UNDERSTANDING THE POPULATION DYNAMICS FROM AN INDUSTRIAL WASTEWATER TREATMENT PLANT AND HOW TO USE IT AS AN OPERATIONAL TOOL

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ABSTRACT

Biological treatment technology is commonly used to treat dairy factory processing wastewater in New Zealand at sites where irrigation is inappropriate. When advanced treatment was assessed as appropriate for the Stirling factory site, Membrane Biorector (MBR) technology was proposed – the first MBR plant treating dairy factory wastewater in New Zealand.

Commissioning challenges included the maintenance of nitrification. Dairy factory wastewater has many characteristics that could contribute to nitrification inhibition including high temperatures and fluctuating pH. The influent streams were assessed for inhibition, however no one inhibitory stream was identified. A nitrosomonas growth reactor is proposed for this dairy season to ensure ongoing compliance with ammonia concentrations in the discharge.

Although the plant was not designed to remove additional phosphorus biologically, it was observed that this was occurring intermittently. The causes for this were investigated and attributed to a combination of the operation of the dissolved air flotation (DAF) equipment, the solids capture of the decanter, and the consequent processing of the decanter centrate through the DAF unit.

The mixed liquor from the MBR was regularly observed microscopically and compared with analytical results. The number and types of filamentous bacteria present are a general indication of conditions in the sludge during the last three sludge ages, while the number and type of protozoa indicate current conditions.

There has also been a mixed presence of both Glycogen Accumulating Organisms (GAOs) and Phosphate Accumulating Organisms (PAOs) with relative numbers altering throughout the season.

KEYWORDS

MBR, dairy, EBPR, phosphorus removal, nitrification, microscopy, PAO, GAO

1 INTRODUCTION

The township of Stirling is located in the Clutha district of South Otago. The nearest large town is Balclutha which is on State Highway 1. Both towns are located close to the Clutha River the largest river in New Zealand (by volume).The Stirling factory employs 105 staff (78 in production & 27 tanker drivers) who live in the surrounding district. Fonterra Stirling is one of the largest employers in the Clutha district. Stirling is located 9 km upstream from the mouth of the Clutha River.

The factory processes locally produced milk into largely Fonterra branded cheese. The whey produced during cheese manufacture is further processed into sweet WPC80 and lactose concentrate. The lactose concentrate is transported to the Fonterra Clandeboye (Timaru) or Fonterra Edendale plants for lactose recovery.

Salt whey produced during the salting operation is removed from the process at source and is truck spread on local land where the nitrogen contained in the by-product is used as a fertiliser supplement. This is covered by land discharge consent.

Fonterra or legacy companies have operated a cheese factory in Stirling for the past 30 years (built in 1982). The site obtained consent to discharge DAF treated low strength factory wastewater to the Matau branch of the Clutha River. However silting of the Matau branch of the river has seen a progressive reduction in the flow in this branch and some stream bed degradation was observed as a result of the discharge.

Growing pressure from the Otago Regional Council encouraged Fonterra to look for alternative treatment options for the site wastewater.

Fonterra operates a number of different types of biological wastewater treatment plant. Most are activated sludge processes and most have nitrogen removal processes at the front end (denitrification tanks). Fonterra also operate one Sequencing Batch Reactor (SBR) at Hautapu, an oxidation ditch at Te Rapa and two small (site sewage) MBR plants at its Clandeboye and at Reporoa sites.

Fonterra is interested in employing new technologies where these can be shown to improve environmental outcomes and MBR technologies have shown promise in this regard. The Stirling site performance upgrade was seen as a good opportunity to look at alternative treatment processes and MBR technology was one technology considered.

The reasons for this included:

- Stable operation- established site with limited potential for increased milk supply
- Known wastewater compositional and volume data
- Mid-sized site with moderate waste volumes
- Fonterra owned land in close proximity to the site
- Surrounding farmland not ideally suited to spray irrigation- prone to flooding and soil types also not ideal
- Preference for continued disposal to surface water given waterlogged soil conditions at some times of the year.

Cost Benefit analysis undertaken:
The two treatment technologies considered for Stirling were an activated sludge process or an MBR process incorporating nitrification/denitrification and possibly Enhanced Biological Phosphorus Removal (EBPR). EBPR is the process where Phosphorus Accumulating Bacteria (PAO's) are encouraged to accumulate more than the usual concentration of phosphorus in their cells- "luxury uptake" by manipulating process conditions to encourage this response. The phosphorus is stored in the form of polyphosphate granules.

The cost/benefit analysis indicated that an MBR process would be less capital intensive than an activated sludge process but that it would consume more electricity (used to run the UF feed pumps). The sludge production would be less from an MBR process and that the MBR process could be expected to produce a treated effluent considerably “cleaner” than that produced by a conventional activated sludge process.

Tenders were sought from three consortia thought capable of delivering an MBR process in the required timeframe.

Initially the tenderers were required to include an EBPR option in the MBR offer but it became evident that no tenderer was confident that enough was known about EBPR to meet the required guarantees.

The tenderers were asked to resubmit their offers with the requirement for EBPR removed.

The outcome of the tender process was that a consortia led by Tetrapac and with the process technology supplied by Wehrle (Germany) being engaged to design and build an MBR plant at Stirling.

1.1 EFFLUENT COMPOSITION AND VOLUME

The Stirling wastewater volume and compositional data was characterised so that a plant of the correct size could be built to treat it to better than the consent discharge compositional requirements.

Site wastewater characteristics:

Characteristic	Typical value/mass	Typical value mg/litre
Wastewater volume	3500 m3/day	-
COD	6500 kg/day	1800mg/l
TKN	230 kg/day	83mg/l
NO3-N	215 kg/day	63mg/l
Total Phosphorus	100 kg/day	29 mg/l
Influent temperature (average)	33°C	-
Fat	175 kg/day	50 mg/l
Ammonia nitrogen	136kg/day	39mg/l

Consented discharge values: (95%ile, 20 samples/year):

Measure	Value
Maximum volume	3700 m3/day
BOD	Less than 30 mg/l
Suspended solids	Less than 200 mg/l
TKN	Less than 15 mg/l
NO3-N	Less than 10 PPM
TP	Less than 20 PPM
E.coli	Less than 10 (n/100 ml)

1.2 PROCESS DESCRIPTION:

The Stirling process consists of two tanks, a denitrification tank into which Dissolved Air Floatation (DAF) treated site wastewater enters and a larger nitrification tank. There is significant recycle from the nitrification tank to the denitrification tank.

The nitrification tank is aerated using three Robushi blowers and two jet pumps (jet aeration). The Dissolved Oxygen (DO) concentration in the nitrification tank wass maintained at not less than 1.8 PPM. This was reduced to 1.5 PPM to prevent nitrate leakage into the anoxic zone. The blowers speed up or slow down to maintain the required DO concentration.

Treated wastewater is removed from the process through straw type membrane cross flow Ultra Filtration (UF) membranes. The membranes are ca. 6 meters long and have an internal diameter of ca. 8 mm. The process Mixed Liquor (ML) is pumped through the straws and permeate is collected from the outside. The straws are contained in vinyl ester resin modules equipped with both sludge and permeate ports. There are 6 loops with 6 membrane elements per loop and the number of loops required to be run is determined by the level in the nitrification tank. For most of the time no more than 5 loops are required to be run and at times (overnight) the number of loops operating may reduce to two. Each loop is Cleaned in Place (CIP'ed) every 6 weeks. The chemicals used are typical of those used in the dairy industry, nitric acid, caustic soda and sodium hypochlorite. Low concentrations of chemical are required- compared to those required for dairy plant CIP processes. Sodium hypochlorite use reduces membrane life and the concentration used is carefully controlled to ensure maximum membrane life. The life of the membranes is anticipated at between 5 and 7 years.

Waste biomass from the process (WAS- Waste Activated Sludge) is removed from the process by taking a proportion of the slightly concentrated RAS (Return Activated Sludge) from the header line post the last UF loop. A small Alfa-Laval decanter is used to dewater the biomass to a solids content of around 14.5%. The decanter dewatered WAS is ploughed into local farmland and is used as a fertiliser supplement and soil conditioning agent.

Permeate from the process is continually monitored for flow rate and turbidity.

The decanter centrate is returned to the DAF process to remove the small quantity of solids not captured by the decanter.

The flow of wastewater from the factory is managed by two storage steps, one prior to the DAF unit and the other between the DAF and the denitrification tank.

Flow proportional samples are taken daily for both the process influent and for the UF permeate. These samples are analysed daily for the concentrations of contaminants and this information is used for process control.

The process MLSS is maintained by analysing the MLSS at the commencement of each day and the decanter is run to maintain the required MLSS concentration.

1.3 MAINTENANCE OF NITRIFICATION

The only problem encountered during the commissioning phase that affected effluent quality was that of nitrification (high concentrations of ammonia in permeate). During commissioning it was expected that the process would "commence nitrifying naturally". After some months of waiting it became evident that nitrification was unlikely to commence naturally and that bioaugmentation of the process with a culture of nitrifying bacteria would be required.

A culture of "Nitrosomonas" bacteria was sourced from overseas and was placed in the bioreactor. Within a few days the process was completely nitrifying. This condition persisted until a very hot day early in February 2009 when the process temperature exceeded 37°C. Nitrification was lost at that time and was not able to be re-established for the remainder of the 2009 season.

Since that time Fonterra has purchased a number of nitrifying bacterial cultures, one which successfully re-established nitrification and two other shipments which did not.

NIWA (National Institute of Water and Atmospheric Research) was commissioned to investigate the possibility of nitrification inhibitors being present in site wastewater and despite one small process stream being identified as being "possibly" inhibitory, the bulk of the process streams were found to be non-inhibitory. The reason for the process not naturally establishing nitrification and the reason for a non-temperature related nitrification loss remain a mystery.

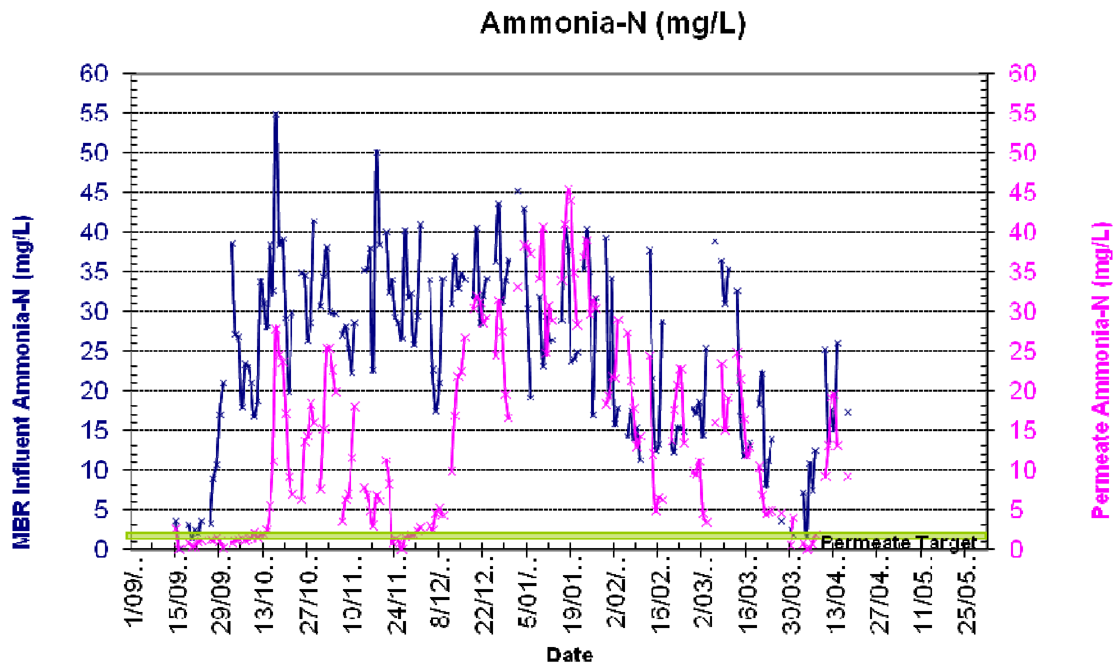
It is likely that Fonterra will establish a "Nitrosomonas" growth reactor beside the MBR process to enable fresh cultures of nitrifying bacteria to be grown on site and for these to be added on a frequent basis so that ongoing compliance with the consented permeate ammonia concentration can be achieved.

Treated Effluent Quality:

Contaminant	Concentration achieved
Suspended Solids	<3 mg/l
COD	16 mg/l
BOD	<1 mg/l
TKN	48 mg/l (when not nitrifying)
Ammonia	43 mg/l

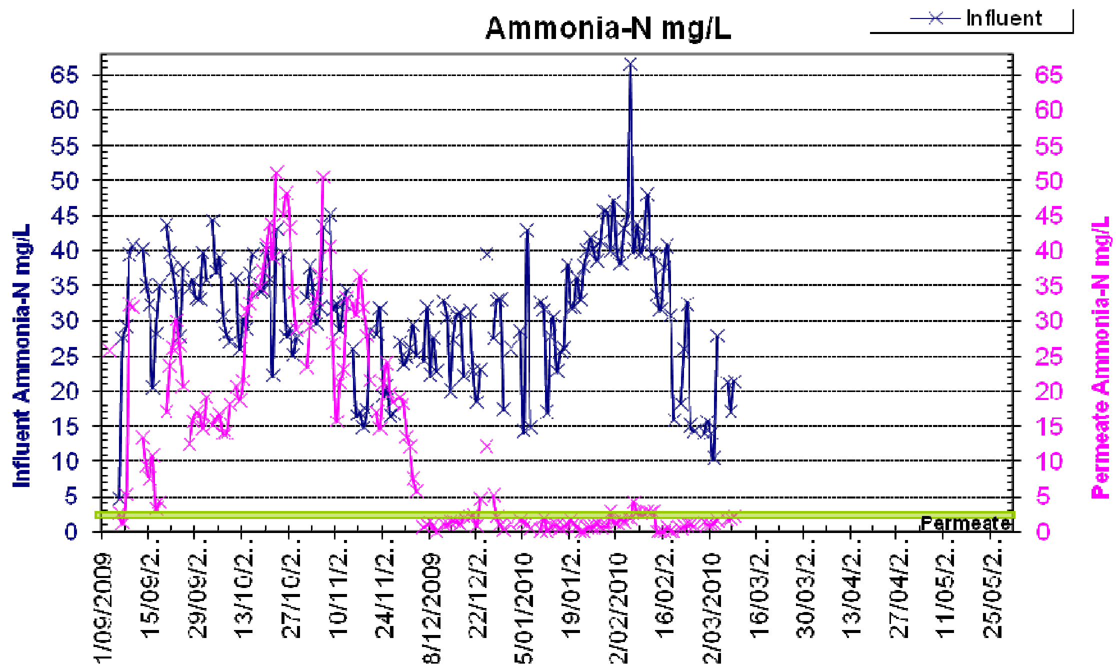
Total Phosphorus	17 mg/l
E.coli	<1 CFU/100 ml

The concentration of ammonia in permeate is determined by nitrification activity. During the F-11 dairy season, there were a number of peaks in the ammonia concentration in the treated wastewater prior to loss of nitrification around December 9th as seen below.



Graph 1: Influent and permeate ammonia concentrations for the 2010 through 2011 season.

The reason for the partial loss of nitrification during these periods has not been determined. It appears that there is something inhibitory in the factory wastewater. During the previous season there was a prolonged period of almost complete nitrification- after the process had been inoculated with a culture of nitrifying bacteria. Complete nitrification occurred from early December and continued through till mid March 2010. As graph 1 shows, the process went into the F-11 season nitrifying.



Graph 2: Influent and permeate ammonia concentrations for the 2009 through 2010 season.

1.4 ENHANCED BIOLOGICAL PHOSPHORUS REMOVAL (EBPR)

During the 2009/10 season, EBPR was found to be occurring at the Stirling site. This commenced during December 2009 and returned during January 2010.

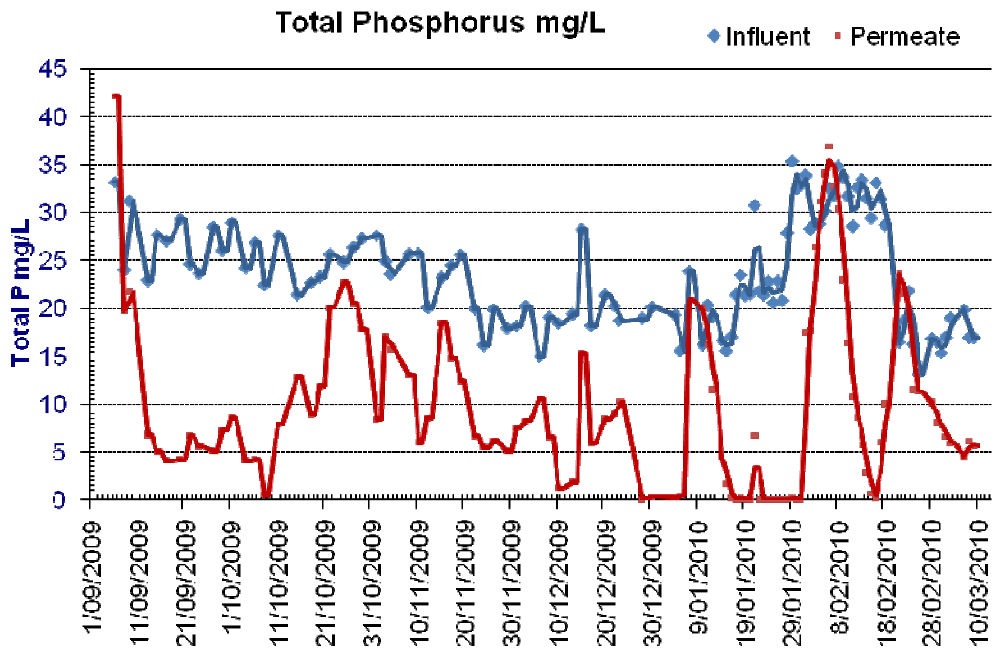
Conditions for the establishment of EBPR appear to require the following:

1. Operation of the DAF equipment at a pH of 6.5
2. Operation of the decanter at a reduced solids capture rate (say <80%)
3. Processing of the decanter centrate through the DAF unit

Proposed mechanism for EPBR:
When the DAF is operated at close to neutral pH, bacterial activity to produce VFA's (Volatile Fatty Acids) (fermentation) is not inhibited. After DAF treatment, the site wastewater enters two balance tanks of 250 m3 each. The HRT (Hydraulic Retention Time) in these tanks is around 3.5 hours and this is long enough for fermentation to occur. The VFA concentration was measured as the site effluent was fed into the MBR. Concentrations of between 50 mg/litre and 150mg/litre were found.

When the decanter is operated at low capture rates, the incoming factory wastewater is inoculated with bacteria able to effect the fermentation. VFA's are the preferred carbon source for poly-P accumulating micro-organisms (PAO's) and the presence of low molecular weight VFA's (Acetic and Propionic acids) enables the PAO's to build to sufficient numbers for almost complete removal of phosphorus from the treated wastewater to occur. The Stirling process has a denitrification tank at the front end of the wastewater treatment process (post the balance tanks) and it appears that this process is anoxic enough for phosphorus release to occur and for luxury phosphorus uptake to occur in the nitrification tank (aerated).

The effect of EBPR was that the phosphorus concentration in the treated wastewater reduced to values below the detection limit (0.1 mg/litre). When these values were measured by site technicians the equipment suppliers, Wehrle, asked that phosphorus be added to the process influent to ensure adequate Phosphorus was present for cell synthesis as acceptance testing was in progress.



Graph 3: Total phosphorus concentrations in MBR influent and permeate.

As will be seen, in late December 2009 and in early January 2010, there were a number of days when the permeate TP results were at or close to 0 mg/l. At these permeate concentrations the biomass is likely to exhibit nutrient deficiency symptoms (excessive numbers of filamentous bacteria). At the request of the equipment suppliers, the influent concentration of phosphorus was increased from around 22 mg/litre to around 30 mg/litre. The effect of phosphoric acid dosing was to immediately increase the permeate phosphorus concentration. When the DAF pH was returned to 6.5, the phosphorus concentration progressively reduced to close to 0 mg/litre. The TP concentration of the biomass was measured during these episodes. When EBPR was not occurring, the TP concentration in the biomass was ~2% w/w and when EPBR was in evidence the TP concentration was measured at ~3.7% w/w. During this period, 1000 litres of 85% w/w phosphoric acid was added to the process. While conditions suitable for EPBR were maintained, the addition of phosphoric acid had little effect on the concentration of Phosphorus in the treated wastewater (when the DAF was operated at high pH). The Phosphate accumulating bacteria increased the amount of phosphorus stored in the cytoplasm at the expense of a phosphorus residual in the permeate.

1.5 WHY THE PROCESS HAS NOT BEEN DEVELOPED

1. The DAF acts to limit extreme COD loads to the process. When the DAF is operated at a pH close to neutral, fat and casein protein is not removed efficiently from the wastewater. If a milk loss occurs, process overloading can result- observed as depressed DO values in the MBR. If large amounts of protein enter the MBR then process foaming can occur, this has caused a loss of containment- (tank overflow) on one occasion.

2. A decanter is used to remove WAS from the process. Decanter dewatered solids contain around 14% by weight of biomass. Biomass removed from the DAF is around 4% solids so there is an increase in the cost of WAS disposal- DAF costs about as much to dispose of as does decanter dewatered WAS.

3. A 1000 litre pod of Phosphoric acid costs around $5000. When EBPR was occurring the site added close to 100 litres of concentrated acid into the MBR each day. This is a substantial and an avoidable cost.

2 MICROSCOPIC EXAMINATION OF THE MIXED LIQUOR

AWT Water regularly receives samples from the Fonterra biological treatment plants for microscopic analysis. Tracking the populations of organisms in a wastewater treatment plant regularly can help to identify potential developing issues, and assist with targeted optimisation and troubleshooting.

The mixed liquor from the Fonterra Stirling WWTP has been monitored microscopically since plant start-up. The following are a selection of interesting observations.

2.1 PERIOD 1 NOVEMBER 2009 –

2.1.1 MICROSCOPIC OBSERVATIONS

The sample from the beginning of November 2009 contained many unflocculated, single cells and abundant filaments especially Nostocoida limicola spp. There were hardly any protozoa present.

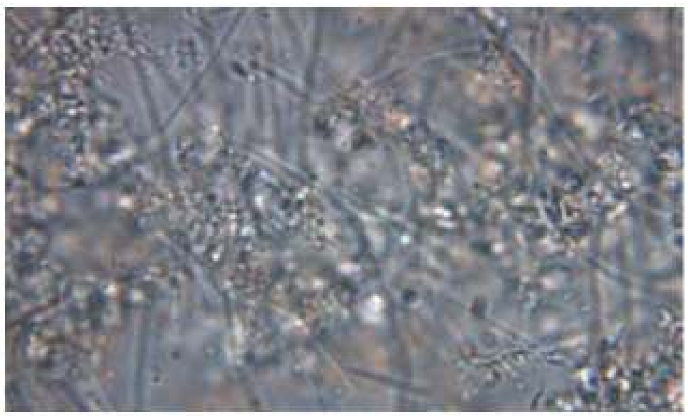


Figure 1 Stirling WWTP mixed liquor, phase contrast microscopy, 1000X magnification

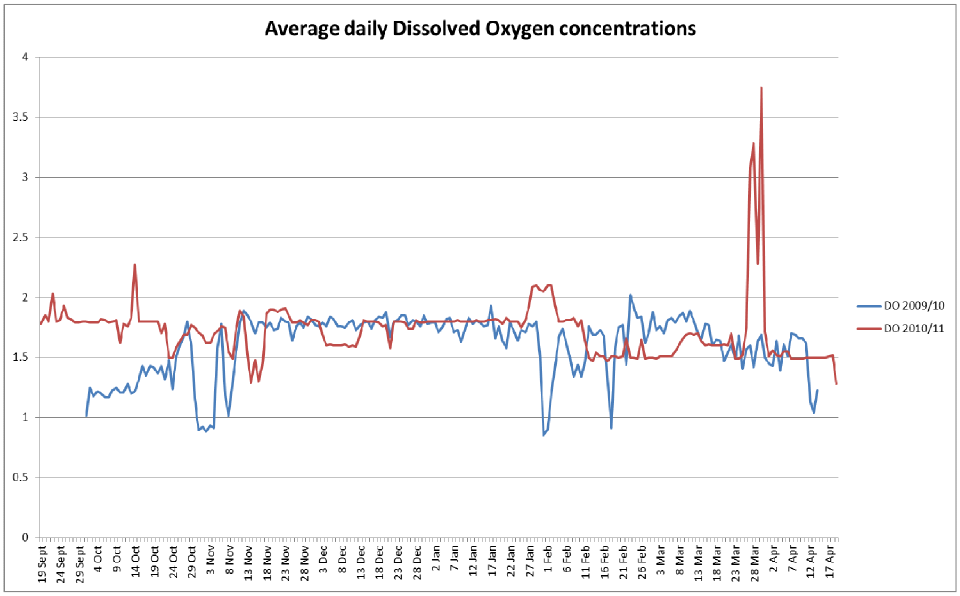
The presence of many free cells at a low Food to Microorganism (F:M) ratio and very low numbers of protozoa can both indicate a **lack of oxygen** or **toxic** influent.

N. limicola will only become the dominant organism in a mixed liquor under certain conditions:

1. **Low F:M** ratios
2. **Septicity**/volatile fatty acids – either in the treatment plant, plant side streams or influent.
3. Nutrient deficiencies, especially phosphorus deficiency.

2.1.2 ACTUAL CONDITIONS

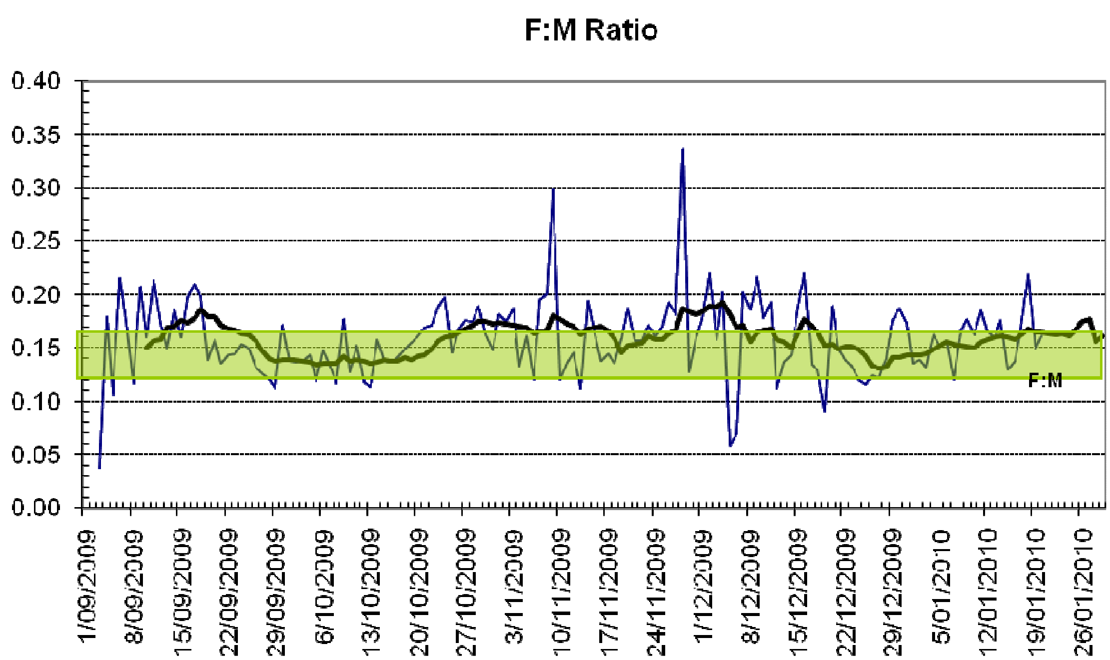
There were initially some commissioning issues at the Stirling MBR plant causing **low dissolved oxygen** concentrations over two weeks in early November 2009 (Graph 4).



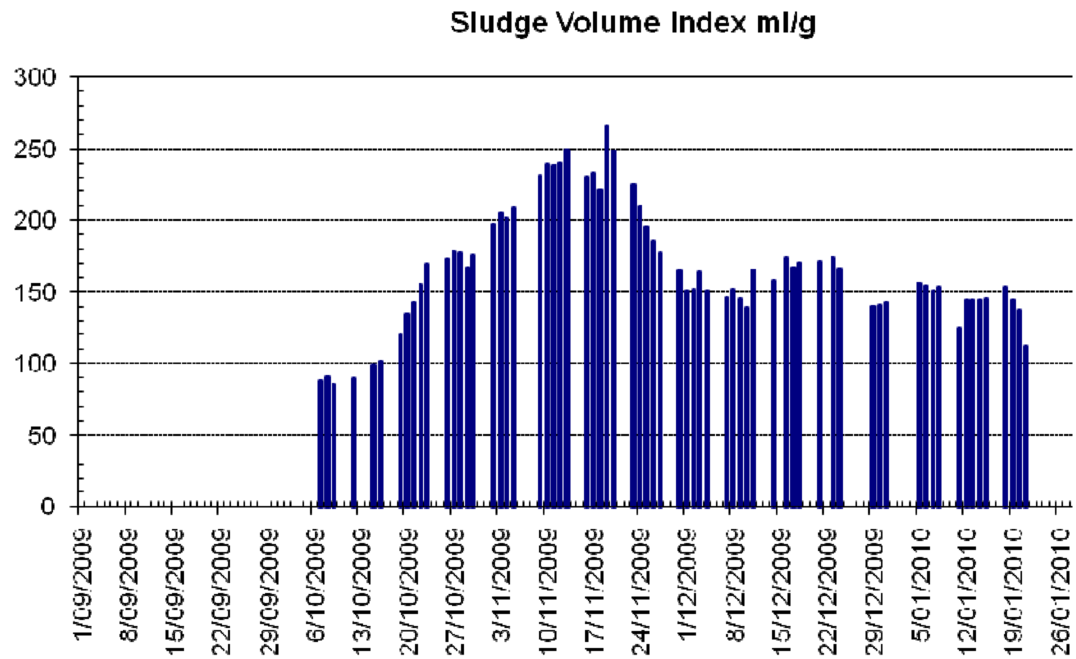
Graph 4: Dissolved Oxygen Concentrations

There was also a period of low F:M ratios during October 2009. Organic loading increased and MLSS concentrations were reduced in the latter part of November 2009 which increased the F/M ratio significantly (see Graph 5).

Consequently the sludge volume index (SVI) improved dramatically in the last week of November 2009 indicating that filament numbers had reduced (see Graph 6). This reduction in SVI would have been significant in a conventional activated sludge plant, however one of the advantages of an MBR type plant is that there is no settlement process, and therefore the impacts of filamentous bacteria proliferation will be less.



Graph 5: Food to Microorganisms ratio



Graph 6: SVI

Ultimately solving on-site commissioning issues to increase both the dissolved oxygen concentrations and the food to microorganism ratios lead to a significant improvement in the sludge settleablility.

2.2 PERIOD 2 APRIL 2011

2.2.1 MICROSCOPIC OBSERVATIONS

Samples taken during most of the 2009-2010 season were showing the following characteristics:

1. Small flocs
2. Spirochaetes
3. Filamentous bacteria very common – Type 0041, Nocardia, Type 0803, H. hydrossis
4. Many protozoa

The filamentous bacteria present all grow under conditions of low dissolved oxygen, septic influent (volatile fatty acids), high sludge age and/or nutrient deficiency (especially phosphorus deficiency). Enhanced biological phosphorus removal was being observed intermittently through the season verifying the presence of vfas and possibly P deficiency.

The sample taken on 4th April 2011 showed some differences from normal:

1. Few protozoa
2. Filamentous bacteria - Nocardia, Type 0041 and H. hydrossis were all still present however Thiothrix and fungi had also appeared (see Figure 2 below).
3. Naked amoeba

Figure 2 Stirling WWTP mixed liquor, phase contrast microscopy, 1000X magnification

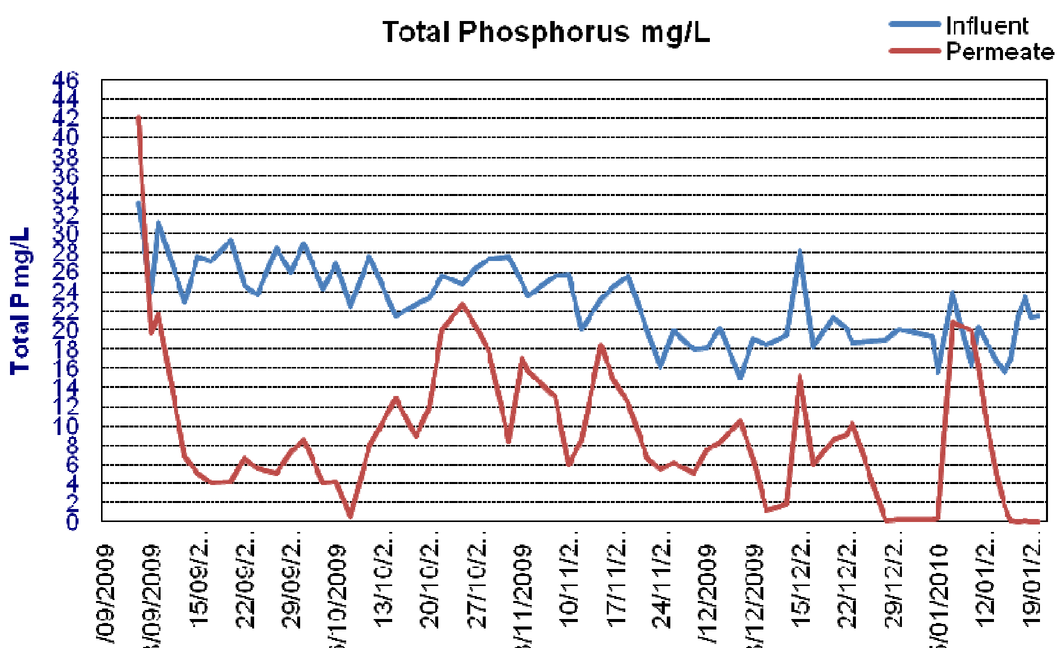
Naked amoeba indicate a young sludge age, possible from a recent upset. Fungi are not usually observed in activated sludge plants and indicate septicity, low pH and/or severe phosphorus deficiencies. The reduction in protozoa numbers indicate that less than ideal conditions were present.

2.2.2 ACTUAL CONDITIONS

Graph 3 above shows a dramatic increase in dissolved oxygen concentrations between March 27 and 31. Increases in dissolved oxygen like this often indicate a toxic event (organisms are deactivated and not able to utilise dissolved oxygen). The plant stopped nitrifying soon after. Nitrifyers are often the first organisms to succumb to a toxic event.

2.3 MONITORING ENHANCED BIOLOGICAL PHOSPHORUS REMOVAL (EBPR)

The MBR plant at Stirling was not designed to guarantee biological phosphorus removal, however there have some very low total phosphorus concentrations recorded in the discharge (permeate) as shown in Graph 3.



Graph 6: Influent and permeate Total Phosphorus concentrations

There has also been a mixed presence of both Glycogen Accumulating Organisms (GAOs) and Phosphate Accumulating Organisms (PAOs) with relative numbers altering throughout the season.

PAOs grow in clumps of grape-like clusters that stain Neisser positive throughout the cell due to the high concentrations of polyphosphate contained in the cell. These cells will also stain purple-pink under the methylene blue stain.

GAOs appear as a cluster of cells staining Neisser positive only at the cell wall. GAOs accumulate polysaccharides rather than poly-P in the aerobic zone and can reduce biological P removal in a system by out-competing the PAOs. The presence of GAOs may not always signal poor EBPR performance provided there is sufficient influent carbon, however they do indicate that there is a risk of insufficient substrate for efficient EBPR to occur. [1] GAO growth may be encouraged by high sludge age, high temperatures, longer unaerated zones, stronger wastes, and low mixed liquor pH.

It is hoped to understand better the mechanisms involved in the EBPR process at Stirling and other Fonterra biological wastewater treatment plants by combining the use of sludge microscopy techniques with on-site analysis.

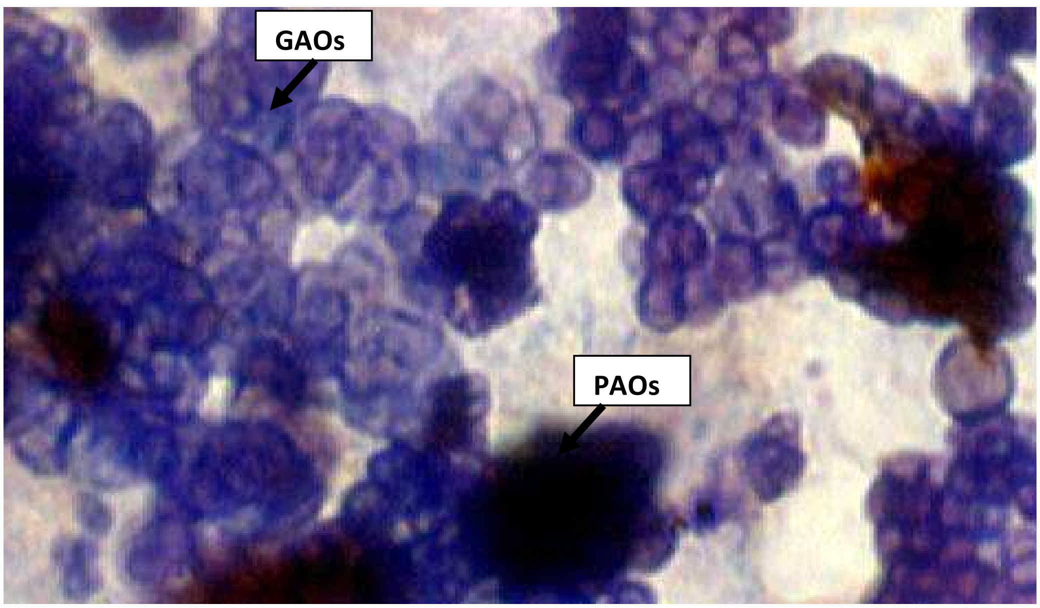


Figure 3 Bacteria important in Enhanced Biological Phosphorus Removal

3 CONCLUSIONS

The installation of a MBR plant to biologically treat dairy factory wastewater has significantly improved the discharge from the Fonterra Stirling processing site. This project was a good opportunity to review the MBR technology and its suitability for the treatment of dairy processing wastewater which historically struggles with filamentous bulking due to the nature of the wastewater.

It was also a good opportunity to correlate on-site performance with microscopic evaluation of the mixed liquor and to better understand some of the mechanisms operating in the Stirling MBR plant.

[1] WERF Report "Factors Influencing the Reliability of Enhanced Biological Phosphorus Removal."