreactor hydraulics (e.g. short-circuit) during diurnal peak flow and low DO in the aerobic zone during peak load. The VFA output from the fermenter was excluded from data shown in Figure 1 but it did not show any significant diurnal variation and did not affect the trend. This pattern of behaviour was confirmed by repeated sampling on different days and Figure. 1 shows a typical diurnal profile.

When Noosa STP was commissioned in Nov 1997 it appeared that the influent was not favourable for reliable bio-P, and supplementary acetate dosing was implemented. Initially, acetate dosing worked well as shown by results obtained during 1998 (Figure 2). However, in 1999 increasing variability in bio-P was observed and more importantly, phosphorus removal was not improved by simply increasing the acetate dose.

The period of poor bio-P in 1999-2000 coincided with the primary sedimentation tanks and fermenter being out-of-service for odour control modifications (Figure 2). The fermenter was out-of-service from Nov 98 until Apr 00, and during this time the acetate dosing was increased to compensate for the loss of VFA production by the fermenter. Furthermore, there was only a slight improvement in bio-P performance when the fermenter was returned to service in Apr 00, while acetate dosing continued.

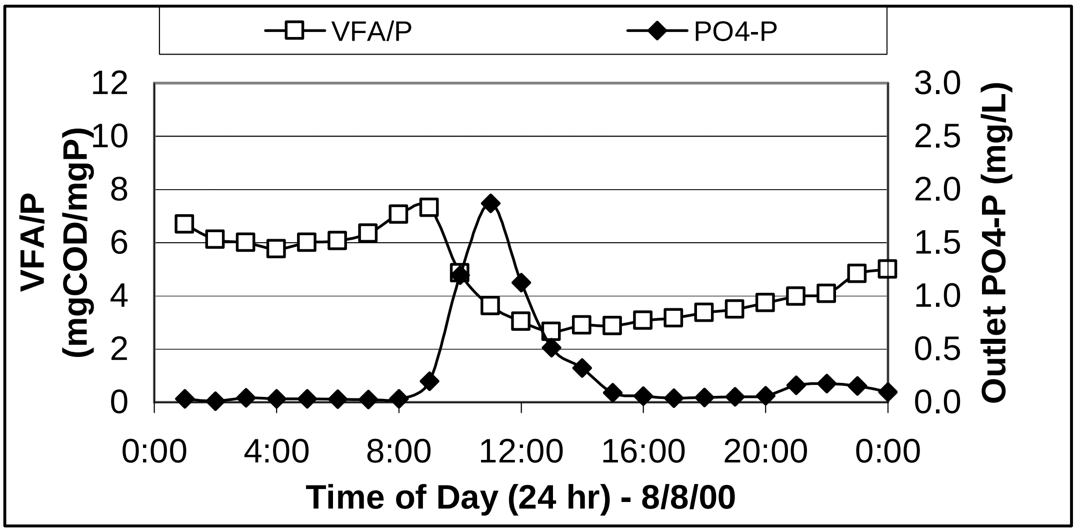

Figure 1: ***Effect of diurnal sewage VFA:P ratio on dynamic P removal behaviour***

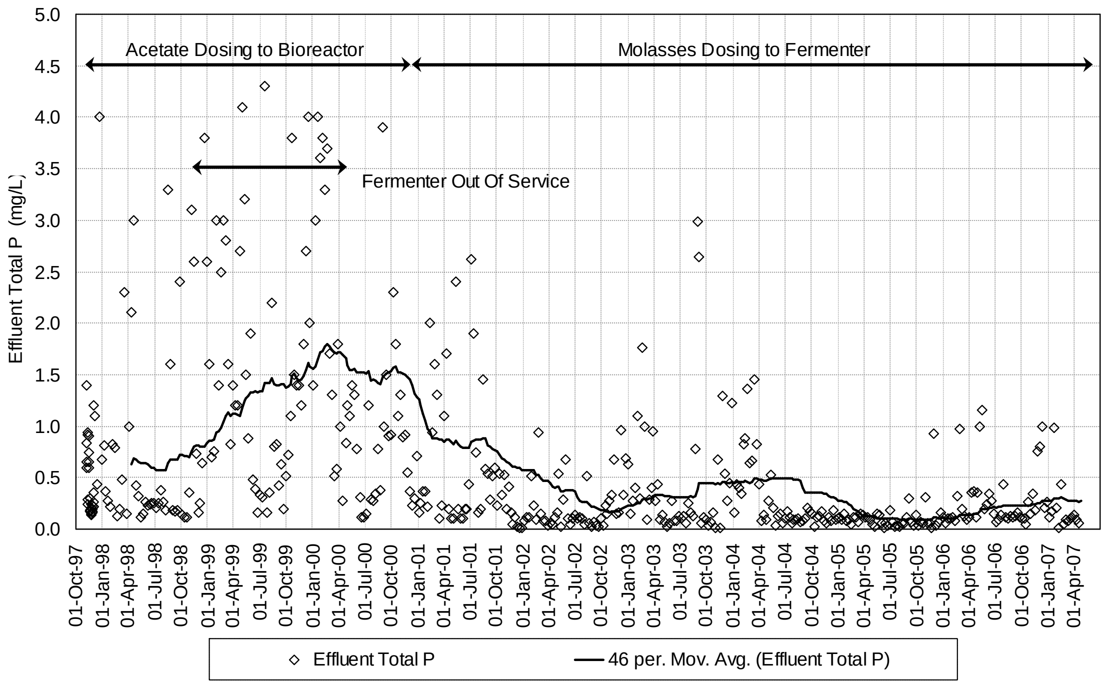

Figure 2: ***Variable P removal with acetate dosing and improved P removal with molasses dosing***

The high operating cost associated with acetate dosing, coupled with the unsatisfactory bio-P performance, ultimately lead to a search for an alternative, locally available, economical carbon source that was fermentable. The outcome was that molasses dosing into the fermenter was implemented in Dec 2000. Continued analysis of the fermenter outlet showed high concentrations of propionate as a result of molasses dosing, and the effluent phosphorus was generally maintained below 0.5 mg/L since Jul 2001 (Figure 2).

Analysis of the VFA species present in the raw sewage and fermenter outlet provided another one of the important clues to understanding bio-P behaviour. The VFA fraction in the raw sewage was typically 85% acetate and 10% propionate, whereas in the fermenter effluent in was 40% acetate and 45% propionate, and obviously the acetate that was dosed contained 100% acetate.

Therefore, when the fermenter was out-of-service and poor bio-P performance was occurring, the predominant type of VFA was acetate. Whereas when the fermenter was in service and good bio-P performance occurred, the VFA supply contained a significant concentration of both propionate and acetate. This highlighted the potential importance of propionate.

3.2 Effect of pH

Another significant factor that may have contributed to improved bio-P was the implementation of magnesium hydroxide ($Mg(OH)_2$) dosing into the sewer network for odour control. This happened progressively from Sept 2002 onwards, and its affect can be observed in the increasing influent sewage pH levels (Figure 3). The influent sewage pH has been maintained above 8.0 since May 2004, and this has coincided with an extended period of stable bio-P performance. This highlighted the potential for pH control to provide a mechanism for optimizing bio-P. Extensive independent studies have shown that PAO growth is favoured and bio-P performance is improved at pH levels around 8.0 (refer to Thomas, 2008; Hartley, 2013).

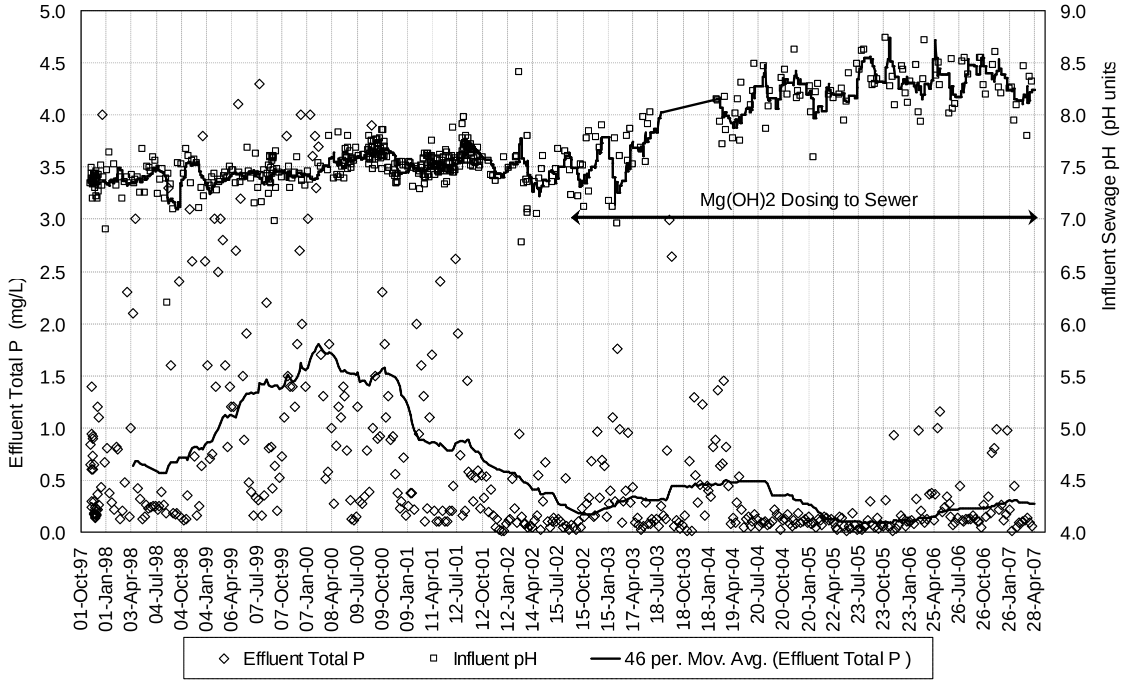

Figure 3: ***Increased influent sewage pH coincided with stable P removal***

Based on the results shown in Figure 2 and Figure 3 the relative importance of propionate substrate and a bioreactor with pH = 8 for ensuring reliable bio-P cannot be definitively resolved. However, the improvement in P removal that followed the implementation of molasses dosing indicates that a supply of propionate was potentially more important for developing and maintaining an active PAO population.

3.3 PAO and GAO Population Dynamics

It is understood that GAOs and PAOs can co-exist within the BNR activated sludge population and are a known competitors for the limited supply of VFA typically present in the influent to BNR plants.

It is also likely that variability in bio-P performance is caused by variations in the relative population sizes of PAOs and GAOs, rather than variations in the biochemistry of a fixed population of PAOs (Thomas, 2008).

Fluorescent in-situ hybridization (FISH) molecular probes for PAOs and GAOs were used to identify and enumerate the PAO and GAO microbial populations (Thomas, 2008). Initial results for Noosa BNR sludge confirmed the presence of significant numbers of GAOs (Thomas *et al*, 2003). As bio-P performance improved from 2001 onwards, further microbial population analysis of Noosa BNR samples confirmed increasing counts of PAOs. These observations provided strong evidence that the variability in bio-P performance was due to variations in the populations of PAOs and GAOs. Furthermore, in order to control this variability it would be necessary to control the growth of GAOs. The latest research on the combined influences of propionate, acetate, and bioreactor pH and temperature on PAO and GAO population dynamics has been summarized by Hartley (2013).

Extensive laboratory-scale investigations comparing acetate and propionate utilization by mixed cultures or enriched cultures of PAOs and GAOs, and investigating competition between PAOs and GAOs have been carried out during the last 10 years. Full reference details regarding the population dynamics of PAOs and GAOs that are discussed in this section are listed in Thomas (2008). In virtually all cases it was confirmed that better bio-P performance was obtained with propionate, or a mix of propionate and acetate, than with acetate alone. FISH molecular probes were also used to monitor the changes in population in one laboratory-scale investigation and it was found that the acetate-fed reactors were dominated by GAOs and the propionate-fed reactors were dominated by PAOs. Therefore, the importance of specific VFA species in the microbial population dynamics has been confirmed.

The hypothesis that GAOs are completely unable to utilize propionate was shown to be incorrect. Although it appears that acetate-utilizing GAOs are a different group of bacteria to propionate-utilizing GAOs. Therefore, under certain feed conditions different types of GAOs can potentially compete with PAOs, however, PAOs in enriched cultures can effectively utilize both acetate and propionate. Consequently it was shown that alternating the feed source between acetate and propionate produces a highly enriched culture of PAOs. Therefore, it appears that although some GAOs may be capable of utilizing propionate, they cannot compete effectively for propionate against PAOs.

PAOs that utilize lactate have also been studied, and in this case the lactate was produced from hydrolysis of glucose. It is possible that a similar pathway may be active within the biomass at Noosa STP, whereby molasses was hydrolysed to sugars and then converted to lactate, as well as acetate and propionate.

A further question arose regarding why a significant number of laboratory-scale studies have achieved successful bio-P when fed with acetate. Since many investigations were carried out at ambient water temperatures of 20°C in Europe, USA and Japan, it is possible that PAOs have a competitive advantage over GAOs to use acetate at cooler temperatures. However, in warmer climates such as Florida (southern USA), Queensland (Australia) and South Africa, it appears that GAOs have a competitive advantage over PAOs for acetate utilization. The answer seems to be that PAOs have more psychrophilic growth characteristics than GAOs i.e. PAO growth is encouraged at cooler temperatures and GAO growth at warmer temperatures.

4.0 DISCUSSION

A variety of operational strategies can be used to prevent the input of nitrate to the anaerobic zone via the Return Activated Sludge (RAS):

- Optimize overall process nitrate removal to minimize nitrate in RAS.
- Configure the bioreactor so that it includes a dedicated RAS denitrification zone e.g. Modified UCT or Johannesburg configurations.
- Minimize the RAS flow within the practical limits of safe clarifier operation. With good RAS flow control, the clarifier sludge blanket effectively becomes a RAS denitrification zone (Thomas *et al*, 1997).
- Ensure any recycles that contain nitrate are pumped back to the anoxic zone.

Phosphate release during aerobic digestion can be minimized by good aeration control in the digester (Griffiths, 2010). Over-aeration needs to be avoided and the aeration should be controlled so that the digester outlet always has a residual of about 0.5 to 1 mg/L ammonia and <0.2 mg/L nitrate. This operating strategy has been used successfully in aerobic-anoxic digesters at Wetalla and Burpengary East STPs. If anaerobic digestion of BNR sludge is used then chemical treatment of the dewatering liquor is essential to avoid the recycle of released phosphate back into the bioreactor.

5.0 CONCLUSION

The challenge with optimizing bio-P is that multiple factors influence process performance and when all factors are controlled within the optimum range then results demonstrate that reliable bio-P can be achieved in full-scale plants without dosing alum or ferric. The growth of unwanted GAOs can be minimized by providing a mixture of propionate and acetate, and the bioreactor pH should be slightly alkaline i.e. 7.5 to 8.0. The anaerobic zone must have minimum inputs of nitrate and oxygen. The aeration system needs sufficient capacity to maintain DO levels during peak loads. Recycle of P released during sludge stabilization and dewatering must be minimized.

6.0 REFERENCES

Griffiths, P (2010), *Innovation During the Optimisation Phase of an Alliance- Improved Technologies and Control for BNR Plants*, Proceedings Ozwater 2010 Conference, Brisbane, 8-10 Mar 2010.

Hartley, K (2013), *Tuning Biological Nutrient Removal Plants,* Chapter 3, IWA Publishing, ISBN 9781780404820, May 2013.

Thomas, M.P., Ostarcevic, E. & Bliss, P. (1997), *Utilising Clarifier Denitrification for Optimum Biological Phosphorus Removal*, Proceedings BNR3 Conference, Brisbane, 30 Nov-4 Dec 1997, pp. 252-259.

Thomas M., Wright P., Blackall L., Urbain V. & Keller J. (2003), *Optimisation of Noosa BNR plant to improve performance and reduce operating costs*, Water Science and Technology, Vol. 47, No. 12, pp. 141-148.

Thomas, M.P. (2008), *The secret to achieving reliable biological phosphorus removal*, Water Science and Technology, Vol. 58, No. 6, pp. 1231-1236.