Australian Water Recycling
Centre of Excellence

Project Report

Water Treatment Pilot Plant Evaluation at a Dairy Manufacturing Site

A report of a study funded by the
Australian Water Recycling Centre of Excellence

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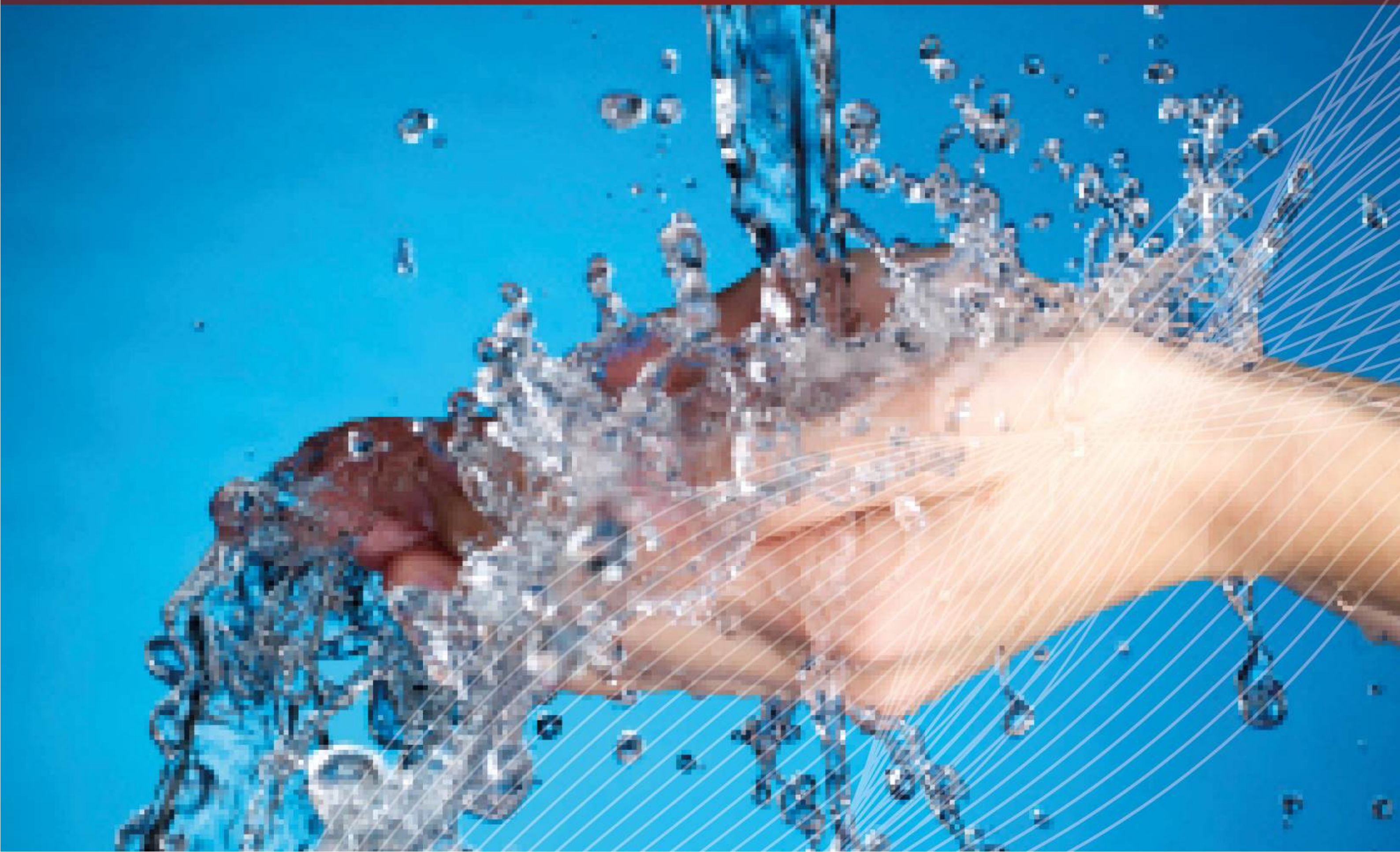

Water Treatment Pilot Plant Evaluation at a Dairy Manufacturing Site

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Partners

CSIRO has been commissioned by the Australian Water Recycling Centre of Excellence, Dairy Innovation Australia Ltd. and a Dairy Manufacturing Site, to undertake this project. For further information about CSIRO, please visit www.csiro.au

About the Australian Water Recycling Centre of Excellence

The mission of the Australian Water Recycling Centre of Excellence is to enhance management and use of water recycling through industry partnerships, build capacity and capability within the recycled water industry, and promote water recycling as a socially, environmentally and economically sustainable option for future water security.

The Australian Government has provided $20 million to the Centre through its National Urban Water and Desalination Plan to support applied research and development projects which meet water recycling challenges for Australia's irrigation, urban development, food processing, heavy industry and water utility sectors. This funding has levered an additional $40 million investment from more than 80 private and public organisations, in Australia and overseas.

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Disclaimer

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Introduction and background

A large dairy manufacturing site in Australia that is committed to environmentally sustainable practices and continually trying to improve their environmental performance has agreed to support the case study to reduce fresh water use in the Agri food sector by increasing the amount of water that is being recycled. The selected dairy manufacturing site participates in water, energy and waste assessment programs and industry projects to improve resource efficiency. There are a number of processes at the dairy manufacturing site which produce water as a by-product. These water sources include condensate from the evaporation of skim milk and other products, and membrane filtration permeates freeing up more than 500 ML of mains water per year.

The wastewater treatment plant at this dairy manufacturing site produces biogas which is captured and used to operate a hot water heater at the treatment plant. This renewable source of energy directly replaces natural gas and saves more than 1500 tCO_2e per year. However, due to limits to potable water supplies and wastewater disposal, plans for growth are also limited. The dairy manufacturing site require a higher volume and long term supply of potable quality water and would also like to reduce the volume of wastewater and importantly the N and P load discharged to sewer.

ADI Systems is a leading global company that designs, and builds waste water treatment systems. To address the water reuse challenges, a proposal was developed specifically for this site in collaboration with CSIRO to demonstrate and evaluate a pilot-scale wastewater treatment to treat secondary effluent to achieve water of sufficient quality to be recycled as process water, or further treated to potable quality water.

Objectives

1. To demonstrate and evaluate a pilot plant suitable for treating secondary effluent to achieve recyclable water using the following technologies:
    - Chemical phosphorus removal and recovery
    - Biological nitrogen removal with a Membrane Bioreactor (MBR)
    - Reverse Osmosis (RO) membrane filtration
    - Ultraviolet (UV) disinfection and chlorination of final product water;
2. To evaluate the value proposition arising by the introduction of this technology; and
3. To assess the regulatory framework for reuse of the treated water and identify compliance requirements.

The scope of the work undertaken was restricted to the wastewater treatment operations of this dairy manufacturing site.

Methodology

Systems overview

The technology for the majority of the trial was well established and included a MBR (2,800 L/day) coupled with a RO membrane filtration system followed by a UV and chlorination disinfection system. In addition, a new approach was evaluated for the removal and recovery of phosphorus prior to the MBR. An overview of the system is shown in Figure 1.

Technical and cost-benefit assessments were conducted to determine the feasibility of the project and opportunities for reuse of the treated water at the dairy manufacturing site was evaluated with reference to the current regulatory framework.

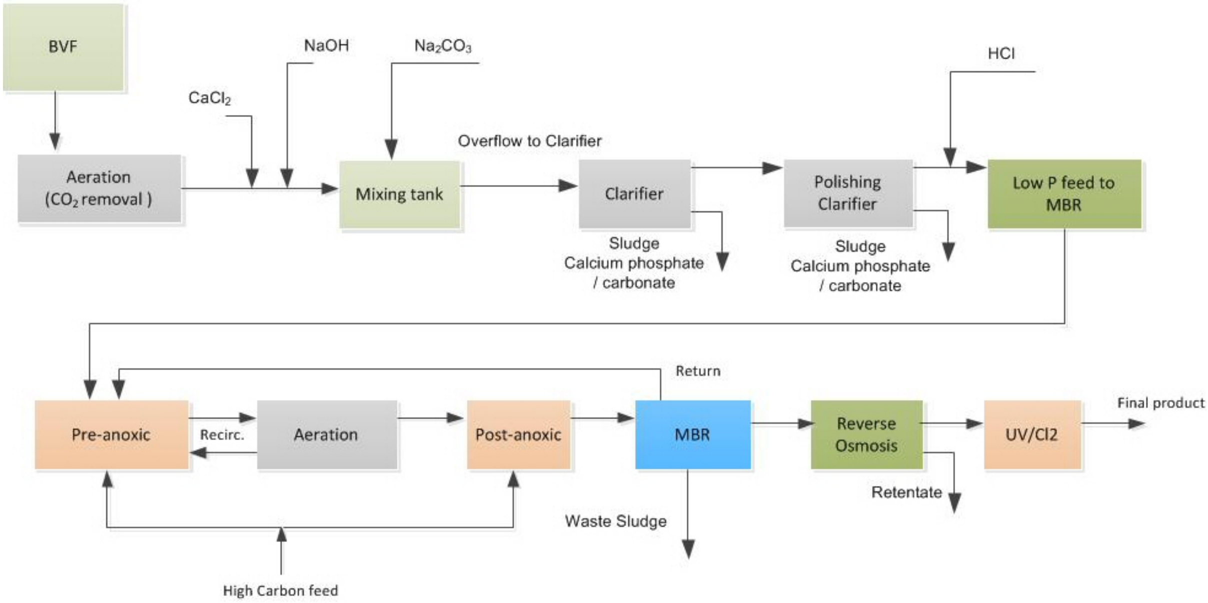

Figure 1. Flow diagram of pilot scale system.

Technology assessment

The phosphorus removal strategy consisted of chemical precipitation of phosphate using calcium chloride. In contrast to the addition of aluminium or iron salts, this approach is expected to allow for more effective reuse of sludge. Preliminary tests on phosphorus removal were carried out at CSIRO laboratories prior to on site trials.

The technology trial focussed on the treatment of secondary effluent from the existing anaerobic bulk volume fermenter (ADI-BVF®) using a membrane bioreactor to achieve appropriate quality water that is fit for recycling. The capacity of the pilot scale bioreactor is approximately 2,800 L/day and this reactor was supplied by ADI Systems.

The Reverse Osmosis plant was supplied by EPI Ltd. The UV / chlorination disinfection system was supplied by CSIRO.

Process data, including energy consumption, chemical and water usage, product and waste stream flow membrane flux and cleaning frequency were recorded and evaluated. Appropriate chemical and microbiological tests were carried out to monitor the quality of the feedstock and the treated water at different points of the system.

Regulatory framework

The regulatory requirements for recycling water in food processing plants are covered within the National Food Standards and State Food Acts. As there is limited information on water recycling in these Standards, an assessment was carried out on the selected recycled water uses to provide better clarity on the regulatory requirements. The use of recycled water from the diary manufacturing plant comes under the Australian Guidelines for Water Recycling and an assessment of treatment requirements, and any health risks associated with the raw and treated water, was made based on the information from the Recycling guidelines.

Value proposition

The value proposition was evaluated using a spreadsheet-based tool developed by CSIRO as part of the project for AWRCoE. This tool provides a net present value calculation which considers capital and operating costs as well as resource recovery and pollution reductions costs. Although this tool does not consider social benefits, it can provide an estimate of the costs to enable this dairy manufacturer to consider whether possible social benefits will be greater than the costs.

Appropriate data from these trials were used in developing the value proposition, including estimates of capital and operating costs for the selected water recycling options. ADI Systems provided estimates of capital and operating costs when scaling up the pilot plant to full scale. The value proposition was evaluated by dairy manufacturer personnel with guidance from CSIRO.

Systems integration

Although the overall system for these trials consisted of a number of unit operations (i.e. phosphorus recovery, MBR, Reverse Osmosis and disinfection), these processes were integrated and coordinated by the operations team at the dairy manufacturing site as well as teams from CSIRO and ADI Systems. The team members had regular meetings and open communications to ensure that the day to day operations proceeded smoothly and problems were addressed early and resolved. Furthermore, the technology assessment activities were well integrated with the development of the regulatory framework and the value proposition so that the whole system could be evaluated with respect to technical, economic and regulatory constraints.

Key results and learnings

Phosphorus removal

The phosphorus (P) removal system has successfully demonstrated that up to 92% of the soluble phosphorus can be removed and recovered from the dairy manufacturing site's effluent depending on BVF feed phosphate concentration. The sludge collected from the process consists of approximately 7% phosphate, making it attractive for application as a solid fertilizer.

Membrane bioreactor

The MBR has successfully demonstrated a high level of treatment of the anaerobic effluent, and the permeate quality was suitable for direct treatment in the RO unit.

The MBR showed excellent performance with 97% COD removal and 95% nitrogen removal, and the suspended solids concentration below detection levels in the permeate. The MBR received the low phosphorus feed from the P removal plant, and generated a high quality permeate which contained on average <40 mg/L COD, <21 mg/L total nitrogen and negligible solids.

Reverse osmosis

The results from these trials give a good basis to design a full-scale RO plant that should operate at reasonable recovery rates. In order to produce water at greater than 50% recovery and with a conductivity equivalent to potable water by Australian Drinking Water Guidelines (or close to current mains water supply), the RO permeate would need to be further treated through a second RO. These trials indicate that it should be possible to operate a one- or two-pass RO system at 70% recovery rate without use of anti-scalants and without increased cleaning.

Disinfection

Final disinfection of the RO permeate to control residual microbial /viral /pathogen activity is needed to ensure that the final product is of portable quality. UV disinfection is well proven to reduce bacterial and viral populations in treated water, while chlorination provides a residual disinfection to discourage any further pathogen growth as the water passes to storage facilities and end use. UV disinfection combined with sodium hypochlorite addition was applied to the RO permeate. Microbiological testing for *E. coli*, *Enterococci* and Heterotrophic bacteria was carried out before and after RO, and additionally after disinfection. The water quality following RO and particularly after disinfection was high.

Value proposition

The demonstration of the value proposition tool at this dairy manufacturing site provided valuable insight into the viability of the water recycling project. It highlighted that uncertainty in the estimates may make it difficult to discern a difference in cost and value. More detailed capital quotes may reduce the uncertainty and clarify any difference in cost and value. Nonetheless, the analysis provides an initial screening of the investment option and defines the range of capital cost estimates for a financially viable project.

The analysis also highlighted the need for water recycling projects to 'bundle' different components of value to gain the greatest value for the project. The value of the recycled water itself was only about 29% of the value of the project. The greatest value came from increased production by overcoming production constraints. Other values such as reduced wastewater and phosphorus recovery were required to make the value comparable to the costs.

The analysis focussed upon financial considerations for the viability of the project. A value proposition with a greater scope may also consider the value to the community – even if valued from the perspective of this dairy manufacturing site in terms of on-going community relations and corporate citizenship. The project also focused upon a short period of analysis which accords with a financial analysis with a relatively high discount rate. However, a strategic perspective may be warranted given the importance of water as a limiting constraint for production in the future. The sensitivity analysis doubled the period of analysis and suggested that value became significantly greater than the cost.

Regulatory framework

There are a number of barriers to the uptake of wastewater recycling and reuse within dairy factories. More specifically, there remains a lack of clarity with regards to the regulations for water recycling. Greater clarity in - and understanding of - the regulations may assist in reducing the apparent reluctance of some companies to initiate investigations into implementing water recycling and reuse processes, technology and options. This provides scope for discussion and engagement with regulators. In addition to this, there is some difficulty in acquiring useful, detailed information regarding the value/costing of the implementation of water recycling and reuse processes, the technology involved and the potential end uses for individual companies and businesses. Often this information is only able to be acquired during consultation processes and associated fees may be prohibitive. The value proposition tool as demonstrated above can provide valuable assessment on the applicability and value of different reuse schemes and treatment methods.

The participation of this dairy manufacturing site in investigations focusing on the implementation of water recycling and reuse processes within their plant has provided us with greater insight into the efficiency and effectiveness of the recycling process via the specified treatment train. Initial testing of the recycled water produced by the treatment plant installed at the site indicates that the water produced by the plant is of high quality, and comparable to town supply water quality. This initial testing has assessed the ability of the recycled water plant to produce water of an acceptable quality for use within the plant. Further testing will be required in order to validate and conclusively determine both the quality of the water produced and it's suitability for use within the plant as a potable water source. If early indications are proven to be correct, then it is anticipated that the wastewater produced by the factory will be able to be safely recycled through this treatment train, and that this recycled water should be acceptable for use within the factory for both potable and non-potable applications.

Operational issues and learnings

It was necessary to run the system continuously for an extended period of time in order to collect a reliable set of data for analysis. This task proved to be more difficult than anticipated and there were many operational and technical problems to be overcome with the phosphorus recovery and MBR systems in particular. We also underestimated the resource requirements and the timescales to undertake a trial of this nature. This experience however, demonstrated the importance of carrying out pilot scale trials before large capital investment decisions are made. As well as the operational learnings, pilot scale trials enable the collection of appropriate data to evaluate the technical and economic viability of the proposed system, thus minimising risk of capital investment.

Conclusions and Recommendations

These trials have demonstrated that a wastewater treatment system comprising of a phosphorus removal system followed by a membrane bioreactor followed by a reverse osmosis system and a UV / chlorination disinfection system will successfully produce water of the required chemical and microbiological quality for a dairy manufacturing site to reuse and recycle in their production facilities. Installation of such a system will enable the dairy manufacturer to satisfy their future demand for water and expand their operations. As the quality of the water produced with the proposed system will be of potable quality, the current regulatory requirements will be fulfilled. An analysis of the value proposition showed that although there was no significant difference of the value compared to the cost for a 10-year period, the value was significantly higher for a 20-year period.

It is recommended that before the dairy manufacturer makes capital investment decisions for a new system to treat their waste water for reuse and recycling, a longer site trial should be carried out on the phosphorus recovery and MBR systems to increase the confidence of the robustness of these systems and to ascertain how these systems will cope with seasonal and other variations in the plant and raw feed. Furthermore, such prolonged trials will enable more process and water quality data to be collected to confirm the results from the current study. In addition, further economic analysis should be carried out to ensure that the value proposition of the proposed system is viable.

Further information

More detailed information on the trials and results are given in the main report in the following sections.

1. Phosphorus Removal System
2. Membrane Bioreactor (MBR)
3. Reverse Osmosis (RO)
4. Disinfection
5. Value Proposition Tool Demonstration
6. Regulatory Framework for Water Recycling

Abbreviations

AC	alternating current
ADWG	Australian Drinking Water Guidelines
ANZFA	Australia New Zealand Food Authority
AQIS	Australian Quarantine and Inspection Service
BOD	biochemical oxygen demand
BVF	bulk volume fermenter
CCF	conductivity concentration factor
CIP	clean in place
COD	chemical oxygen demand
DO	dissolved oxygen
EC	electrical conductivity
FSANZ	Food Standards Australia New Zealand
HACCP	Hazard Analysis and Critical Control Points
HPC	Heterotrophic Plate Count
IBC	intermediate bulk container
LMH	litres per square metre per hour
MBR	membrane bioreactor
MLSS	mixed liquor suspended solids
MLVSS	mixed liquor volatile suspended solids
NHMRC	National Health and Medical Research Council
NRMMC	Natural Resource Management Ministerial Council
OIE	World Organisation for Animal Health
qPCR	Quantitative Polymerase Chain Reaction
P	phosphorus
RO	reverse osmosis
TMP	transmembrane pressure
TN	total nitrogen
TSS	total suspended solids
VSD	variable speed drive
VSS	volatile suspended solids
WAS	waste activated sludge
WCO	World Customs Organisation
WTO	World Trade Organisation
WWTP	wastewater treatment plant

1. Introduction

To address the water reuse challenges at a dairy manufacturing site (DMS), a proposal was developed as a collaboration between CSIRO, ADI Systems and the DMS personnel to demonstrate and evaluate a pilot-scale wastewater treatment trial to treat secondary effluent to achieve water of sufficient quality to be recycled as process water, or further treated to potable quality water. The pilot plant consisted of the following technologies:

- Chemical phosphorus removal and recovery
- Biological nitrogen removal with a Membrane Bioreactor (MBR)
- Reverse Osmosis (RO) membrane filtration
- Ultraviolet (UV) disinfection and chlorination of final product water

Roles and responsibilities

The following table summarises the roles and responsibilities for carrying out various tasks by DMS, ADI Systems and CSIRO personnel.

Activity	Responsibility
Phosphorus recovery system - Developing laboratory system - Scaling up - Installing at DMS and providing technical support	CSIRO
MBR system - Supply and installation - Technical support	ADI Systems
Reverse Osmosis System - Supply - Installation and operations	EPI Ltd. DMS
Disinfection system - Supply - Installation	CSIRO DMS / CSIRO
Operations of all unit operations	DMS
Troubleshooting	DMS, ADI Systems, CSIRO
Analytical work	DMS, CSIRO, outsourcing

Timelines

The MBR system was shipped from Canada in November 2013, delivered to the DMS in December 2013 and was installed and commissioned in January and February 2014.The Phosphorus recovery system was installed in April 2014 followed by the RO and disinfection systems. After resolving a number of technical and operational issues, the whole system was successfully run continuously for a period of six weeks in June / July 2014.

2. Phosphorus Removal System

Principal of operation

The effluent from the anaerobic bulk volume fermenter (BVF) lagoon contains a high concentration of soluble phosphorus (typically 65-90 mg/L PO_4-P). Phosphorus removal from the BVF effluent prior to MBR and RO treatment stages is important, as high levels of phosphorus will increase the likelihood of membrane fouling. A target concentration of 20 mg/L P was set based on previous experience from operational MBR plants. The phosphorus removal strategy using calcium chloride for chemical precipitation was selected instead of the more conventional approaches which use aluminium or iron salts. The reason for using calcium salts is to recover phosphorus in a more readily available form for plants, hence, allowing for a more effective reuse of flocculated sludge. In contrast, current reuse options for iron or aluminium phosphate materials are limited due to the strong chemical (ionic) bonds formed. Preliminary tests on phosphorus removal from BVF effluent were carried out at CSIRO laboratories. A series of jar tests were performed using both Ca^{2+} and Mg^{2+} divalent salts, with calcium providing the most effective removal (Appendix A:- Jar Testing of Phosphate Precipitation).

Chemical processes / design basis

The process of removing and recovery of phosphorus was designed as a continuous dosing operation according to Figure 2. To enable P to be recovered in a form suitable for land application, soluble calcium was added to encourage the formation of hydroxylapatite ($Ca_5(PO_4)_3OH$). Subsequent steps were designed to remove the hydroxylapatite and excess Ca via flocculation/coagulation, and then restore pH to a suitable range to support the microbiological processes within the MBR process. Effective P precipitation was achieved by firstly aerating the incoming BVF effluent to remove excess CO_2, thus partly raising the pH (from 7.9 to 8.3), then inline dosing with calcium chloride (2M stock) to react with soluble phosphate. Due to competing reactions (organic acids) and to ensure adequate removal, the calcium is added in excess, followed by sodium hydroxide (1M stock) addition to adjust the final pH to >9.5. Residual calcium levels must be lowered prior to membrane filtration (Ca <60 mg/L).This was done in the 20L mixing chamber by the addition of sodium carbonate (1M stock) which removes Ca^{2+} via flocculated calcium carbonate. The slow agitation in the mixing chamber encourages flocculation and effluent passes from this via an overflow weir into the clarifiers. Calcium phosphate and carbonate solids are settled and removed in the primary and secondary clarifiers. As the effluent flows into the product water tank, inline HCl dosing (11% stock) occurs to decrease the pH to approximately 8.

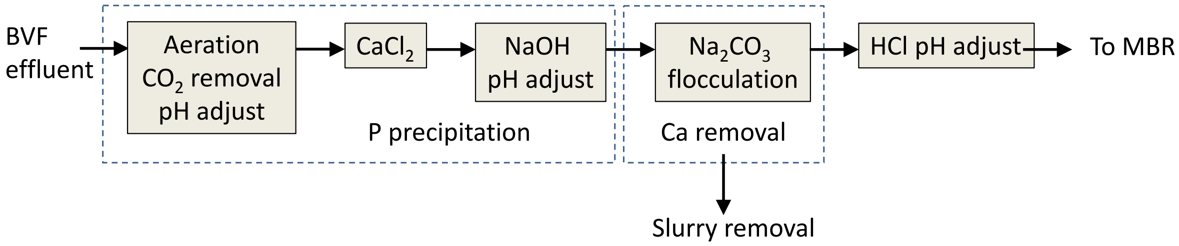

Figure 2. Flow diagram of chemical process.

Methods and Equipment Specifications

Feed through the system was controlled to 1.75 L/min using a Masterflex (L/S Digital Standard Drive with easy load head) peristaltic pump and Masterflex LS35 Norprene tubing.

Aeration CO_2 removal: a 1000 L tank containing 590 L of BVF was aerated using a Hailea Vortex Blower (model VB-600G) able to supply 600L/min. The hydraulic residence time (HRT) was over 5 hours. All chemical dosing was achieved using Iwaki electromagnetic metering pumps (model EW-F10VC-20EPY3).

In-line mixing: $CaCl_2$ and NaOH dosing was achieved by delivering into 10 mm internal diameter tubing of total length 2 m, resulting in a hydraulic retention time (HRT) of 6 seconds.

Mixing tank: a 20 L container filled with 15 L of liquor was stirred using a twin paddle attached to an overhead variable speed mixer (IKA RW20, set to 40 rpm).

Clarifiers: two conical clarifiers were used in tandem. The first being a 70 L with HRT of 40mins, and the second, 55 L with a HRT of 30mins. A Masterflex (7544-60 L/S easy load II head) peristaltic pump was used to extract the coagulated slurry from the bottom of Clarifier 1 at a rate of 0.190 L/min. Minimal solids accumulated in Clarifier 2. A daily routine was established to release 4 L of sludge from Clarifier 1 and 0.5 L from Clarifier 2 in order to maintain consistent clarifier operation.

Figure 3. Photos of P and Ca removal pilot setup. (a) general setup showing green upright tank for CO2 removal with blower at base, mixing tank centre-top, and chemical dosing on far right, (b) Clarifier 1 on left and Clarifier 2 on right, (c) product tank (blue) and clarifier 2 on right, (d) main flow pump on left with four chemical dosing pumps on right, (e) chemical dosing tanks at bottom and pumps above.

Sensors, logging and characterisation

A series of online sensors and monitoring alerts were managed during the length of the trial. Measured conditions were:

- Aeration chamber pH (SensoreX, model S660D)
- Mixing tank pH (Hanna AmpHel® General Purpose Electrode) and temperature (TC Measurement & Control, Sheathed T-type thermocouple)
- Product tank pH (SensoreX model S660D), conductivity (ThermoFisher model Alpha500), level sensor (CYNERGY3).

A data logger (Datataker DT85) was used to control and interrogate the on-line sensors (Figure 4). Remote connectivity was established through a Modmax modem with 3G SIM which reported any alarm trigger to the DataTaker, dEX Web-based Visualisation software. The online sensors were used to manage the major risks of "No water" or "out of spec" water from the product tank sensor outputs, enabling an automated SMS alert to be sent where levels fell out of specification. Pump energy usage was determined using an in-line instantaneous power meter (PowerMate, CCI Pty Ltd). Reported power consumptions were averaged over 12 readings.

Analytical determinations of Al, Ca, Fe, K, Mg, Na and P were achieved using Inductively Coupled Plasma –Optical Emission Spectroscopy (ICP-OES). Samples that were high in sediment were thoroughly shaken and a 1 mL homogenous aliquot was then taken and placed in a test tube. This was treated with 2 mL of 69% HNO_3 and heated until a clear solution was obtained. The resultant sample digests and clear aqueous samples were then diluted as required with Milli-Q (High purity) water and analysed by ICP-OES. Certified multi-element solutions were used to check the accuracy of the calibration standards used and the method. Solids characterisation of clarifier slurries was achieved by oven drying at 105°C, then accurately weighing approximately 0.03 gm of solid into a test tube and digesting over heat (100-105°C) with 2.0 mL of 69% HNO_3. Once cooled, the clear solution was then made up to 100 mL in volumetric flasks with high purity (Milli-Q) water.

Thermal analysis of dried clarifier slurry was carried out using a Netzsch STA 449 F1 Jupiter Simultaneous TGA/DSC Thermal Analyser system with the following conditions; Carrier Gas: Air, Ramp Rate: 10°C/min, Maximum Temperature: 500°C, Sample Holder: Alumina. Evolved gas analysis was carried out by coupling the Netzsch system to a Thermostar Pfeiffer Mass Spectrometer, which detected for gases at the following atomic masses: 2, 12, 14, 15, 16, 17, 18, 28, 32, 33, 40, 44 and 64 amu.

X-ray diffraction (XRD) was carried out on dried solids using a Bruker D8 Advance X-ray Diffractometer using Cu Ka radiation (40 kV, 40 mA) equipped with a LynxEye silicon strip detector.

Figure 4. DataTaker unit.

The trial was run from May 2014 to July 2014, where the system ran continuously for several days at a time, and was taken offline at regular intervals for maintenance and cleaning. In order to get the system to work effectively, some plant modifications and process optimisation work was necessary to cope with seasonal changes in effluent quality and temperature.

Plant Performance

The ability of the P removal system to treat BVF effluent to a quality of < 20 mg/L P and < 60 mg/L Ca is presented graphically in Figure 5. During an extended period of operation (7th May to 14th July) the system averaged 14.0 mg/L P and exceeded 20 mg/L on eight occasions, five of which were during the period of 23rd to 27th June. The high levels of P during this period were a direct result of the depletion of NaOH reagent over the weekend of the 21st-22nd June. Ca levels were on average 45.6 mg/L, with the highest recorded level being 67.2 mg/L.

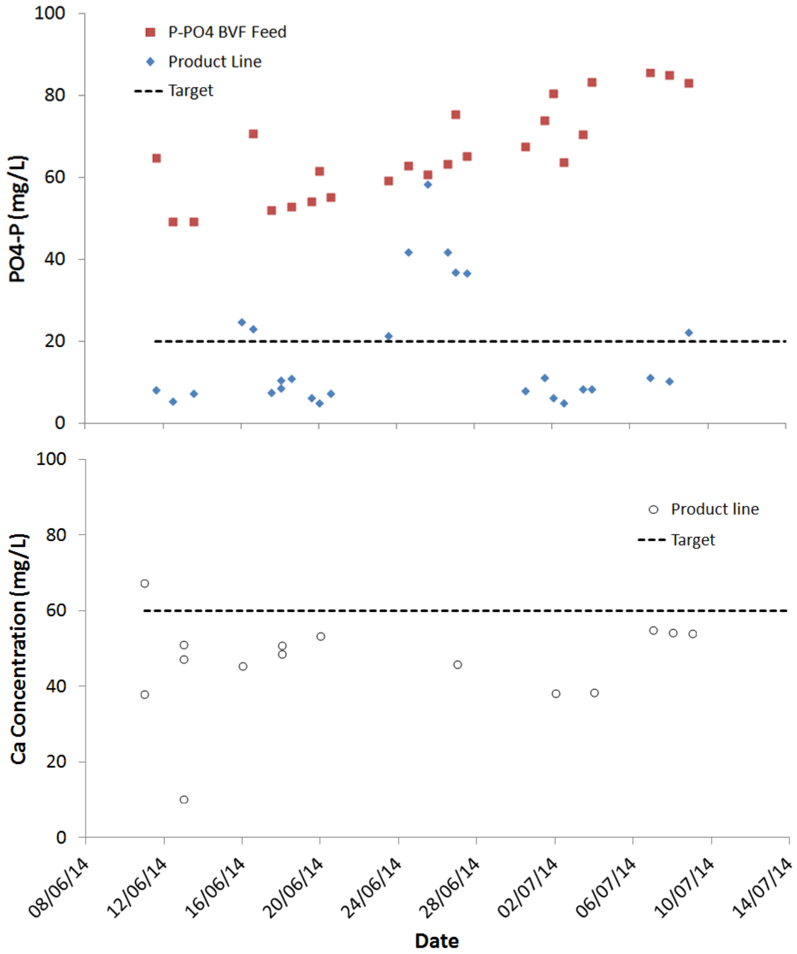

Figure 5. Phosphorus and Calcium concentration during the time period of 8th June to 14th July.

Figure 6 presents logged pH, temperature and conductivity data for the period of 20th June to 14th July. This provides important information about system operation and control.

- The effectiveness of the aeration using the blower consistently led to pH increases from 7.95 ± 0.05 to 8.3 ± 0.1.
- The pH of both the mixing tank and processed effluent showed fluctuations with the diurnal cycle during the period of 23rd June to 30th June, however, thereafter did not continue this trend. Reasons for this are not clear. Correlation can be observed between the pH in the aeration and mixing tanks. A decrease in the average pH of the product effluent coincides with a change in the dosing of HCl during the period of 26th -27th June, followed by refreshing the reagent on the 30th June.
- Manual pH measurements supplemented online data and ensures that trends collected via in-vessel sensors are accurate.
- During the period of the trial the effluent temperature ranged from 13 °C to 22 °C and was typically 5-6 °C warmer than the ambient air temperature.
- The conductivity was typically in the range of 560 mS/cm and featured spikes of up to 1600 mS/cm from time to time, which were found to be aberrations that could be easily filtered out of the data.

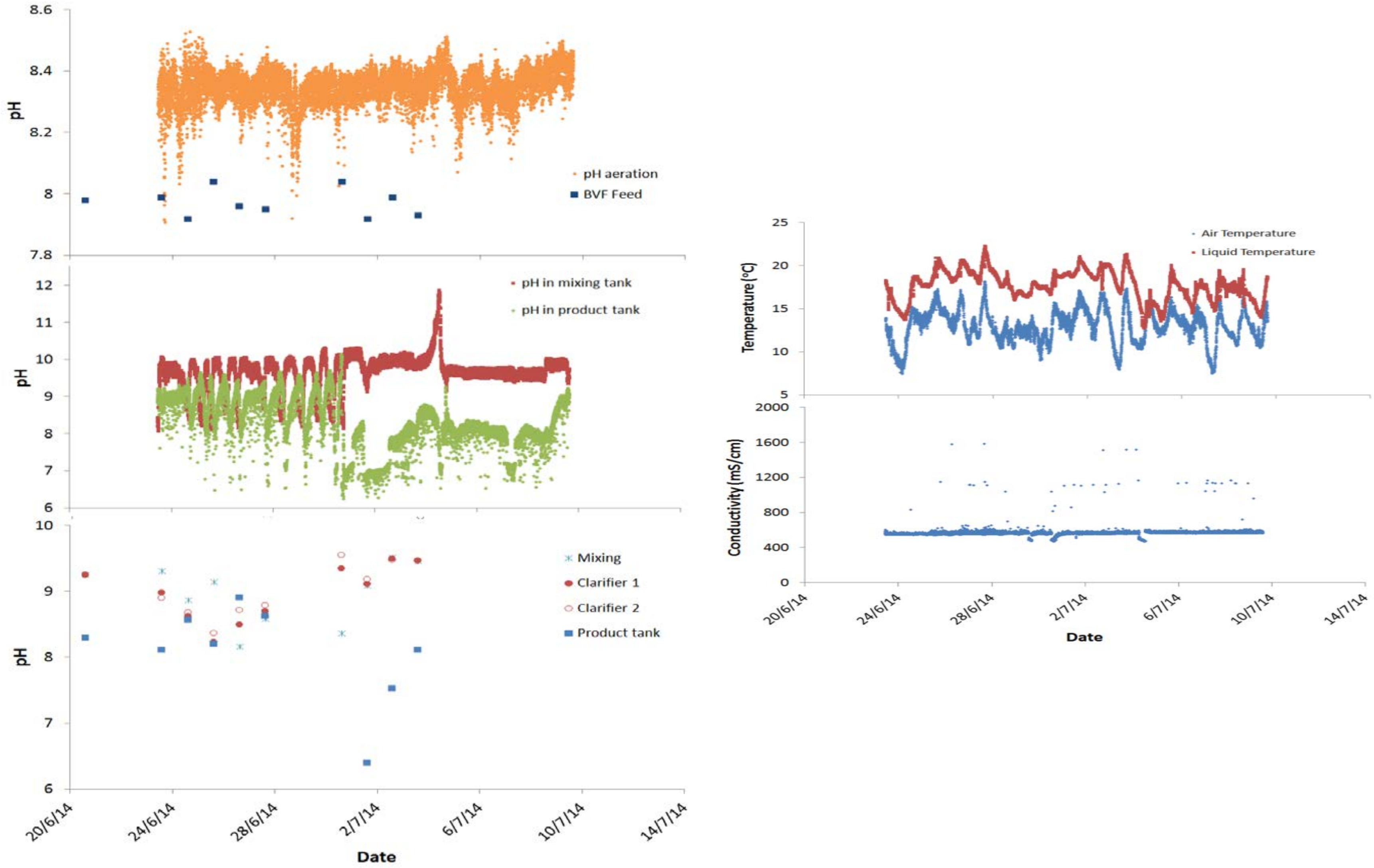

Figure 6. Supporting process data collected during the trial. Left: online and manual pH data. Right: online temperature and conductivity data.

Figure 7 further explores the flow of phosphorus (top) and calcium (bottom) at various points throughout the system. The black column in the top graph represents the total flow of P coming into the system from the BVF. The inline mixing of $CaCl_2$ and NaOH, in conjunction with Na_2CO_3 dosing all act to convert P from soluble orthophosphate to a precipitated form. The open black chart demonstrates that P concentrations in the soluble fraction are typically decreased to around 10 mg/L, thereafter the challenge is to ensure that the solid P does not enter the product tank. Clarification was used to capture particulate P, and Figure 7 shows that the amount of P being carried over in the clarified effluent is similar to those levels measured in the soluble fraction of the mixing tank. This provides confidence that clarification is suitable and also, it can be observed that the effluent quality from the Clarifier 1 is, in general, not too dissimilar to that from Clarifier 2. The effluent from Clarifier 2 is dosed with HCl in order to achieve suitable pH for subsequent biological MBR treatment. Acid dosing will act to solubilise any precipitated material that does carry over into the product tank and therefore increase P and Ca levels. Minimal change in P concentration was observed suggesting that particle carry over from the clarifier was not a major risk, however, calcium levels did increase within the product tank from time to time, which would indicate that some carry-over of solid material did occur.

Interestingly, the soluble fraction of the mixing tank met the requirements of both P and Ca levels, which indicates that alternative approaches to clarification could be explored. For instance, industrial centrifuges, hydrocyclones or screen filters may also be considered.

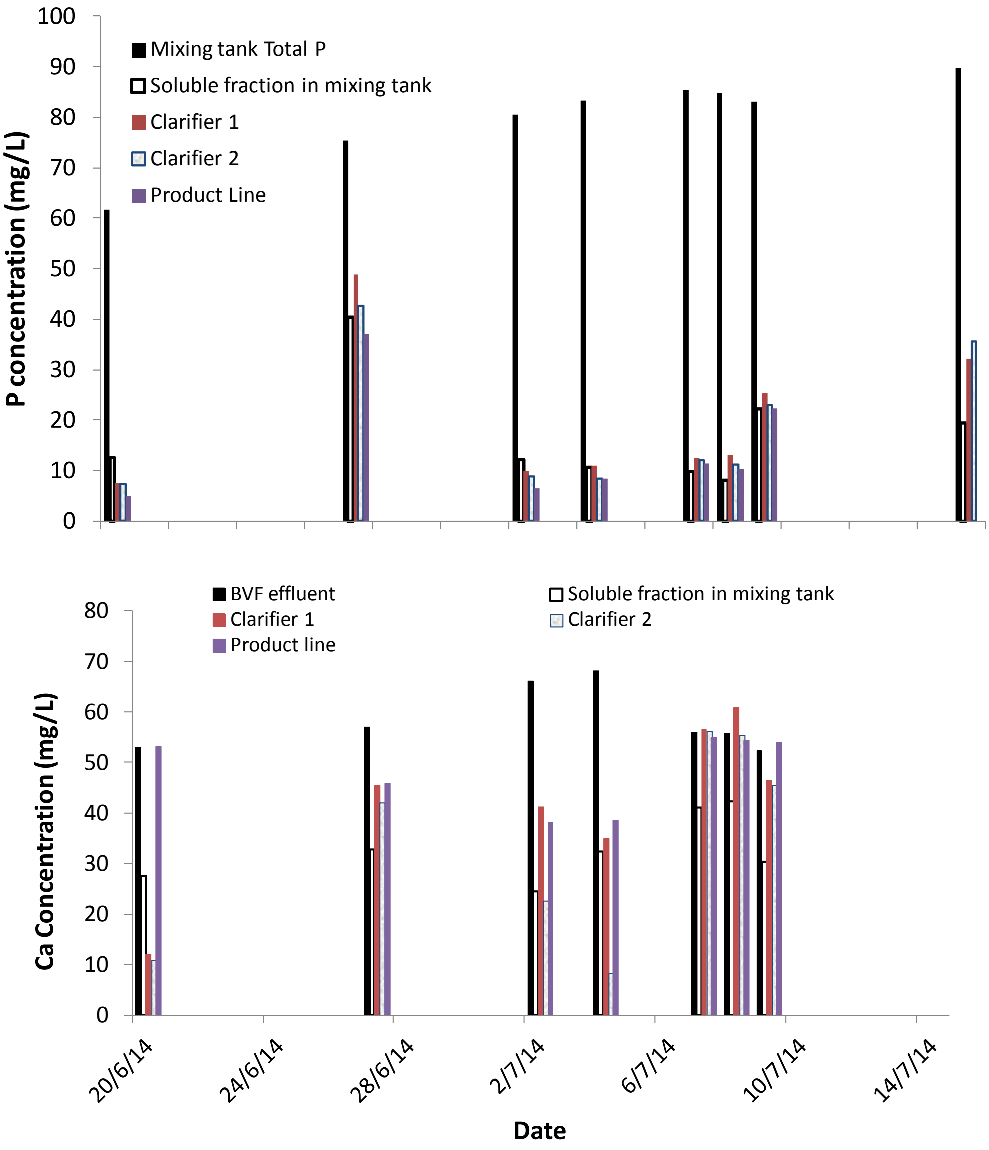

Figure 7. P and Ca concentrations, as determined by ICP-OES for samples taken at different points during the P removal process.

Operating Costs

Table 1, Table 2 and Table 3 provide data on the energy, chemical and infrastructure requirements of the P removal setup used in the pilot trial. Where appropriate, data has also been extended to estimate the magnitude of costs and size of infrastructure for a full-scale system.

The largest energy cost was from the blower (300 Watts) which was used to remove CO_2 from the BVF effluent. In practice, air stripping processes to remove CO_2 on an industrial scale have been designed using much lower energy usage. For instance, design for flows of 250 m^3/day have utilised a 3 kW blower and a footprint of the order of 2 m^3 volume per m^3/hr, i.e. a HRT of 30 minutes, and such installations are able to increase the pH from 7.2-7.5 up to 8, similar to adjusted levels achieved within the current trial (Moerman *et al*., 2009, 2012). It is suggested that a full scale installation (3.8 ML/day) would require a 7kW blower and 50 m^3 vessel.

Table 1. Summary of energy costs for pilot trial.

	Pilot Trial			Full Scale	
Item	Average Power (W)	kWh/day	Cost per day (15 c /kWh)	kWh/day	Cost per day (15 c /kWh)
Blower	299.1	7.18	$1.08	168	$25.2
Mixer	48.3	1.16	$0.17	96	$14.4
Dosing Pump ($CaCl_2$)	4.0	0.095	$0.01	0.36	$0.05
Dosing Pump (NaOH)	4.0	0.095	$0.01	0.36	$0.05
Dosing Pump (Na_2CO_3)	4.0	0.095	$0.01	0.36	$0.05
Dosing Pump (HCl)	4.0	0.095	$0.01	0.36	$0.05
Peristaltic Pump (main)	45.0	1.08	$0.16	180†	$27.0
Peristaltic Pump (slurry)	45.0	1.08	$0.16	48†	$7.20
Total	453.4	10.88	$1.63	493.44	$74.0

† Slurry pumps replace peristaltic pumps (7.5 kW and 2 kW)

Table 2. Chemical dosing requirements for pilot trials and estimated quantities and costs for full-scale operation.

	NaOH (1M)	**$CaCl_2$ (1M)**	**Na_2CO_3 (1M)**	**HCl (11%)**	
Pilot scale					
Total Volume Stock (L)	440	136	103	64	
Usage/day (L/day)	16.92	5.23	3.96	2.46	
Usage/min (mL/min)	11.75	3.63	2.75	1.71	
Chemical cost/kg	$2.12	$1.21	$1.76	$2.20/L	
Total cost ($/day)					$5.84
Full scale (estimated)					
Total chemical usage (L/day)	25519	7888	5974	3712	
Unit cost ($/L)	0.085	0.356	0.187	0.31	
Total ($/day)	2164	2806	1114	1163	$7,247

The cost of chemicals is expected to come down from the reported values here. $CaCl_2$ on a global market sells for approximately AU$0.035/mol ($0.25/kg) and NaOH for AU$0.038/mol ($0.98/kg). These prices suggest that chemical costs could reduce by as much as 60%.

Table 3. Volume of tanks and reactors utilised in pilot trial and estimation of required size for full-scale operation.

	Total size (L)	Volume (L)	Flow rate (L/min)	HRT (min)	Full-scale† volume (m^3)
Aeration tank	1000	590	1.75	337	317
Inline mixing		0.15	1.75	0.1	0.1
Mixing tank	20	15	1.75	8	22
Clarifier 1	70	70	1.75	40	158‡
Clarifier 2	55	55	1.56	35	Not required

† Full-scale volume assuming total flow of 3.8 ML/day. ‡ Full-scale plant suggested to increase clarifier size by 150% of pilot to remove need for second clarifier.

Fertilizer value of recovered P product

The composition of the phosphorus-rich sludge removed from the clarifier was confirmed to consist of a mixture of hydroxylapatite and calcium carbonate using X-ray diffraction (Figure 8). By mass, this ratio was estimated from ICP-OES analysis (after drying of the whole slurry) to be 41-43% hydroxylapatite, 20-35% calcium carbonate, with the remainder being up to 25% Na (as detected using XRD), 5% K and trace quantities of Mg (0.6%), Fe (0.06%) and Al (0.03%). Thermal analysis confirmed calcium carbonate content to be in the vicinity of 20% and that solids dried at 105 °C would retain about 4% moisture (Table 4). The total mass % of dried material contains in excess of 7.8% P, which is almost the equivalent of single superphosphate (8-9% P). The Na component, whilst being detrimental to the fertilizing value of the slurry, will be in the soluble phase and therefore removable through the use of solid-liquid separation technologies such as centrifugation and screen thickening. Once the solid is obtained, it may be incorporated as an input into mainstream fertilizer production, or could be further processed to convert into a form (i.e. granules) where it can be applied to agricultural land using existing farm equipment, thus making it a directly saleable product.

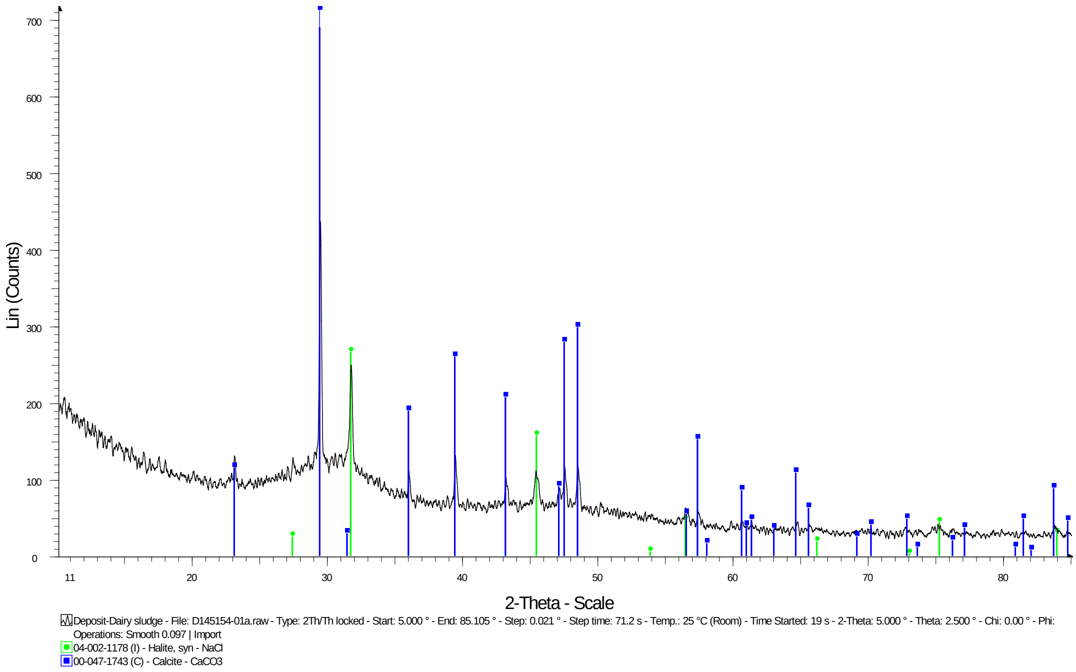

Figure 8. X-ray diffraction scattering as a function of angle, showing crystalline phases of NaCl and $CaCO_3$.

Table 4. Data from combined thermogravimetric and mass spectrometry analysis of dried clarifier slurry.

Temperature Range (°C)	Mass Loss (%)	Gaseous component
35 – 97	1.08	H_2O
97 – 173	2.63	H_2O
173 – 290	3.56	CO_2 (trace SO_2)
290 - 500	5.43	CO_2 (trace SO_2)
Total Moisture	3.71 %	
Total CO_2	8.99 %	
(Total $CaCO_3$)	(20.45%)	

Some preliminary testing was done to investigate the handling of the clarifier slurry. The initial slurry was found to contain 2 wt% solids which could be further thickened through further settling to around 5 wt% (see Figure 9). After this point, further drying of the slurry would be required, potentially through the use of low energy methods (i.e. solar, biogas heat or low-grade heat from site). Once the material reaches approximately 45 wt% solids (< 55% moisture) the material can be handled.

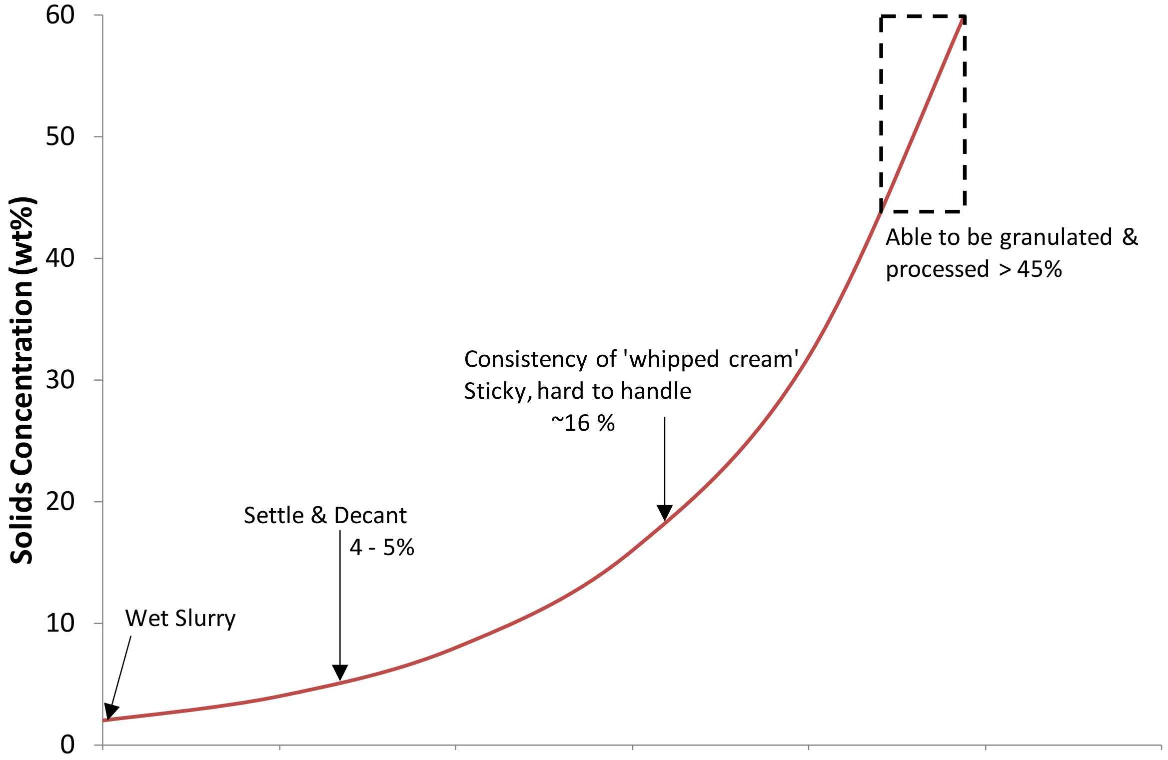

Figure 9. Physical properties of clarifier slurry at various moisture content.

Figure 10(a) provides a visual example of the dried solids after drying to 45 wt% solids, which have a light grey colour and are friable (easily crumbled) in nature. Figure 10(b) shows that the solids can be granulated without the addition of any chemicals. The granules have good strength upon further drying. The colour of the granules was darkened in comparison to the raw starting material. This is attributed to the small amount of organic material within the slurry being able to colour the moisture film on the outside of the granules during tumbling.

Figure 10. Photos of recovered solid (a) after drying to 45 wt% solids, (b) after granulation at 43 wt% solids.

Effective solid-liquid separation will need to be determined in future work, however, preliminary handling trials have shown that a stainless steel screen with 50 µm apertures was effective in its ability to concentrate solids.

The market value of P is somewhat variable and is likely to continue to increase markedly into the future due to it being an increasingly scarce resource that is also prone to geopolitical issues. At the present, P has a value of approximately $3/kg P.

Assuming a 3.8 ML/day flow of BVF effluent containing an average of 90 ppm P and 80% extraction of P into the solids, this equates to a total mass of 274 kg P/day, at a value of $820/day.

Cost and benefit

The total costs of running a full-scale system are estimated and compared with the use of a traditional flocculant/coagulation treatment, such as using ferric chloride or alum sulphate to remove P prior to MBR treatment.

Table 5. Estimated operating costs (per day) of P removal and recovery system as opposed to coagulant dosing.

Operational costs	P Removal and Recovery	Flocculant/Coagulant
Chemical costs	\$2898 (40% of \$7247)	\$1300 to \$3200
Energy costs	\$74.20	\$48.70
Revenue from fertilizer	- \$875 (sold for profit)	+ \$50 (tipping fee)
Labour	2 hrs /day	1 hr /day
Infrastructure cost differences	1. Aeration vessel required 2. Additional solid-liquid separation required for P recovery (to removal Na)	

These costs can be weighed up against traditional methodologies to flocculate and precipitate P using alum and/or ferric. Assuming alum sulphate and ferric chloride are used at \$400/t and \$300/t, respectively, the chemical costs for removing P using coagulants are approximately \$10.93 /kg P for alum and \$4.23/kg P for ferric. In addition pH adjustment would still be required for alum use and possibly ferric. This results in estimated chemical costs of between \$1160 and \$2995, yet producing a P-rich solid that requires disposal with a cost implication.

The ability to develop a market for recovered P would be crucial to committing to the approach utilized in the pilot trial. Further discussion will be required with the fertilizer industry to seek direction and to understand niches in the market that may benefit from a combined HAP and $CaCO_3$ product. Additional labour is required to enable P recovery into a product.

There are a number of suggested improvements to the process that have been learned during the pilot trial:

1. Variations in anaerobic digestate quality. The main factors found to influence the process are soluble P concentration, alkalinity and temperature. There was a factory shutdown early June and the P levels dropped from 81 mg/L PO_4–P to 60 mg/L PO_4–P, and during the course of the trial soluble P concentration increased from approximately 60 mg/L to 90 mg/L PO_4–P. Alkalinity also increased from 1800 to 2100 mg/L. These changes required adjustment of all chemical dosing rates. For instance, pump settings changed according to those in Table 6.

Table 6. Chemical dosing settings used to respond to seasonal changes in soluble P levels in BVF effluent.

Dosing Pump	Low phosphate (60 mg/L)			High phosphate (90 mg/L)		
	SPM	%	Flow rate (mL/min)	SPM	%	Flow rate (mL/min)
$CaCl_2$ dosing	140	70	2.54	140	100	3.63
NaOH dosing	65	65	9.54	65	80	11.75
Na_2CO_3	60	60	1.38	120	60	2.75
HCl	26	35	0.80	40	50	1.71

2. Automation of the system would be particularly beneficial. Future assembly should take the following into account.
    a. Use of low level alarms to alert that there are issues with flow through the system (this includes level alarms within individual chemical tanks to ensure reagent is not depleted).
    b. Chemical dosing pumps can initially be controlled using a feedback loop of the measured pH in the mixing and product tanks.

3. One crucial finding was that soluble P in the mixing chamber achieved effluent quality objectives. Since sodium levels are high it would be advantageous to immediately filter/screen the outflow from the mixer and therefore effectively make clarification redundant. Further trial work will be required to identify appropriate filters/screens along with an investigation of the conversion of the solid P-rich material into a saleable product.
4. Methods to reduce the likelihood of scaling and blockages are key to a successful P removal and recovery system. The most susceptible parts of the system were: in-line mixing, build up in the bottom of the mixing vessel, clarifier weirs and slurry pump lines. Regular cleaning of the in-line mixing, including the dosing nozzles was achieved using 20% citric acid. Weir cleaning could be achieved manually, as could regular flushing of the slurry pump lines. The selection of appropriate materials will also assist in the avoidance of fouling issues. The use of polyvinylidene difluoride (PVFD) piping (i.e. Kynar®) has been recommended by those operating P recovery systems at full scale (Baur, 2012).

Recommendations

1. Develop a commercial understanding of the value of HAP/$CaCO_3$ product and how it could be made into a saleable product.
2. Further investigate the economics of chemical requirements and economies of scale.
3. Investigate technologies to directly dewater the recovered P slurry after the mixing tank.

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3. Membrane Bioreactor (MBR)

Principal of operation

The biological treatment of wastewater typically employs either aerobic or anaerobic processes to reduce the organic content of the waste stream. In aerobic processes, an oxygen supply (aeration) is provided to allow aerobic bacteria to grow and break down the organic components of the wastewater, while anaerobic processes require the exclusion of oxygen. The consortium of bacteria present in an aerobic treatment system is commonly called activated sludge. Aerobic processes have the additional advantage that they can also be modified to remove certain nutrients, such as nitrogen and phosphorus, where appropriate.

A membrane bioreactor (MBR) system is an aerobic process, using modified activated sludge technology to treat wastewater. With a MBR, a physical membrane barrier is used to retain the aerobic biomass within the treatment plant, rather than gravity settling or other liquid/solids separation techniques.

The membrane effectively filters the treated water, which results in a very high quality final effluent with low suspended solids (often below detection levels) and low organic content (<5 mg/L BOD). The filtering reduces the need for external disinfection operations because bacteria are retained by the membrane, and also means that all the biomass is retained in the reactor. This results in the decoupling of the hydraulic and solids residence times, as the solids are retained in the system while water passes through. This means the system can have a high hydraulic load rate, and consequently a small reactor size/footprint.

The physical membrane barrier provides a great deal of flexibility in the biological process and allows for design at much higher mixed liquor suspended solids concentrations (typically 8,000-18,000 mg/l versus 2,000-4,000 mg/l in conventional activated sludge systems). This results in a more robust system where the operating conditions of the biological process can be adjusted to be able to deal with changing influent or environmental conditions, without any impact on the effluent quality. The higher biomass inventory in the MBR system provides resilience to changes, and can greatly reduce the amount of waste sludge that is produced. The use of membranes eliminates potential problems with sludge settling and separation, such as hydraulic washout, growth of filamentous organisms and bulking sludge, and pin floc.

ADI Systems design goals are to produce the simplest and most reliable MBR technology available. ADI-MBR technology is state-of-the-art aerobic treatment which consistently provides a high-quality effluent in a compact, easy-to-operate treatment system. The process requires little maintenance or operator attention, with operational procedures primarily consisting of a daily review and inspection of the system, and collection/completion of any samples/analyses required.

Prior to the ADI-MBR pilot system, chemical precipitation will be used to reduce the phosphorus level of effluent from the existing ADI-BVF® anaerobic reactor to below 20 mg/L phosphorus. Phosphorus can be removed biologically in aerobic systems, through modifying the process to enable bacteria to store phosphorus. For this project, biological P removal is not suitable, as waste aerobic sludge from the process will be returned to the existing anaerobic reactor. Under anaerobic conditions, all the stored phosphorus is rapidly released, resulting in an increase of overall phosphorus levels in the treatment plant. It is important to have low phosphorus in the MBR system to manage the formation of calcium phosphate precipitation and scaling which result in inorganic fouling of the membranes.

Biological nitrogen removal is achieved in an aerobic system through the use of alternating anoxic (low oxygen) and aerobic sections. In the aerobic section, the bacteria use the available oxygen to convert ammonia (NH_3) to nitrate (NO_3), which is known as nitrification. In the anoxic stages, a different group of bacteria convert nitrate to nitrogen gas (N_2) which is released into the atmosphere, in a process called denitrification. A readily available carbon source is required for denitrification to occur. Untreated (raw) wastewater from the factory will be used to provide a carbon source for denitrification in the anoxic zones. The nitrogen removal process is important for the downstream reverse osmosis plant, which has limited nitrogen tolerance.

The complete MBR pilot reactor consists of a pre-anoxic tank, aeration tank, post-anoxic tank and aerated membrane tank. Anaerobically treated wastewater, following phosphorus removal, will pass through these tanks and be recycled to facilitate efficient COD, BOD and nitrogen removal. Raw wastewater from the factory is also dosed into the two anoxic tanks to facilitate denitrification.

Following the alternating anoxic/aerobic treatment, high quality permeate is extracted through the membranes, and sent to the RO unit for further purification.

Design Basis

The original design basis is shown in the process flow diagram in Figure 11.

Effluent from the ADI-BVF® anaerobic reactor, pre-treated to reduce the phosphorus concentration to below 20 mg/L P, was fed directly into the 800 L pre-anoxic tank at a design flow rate of 2,500 L/day.

Raw wastewater from the factory is also dosed into the pre-anoxic tank as a carbon source for denitrification, at a design flow rate of 100 L/day.

From the pre-anoxic tank, the wastewater is pumped to the 1,100 L aeration tank, then flows by gravity into the 600 L post-anoxic tank. Mixed liquor from the aeration tank also flows by gravity back to the pre-anoxic tank, recycling the biomass. The post-anoxic tank also receives supplemental carbon (raw wastewater) for denitrification at a design flow rate of 200 L/day.

Wastewater is pumped from the post-anoxic tank to the membrane tank for the second round of aeration. The 340 L membrane tank is fitted with 10 full-size membrane cartridges for filtration. The airflow provided for air scour to control the biomass layer on the membrane surface also supplies the biological oxygen requirements.

Mixed liquor is recycled from the MBR tank to the pre-anoxic tank, recycling biomass through the alternating anoxic/aerobic treatment steps. The pilot plant components are shown in Figure 12 to Figure 14.

Permeate is drawn through the membrane cartridges by the permeate pump. The design flow rate is 2,800 L/day, with a design membrane flux rate of 0.40 m^3/m^2/day. The Kubota membrane system operates with an alternating cycle of permeate suction, and relaxation. In relaxation, the permeate pump does not operate, and the membranes relax (become less tight) without the suction pressure. This allows air bubbles to more effectively clean the membranes and prevent excessive biomass build-up on the surface.

The transmembrane pressure (TMP), the difference between the static and operating pressure across the membranes, is monitored to determine the flux rate that can be sustained and whether membrane cleaning is required. Membrane cleanings are required when the TMP exceeds 30 inches H_2O, and can be a result of organic or inorganic fouling. Organic fouling is typically due to biomass growth in a biofilm on the membrane surface, while inorganic fouling is usually from scale formation due to precipitation of chemicals such as calcium phosphates.

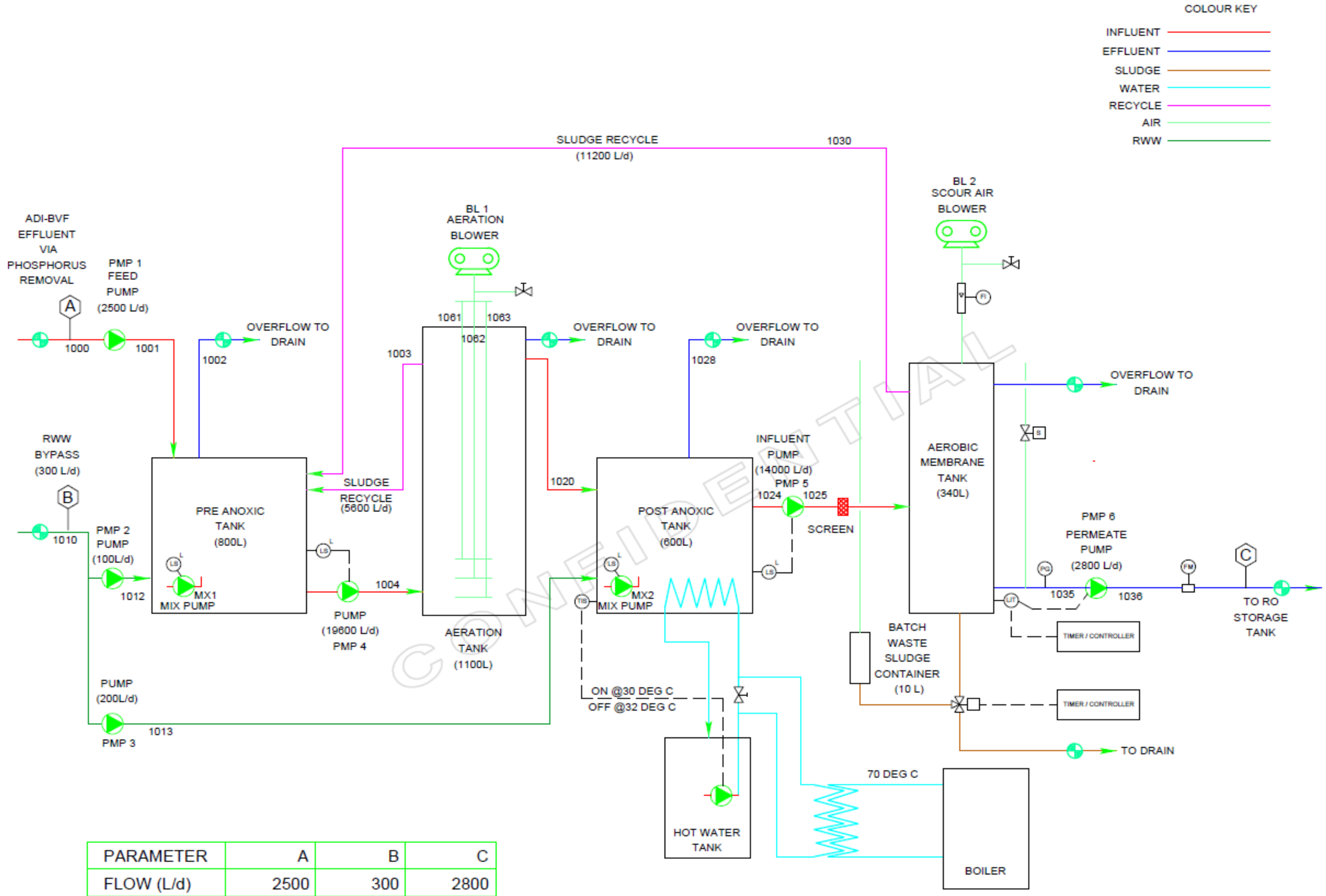
Waste activated sludge (WAS) is automatically wasted from the membrane tank in batches via the 10 L batch WAS tank. The goal is to maintain a mixed liquor suspended solids concentration of 10,000 – 15,000 mg/L.

Methods and Equipment Specifications

Many different types of membranes are available for use in MBR systems. These range from external cross-flow membranes to internal submerged flat sheet membranes, with each having different design advantages. The ADI-MBR process piloted in this trial incorporates Kubota submerged membranes. Kubota membranes were developed in Japan, and have nearly 20 years of proven full-scale experience. ADI Systems have used these membranes successfully in similar applications in over 20 facilities around the world.

The 340 L MBR tank has one Kubota LF10 membrane cassette, with 10 full-size type 510 Kubota membrane cartridges.

The reactor was seeded with waste activated sludge from aerobic wastewater treatment plants (WWTPs) processing similar wastewaters (i.e. dairy wastewaters). Non-industrial plants were specifically excluded, as municipal (sewage) wastewater treatment plant seed sludge could potentially contain human pathogens, and the perception of the project by general public was likely to be negatively impacted. Seed sludge was obtained from a Murray Goulburn WWTP and a Fonterra WWTP.



PARAMETER	A	B	C
FLOW (L/d)	2500	300	2800
BOD (mg/L)	100	4700	<5
COD (mg/L)	1000	6900	<100
TSS (mg/L)	700	970	<5
TN (mg/L)	170	170	<15
TP (mg/L)	20	110	30

Figure 11. Process flow diagram for the MBR system.

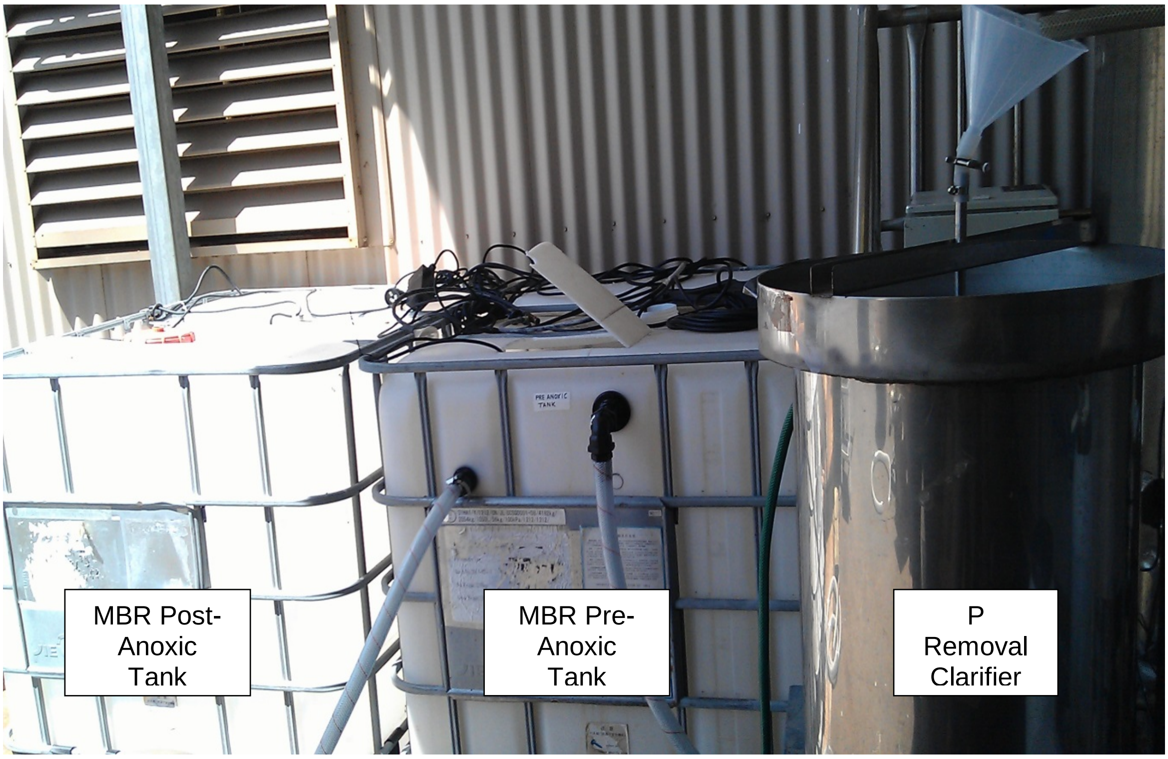


Figure 12. MBR system pre- and post-anoxic tanks, with the clarifier from the phosphorus removal system in the foreground.

Figure 13. MBR system pre-anoxic and aeration tanks, with the clarifier from the phosphorus removal system in the foreground.

Figure 14. MBR system aerobic membrane tank.

Sensors and logging

The following parameters were monitored on a daily basis in the system:

- pH
- Dissolved oxygen (DO)
- Temperature
- TMP
- Permeate flow rate

In addition, the influent wastewaters, permeate and reactor contents were tested up to 3 times per week for:

- Mixed liquor suspended solids (MLSS)
- Mixed liquor volatile suspended solids (MLVSS)
- Chemical oxygen demand (COD)
- Total suspended solids (TSS)
- Volatile suspended solids (VSS)
- Ammonium
- Total nitrogen
- Phosphate
- Total dissolved solids
- Filterability

Plant Performance

The MBR pilot was initially commissioned with seed sludge from another diary site's WWTP with an active denitrifying population. Several mechanical issues, such as tubing blockages and pump failures, resulted in the overflowing of one or more of the process tanks and loss of the biomass. Additional seed sludge was obtained from the Fonterra WWTP. The new seed sludge contained many small inorganic contaminants (such as fine synthetic fibers) and had poor filterability. This resulted in additional tubing blockages and foaming, creating further difficulties with retaining the biomass.

While some foaming can occur in the first weeks of MBR operation at both pilot and full scale, the other issues experienced with the pilot plant during the first months of operation (such as tubing blockages) are specific to pilot scale reactors predominantly due to the smaller pipes and tubes used with the lower flows. Therefore, these will not be explored in detail in this report, other than to draw the conclusion that all debris should be cleared from systems prior to start up, and seed sludge should be screened prior to addition to the reactor.

Within 2–3 weeks of seed sludge addition, the fresh biomass adapted to the new environment and the majority of the foaming subsided.

Mechanical difficulty was experienced with maintaining the design flow rate of 2,800 L/day through the membrane. The flow rate had to be reduced to retain the TMP below 30 inches H_2O. Membrane cleanings were carried out with both hypochlorite solution (for organic fouling) and citric acid (for inorganic fouling) with no improvement. This, in combination with the poor filterability results of the MBR mixed liquor, indicated that the sludge characteristics were responsible for the poor flux rate.

Ideally, a seed sludge with good filterability would be used to seed a MBR. Sludge will typically adapt to the new environment and may show an improvement in filterability over time, however, this can be a slow adaptation process. Improved filterability was not observed in the duration of these trials, and new seed sludge could not be introduced within the timeframe of this project.

As a result of the poor filterability of the reactor biomass, the system was operated at a lower permeate flow rate than design, resulting in a lower membrane flux rate. The permeate flow rate and flux achieved are shown in Figure 15 to Figure 17, along with the MBR temperature, TMP and sludge filterability. The temperature was initially low with an average of 13.7°C, however increased to an average of 24.7°C following the installation of a heating coil on 9 May. As can be seen from Figure 15 and Figure 17, both the flow rate and the flux were trending upwards, and at the end of the trial the permeate flow rate was 1.2 L/minute (~1,500 L/day), giving a flux of 0.21 $m^3/m^2/day$.

The flux rate does not affect permeate quality, and the MBR demonstrated excellent biological performance with an average of 97% COD removal and 95% nitrogen removal, as shown in Figure 18 and Figure 19. The average COD concentration of the MBR permeate was less than 40 mg/L. The average total nitrogen concentration measured during the trial was 21 mg/L, with improving performance towards the end of the trial resulting in a TN concentration of less than 10 mg/L in the final two weeks.

In addition to the high level of COD and nitrogen removal, the MBR permeate contained suspend solids concentrations that were below detection levels.

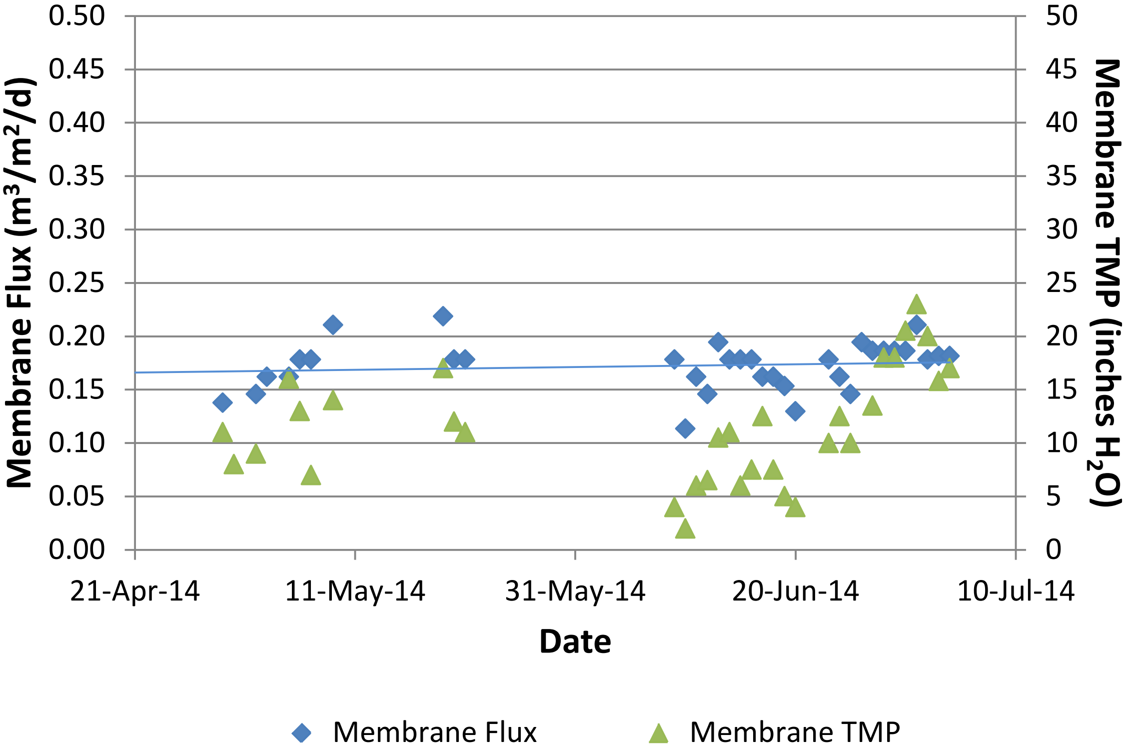


Figure 15. Membrane flux achieved during the pilot trial, relative to the TMP.

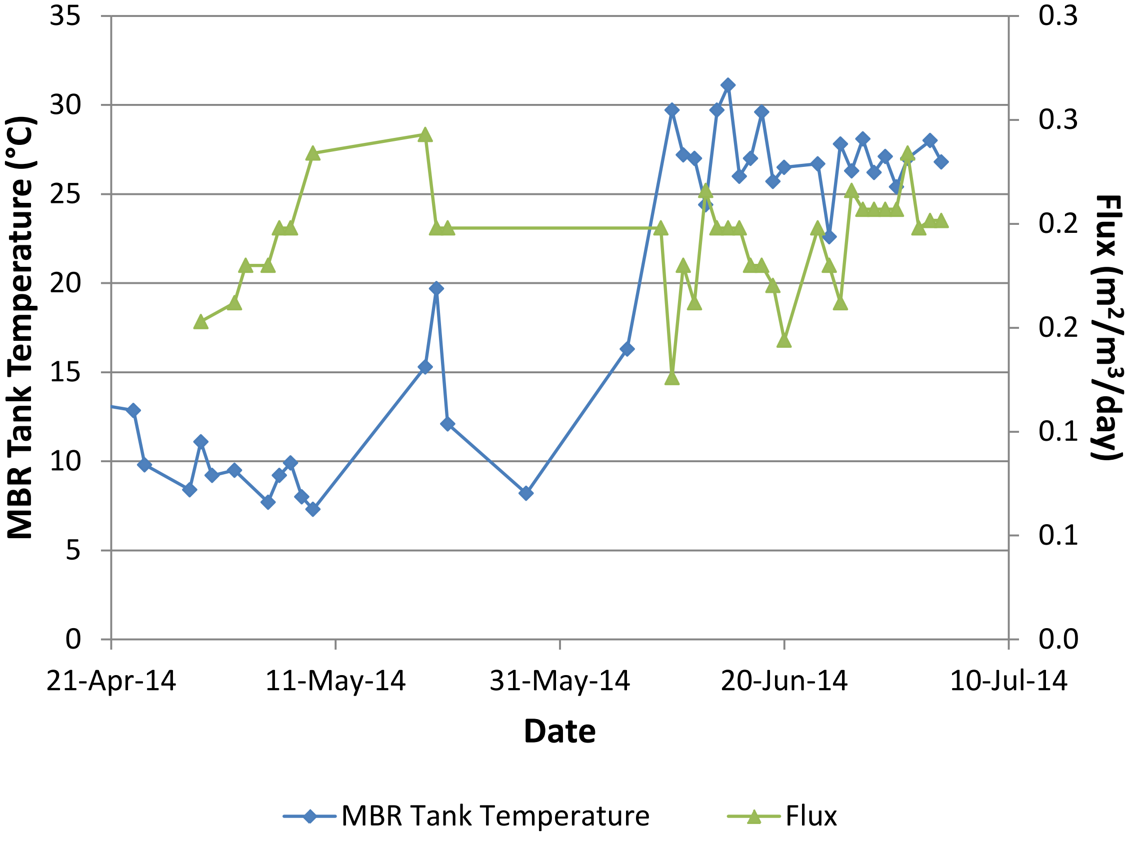


Figure 16. Membrane flux achieved during the trial in response to MBR temperature.

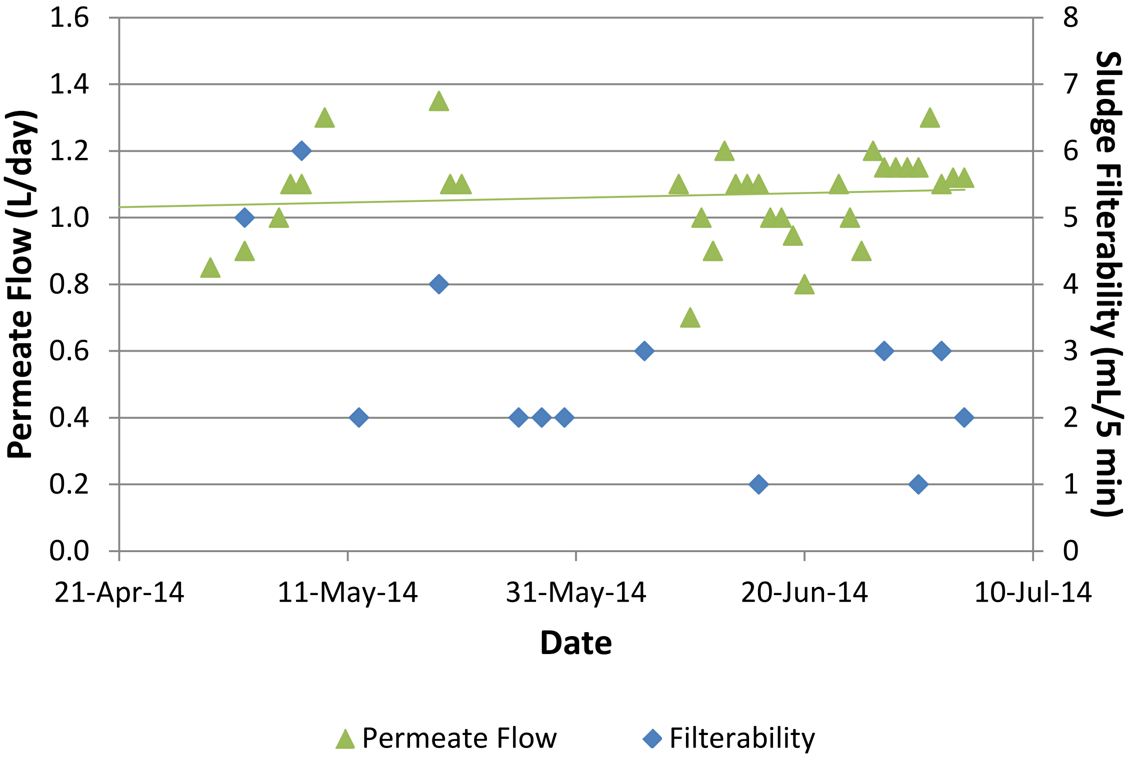


Figure 17. Sludge filterability and permeate flow rate achieved during the pilot trial.

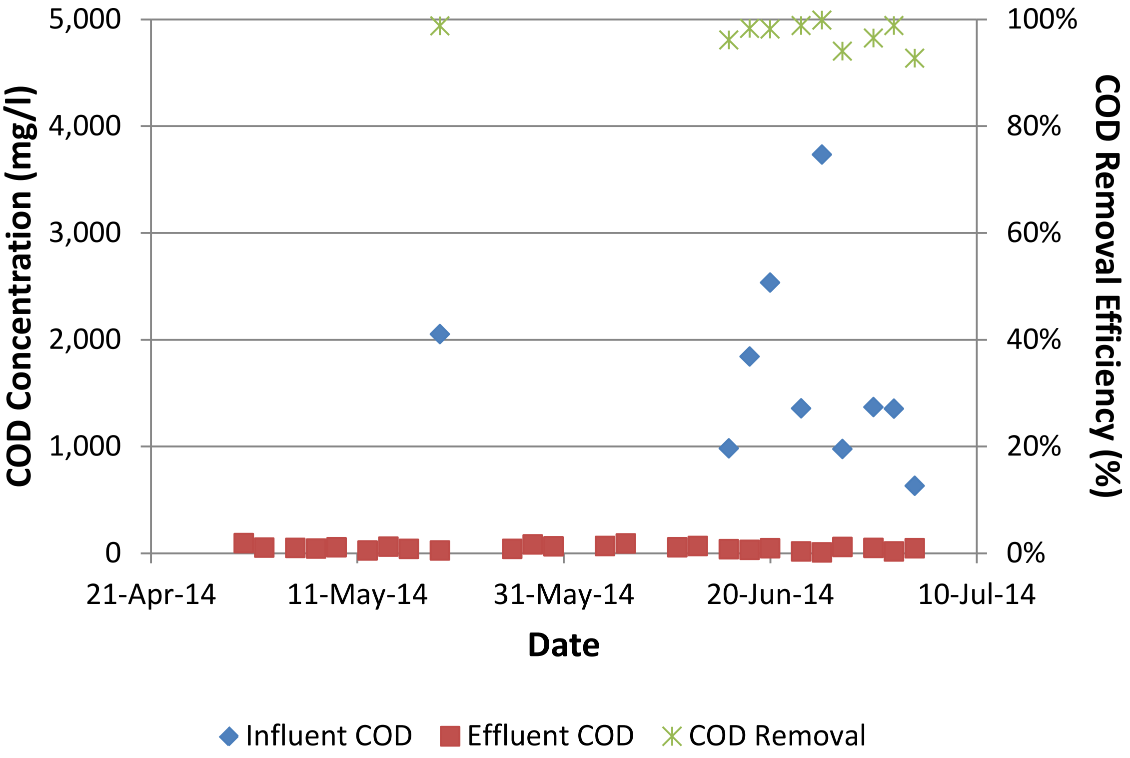


Figure 18. Average COD concentration of the combined influent streams (RWW and treated ADI-BVF® effluent) and MBR effluent COD concentration, showing removal efficiency.

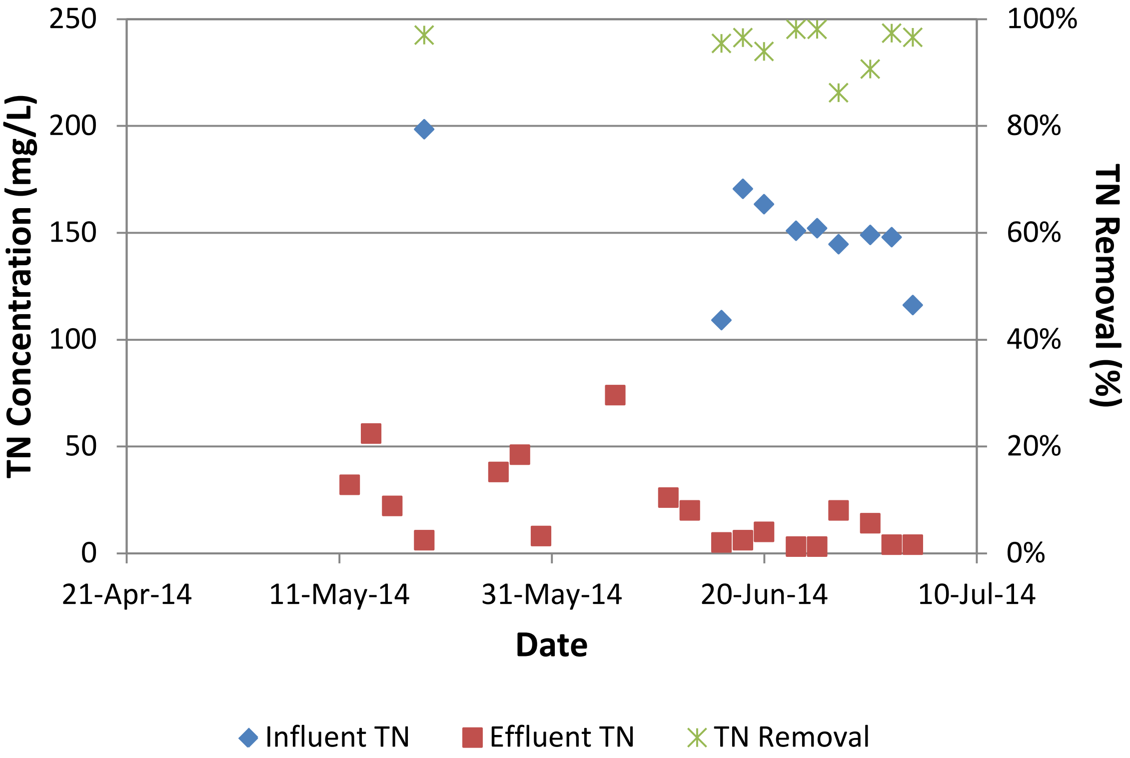


Figure 19. Total nitrogen level in the combined MBR influent streams, and the MBR permeate. The nitrogen removal efficiency is also shown.

Results and Discussion

The flux rate achieved during the trial was below the design flux, and approximately half of the flux typically achieved in full scale MBR plants treating dairy wastewater. While the flux is significant as it is used to determine the number of membranes required to treat a given flow rate, this does not impact the quality of the effluent generated. The flux rate of a given system can be impacted by a number of factors, including temperature, sludge filterability and inorganic or organic fouling. For the latter period of operation shown in this report, from 9 May 2014, the MBR temperature was maintained at an average of 24.7°C. The flux rate did not significantly increase following this improvement, and from this point onwards is unlikely to have negatively impacted the flux rate. Similarly, membrane cleaning with sodium hypochlorite or citric acid (which remove organic and inorganic fouling respectively) did not demonstrate a significant improvement in TMP or the permeate flow rate that could be sustained. The sludge was shown to have poor filterability for the duration of the trial, and is the most likely cause of low flux. Conditioning and adaptation of the sludge can result in improved filterability, but for improved performance it is advised that sludge with good initial filterability is used to seed the reactor.

The MBR permeate quality was very high, with less than 40 mg/L COD, 21 mg/L TN or less, and non-detectable suspended solids. This permeate was suitable for treatment by reverse osmosis, without the need for additional polishing steps such as filtration. As such, the MBR provides a single treatment step contributing to a simpler overall process for generating potable water.

The nitrogen removal efficiency showed continued improvement through the trial. Nitrifying bacteria are very slow growing, and this improvement indicates the population had increased and reached a level of maturity suitable for high levels of nitrogen removal.

Conclusions

The biological performance of the MBR was excellent, with high rates of both COD and nitrogen removal demonstrated. The physical performance in terms of filterability of the sludge and the flux rate that was achieved were below expectations, however, these factors did not impact the quality of the effluent or suitability for direct treatment in the reverse osmosis plant.

Recommendations

MBR is a suitable technology to polish anaerobic effluent and generate a permeate stream that can be sent directly to an RO unit for further purification, without the need for additional polishing. MBR technology can also be used as a stand-alone treatment step of dairy wastewaters, however, the energy balance of combined anaerobic/aerobic technologies is more favourable. The high quality of the MBR permeate also allows water reuse in some applications (non-potable), without the need for the additional RO, UV and chlorination steps. Overall treatment system capital and operating costs should be evaluated on a case by case basis in relation to the water reuse requirements for a particular site.

ADI Systems Project Team

Bernice Chapman, PhD

Wastewater Treatment Specialist

Berni has over 10 years of experience as a wastewater treatment specialist with a special focus on waste-to-energy projects and research and development into bioenergy (biogas) harvesting from different waste streams. Her range of experience includes process design of anaerobic treatment systems handling a variety of food industry and agricultural wastes, preliminary project evaluations and feasibility studies, research and development testing, and process commissioning of treatment plants.

Erik Gotlieb, NZCE

Electrical and Controls Engineer

Erik has 15 years of experience with most aspects of waste treatment plants. He specialises in control systems, providing electrical architecture, control system design, and CAD electrical schematics. He has experience in all aspects of plant control such as PLC programming, SCADA and telemetry, remote access, and reporting. Additional roles include HAZOP leadership, instrumentation installation and commissioning, hazardous area classification, and zoning. He has been involved in numerous projects involving remote monitoring and control of pilot plants situated around the globe from his desk in Dunedin, New Zealand. This expertise allows ADI Systems to observe the performance of a plant (with appropriate infrastructure) and provide operational advice or, where technology allows, control the electronic operations remotely.

Chris Hearn, PhD BTech

Process Design Manager

Chris has more than 25 years' experience in waste treatment research, design and implementation of waste-to-energy projects. He has extensive experience in plant operation and operator training. Specialist areas of expertise are start-up and commissioning of anaerobic digesters, troubleshooting for waste treatment plants, and the provision of "operator friendly" plants. Chris' experience and technical expertise is widely sought after for advice and makes him well suited to contribute to waste-to-energy and wastewater projects. Practical experience with a range of process equipment and a fundamental understanding of the theory and practise allows Chris to maximise facility energy balances with a focus on minimising life-time costs.

Shannon R. Grant, MSc.W., MBA, P.Eng.

Vice-President of Technology

Shannon is the Vice President of Technology for ADI Systems and has a leadership role in the company's research and development of new biological processes for treating industrial wastewaters, as well as process design for industrial customers. He has authored over 70 technical papers on biological industrial wastewater treatment using anaerobic, aerobic and/or membrane bioreactor processes. He has been an employee of the company since 1992.

Dwain R. Wilson, MSc.E, P.Eng.

Director of Operations/Process Engineer

Dwain Wilson is a senior process engineer who has spent the past 25 years working at ADI Systems specializing in industrial wastewater treatment process design, detailed design and system start-ups. During his career Dwain had served as the manager of ADI's R&D laboratory, continues in his development and design of a number of ADI's proprietary pieces of equipment and currently holds the position, Director of Process Operations. He has been involved, in some capacity, in all anaerobic treatment projects completed during the past 20+ years and in many of the aerobic projects. In addition, he has been the supervisor of dozens of start-ups providing mentoring and guidance to junior and intermediate engineers/scientists and over saw ADI's aftercare service agreements (ASAs) for more than 15 years. More recently much of his time is spent on process design, continued new equipment development and business development in both the domestic and overseas markets.

4. Reverse Osmosis (RO)

Principal of operation

The pilot RO was supplied by Environmental Products International Limited (EPIL). Unit model number S1032-PP-1. The EPIL pilot plant is a test system for the evaluation of filtration using either spiral-wound Microfiltration, Ultrafiltration, Ultra Osmosis or Reverse Osmosis elements. The unit uses standard 4" x 38" long spiral-wound elements.

The pilot plant represents a basic membrane system, consisting of an inlet filter, a feed balance tank, a high pressure pump controlled by a variable speed drive (vsd), two membrane housings and a backpressure control valve (Figure 20). It is capable of performing trials in a variety of batch, single pass and recirculation modes. There is a wedge wire filter placed behind the balance tank to protect the system from large foreign objects. Flow through the filter is regulated by a valve, which is controlled by a float in the balance tank. This mechanism allows a constant level to be maintained in the balance tank during continuous trials. The balance tank also has a temperature indicator, and a low level float which protects the pump from running dry. The balance tank has a gullet bottom which minimises the hold up volume in the tank when the pump cuts out. The high pressure pump is driven by an 11 kW motor via a belt and pulley arrangement controlled by the vsd unit. As it is a positive displacement pump, a pressure relief valve has been installed to protect the system from accidental over-pressuring.

The plant can be run with either one or two modules in place. The unit was operated with only one module at an operating pressure of 2000 kPa and the vsd set manually to control the pump speed at 500 rpm. At this vsd set point, the pump flow rate was 64 L/min. The system volume is approximately 120 L.

Permeate and retentate streams can be directed either back into the balance tank or out of the system. The valves on the permeate and retentate lines are arranged so that the flow cannot be accidently shut off, which would damage the membrane and the pump.

Three phase electrical connection is made by way of a single Reyrolle plug. The variable speed AC drive unit incorporates stop/start functions.

Continuous feed to the balance tank was achieved using an Onga pressure pump drawing MBR permeate from the bottom outlet of a 1000L IBC storage tank.

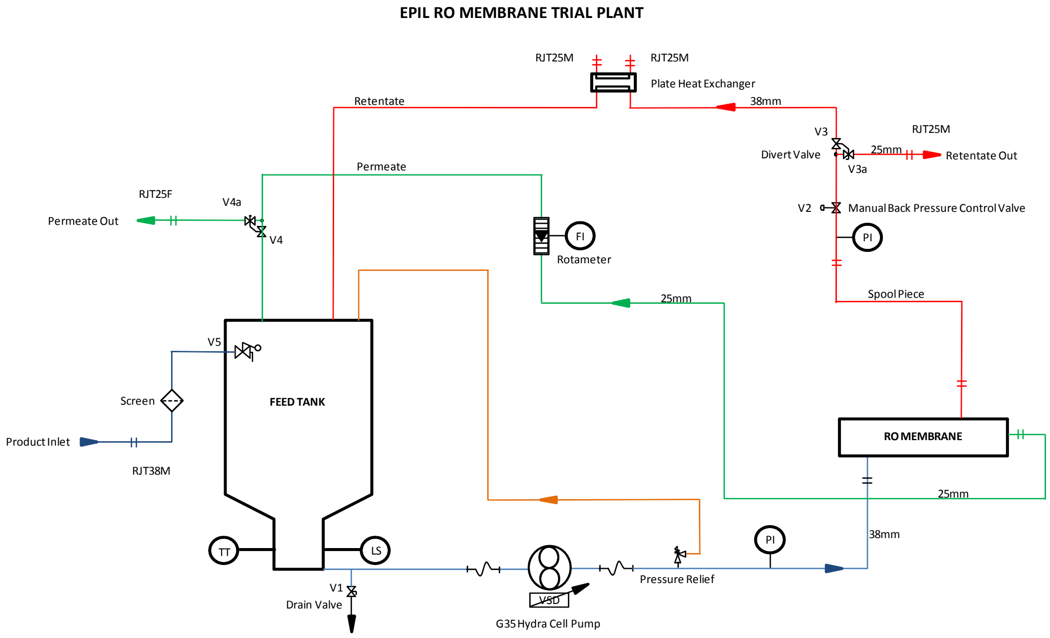


Figure 20. Process flow diagram of the reverse osmosis pilot plant.

Chemical processes

The RO system was cleaned in place (CIP) after each trial run, using only demineralised water sourced on site at the DMS. The system was operated in filtration mode with retentate and permeate streams both returned back to the balance tank. The system was rinsed twice after product, followed by an alkali wash and a single rinse, followed by an acid wash and a single rinse, followed by another alkali wash and a final rinse. A sanitizer step followed by a rinse was performed twice during the week-long trial after the second alkali wash and rinse step.

The alkali used was Orica Reflux A280, adding 1L-1.2L to achieve a pH between 9.5 – 10.5 and circulating for 30 minutes at 46°C. The second alkali step was identical to the first except only run for 20 minutes. The acid used was Orica Reflux 405, adding approximately 300 mL to achieve a pH between 1.8 – 2.1 and circulating for 30 minutes at 46°C. This was sometimes left to soak overnight due to time restraints and also to facilitate mineral removal. The sanitizer used was Orica Reflux S830, adding approximately 180 mL to achieve a pH of 3.5-5.5.

MBR permeate feed to the RO had a typical turbidity of 0.2NTU – 0.4NTU, pH of 8.1 – 8.2 and conductivity of 7800 μs/cm– 8800 μs/cm. The average levels of minerals as measured by ICP at the CSIRO labs were calcium 35 mg/L, potassium 281 mg/L, sodium 1454 mg/L and phosphorus 28 mg/L.

Methods and Equipment Specifications

The RO pilot plant is illustrated in Figure 21. The new RO membrane supplied by EPIL was a Koch 3838 HRX-VYV sanitary element. This is a polyamide spiral wound high rejection membrane with an active area of 5.7 m². The membrane has an operating temperature range of 5°C-50°C, an allowable continuous pH of 4.0 – 10.0 and an allowable CIP pH range of 1.8 – 11.0.

Figure 21. Reverse osmosis pilot plant.

Sensors and logging

The RO was set up with in-line analogue temperature measurement at the base of the balance tank. A K-type thermocouple was taped to the stainless steel RO housing to give a direct accurate temperature reading of the RO section of the system using a digital 307 Thermometer.

The RO system used a Benney analogue pressure gauge to measure the RO pressure.

Conductivity was used as the concentration measurement for the trial, using a Hach Sension 156 meter. pH was measured using a Thermo Scientific Orion Star pH meter.

Time was measured using an i-phone stopwatch.

All measurements were manually recorded.

The RO was commissioned with a new membrane on 7th July. Flux tests were performed after each CIP and during each configuration trial at set intervals. The plant was operated using internal batch concentration mode, modified batch concentration mode and continuous concentration mode.

Trial 1: On the 7th July the system was operated in **modified batch concentration mode** with all RO permeate being removed from the system and with RO retentate returned to the balance tank. MBR permeate feed was supplied continuously to the balance tank to replace the RO permeate bled from the system. System temperature, conductivity in the balance tank and RO permeate flux and conductivity were measured at set intervals throughout the run.

Trial 2: On the 8th July the system was operated in **continuous concentration mode** (feed and bleed) with RO permeate being removed from the system and part of the retentate being removed. The remainder of the RO retentate was returned to the balance tank. MBR permeate feed was supplied continuously to the balance tank to replace the RO permeate and retentate bled from the system. System temperature, conductivity in the balance tank and RO permeate and retentate flux and conductivity were measured at set intervals throughout the run.

Trial 3: On the 9th July the system was operated in **batch concentration mode** with the balance tank being filled with MBR permeate to the fill level of 235 mm from top of balance tank and then the feed turned off. All the RO permeate was removed from the system and all the retentate was returned to the balance tank. The system was run until the level of the balance tank reached the bottom of the straight walls of the balance tank. The level of the balance tank contents from the top of the balance tank were measured at set intervals along with system temperature, balance tank conductivity and RO permeate flux and conductivity throughout the run.

Trial 4: On the 14th July the system was again operated in **continuous concentration mode** (feed and bleed) for the purpose of operating the system to obtain consistent RO permeate while microbiological samples were taken. System temperature, conductivity in the balance tank and RO permeate and retentate flux and conductivity were measured at the start and end of the run only.

Trial 5: On the 15th July the system was operated in **batch concentration mode** with the balance tank being filled with MBR permeate to the beyond normal fill level of 20 mm from top of balance tank and then the feed turned off. All the RO permeate was removed from the system and all the retentate was returned to the balance tank. The system was run until the level of the balance tank reached the bottom of the straight walls of the balance tank. The level of the balance tank contents from the top of the balance tank were measured at set intervals along with system temperature, balance tank conductivity and RO permeate flux and conductivity throughout the run.

All flux results were adjusted for temperature using temperature correction factors supplied with EPIL manual and calculated as litres per square metre per hour (LMH).

The average levels of minerals for the RO permeate as measured by ICP at the CSIRO labs were calcium 1.8 mg/L, potassium 52 mg/L, sodium 237 mg/L and phosphorus 1.8 mg/L.

The average conductivity for the mains water supply to the factory is 199 µs/cm.

Results and Discussion

Trial 1: The permeate conductivity steadily increased from 172 µs/cm to 520 µs/cm as permeate flux steadily decreased from 39 LMH to 29 LMH (Figure 22). The conductivity-based concentration factor (CCF) increased from 1.2 to 2.1. These results were as expected due to all retentate being retained in the system, although the permeate conductivity increased by a factor of 3 compared to an increase in system conductivity by 2.13. The final level of mineral in the permeate was higher than anticipated and might indicate that there was a slight leak in or past the membrane.

Balance Tank Starting and Finishing Level (from top edge) = 235mm= 145L, plant turned on at 4.10pm. 7850µs/cm, 16°C
VSD Set 500RPM = 64L/min, Back pressure Set 2000kPa
Constant Feed to RO balance tank
Feed source to balance tank 7850 µS/cm
Constant bleed of RO permeate
Start permeate bleed at 4.15pm

Time	Minutes	Temp ◦C	TCF	Balance Tank EC µs/cm	Permeate EC µS/cm	Permeate Flux Minutes	Litres	Permeate Corrected Flux L/min	Permeate Corrected Flux LMH	CCF
Initial Conditions		16	1.243	7850						
4.15pm	0	28	0.935	9410	172.1	1.256	5	3.723	39	1.2
4.20pm	5	28	0.935	9320	193.4	1.234	5	3.788	40	1.2
4.25pm	10	27	0.956	11000	238	1.305	5	3.663	39	1.4
4.30pm	15	26	0.978	11810	269	1.371	5	3.568	38	1.5
4.35pm	20	26	0.978	12980	326	1.449	5	3.376	36	1.7
4.40pm	25	25	1.000	13900	366	1.499	5	3.336	35	1.8
4.45pm	30	25	1.000	14660	400	1.572	5	3.181	33	1.9
4.50pm	35	26	0.978	15530	437	1.632	5	2.997	32	2.0
4.55pm	40	26	0.978	16200	480	1.707	5	2.866	30	2.1
5.00pm	45	26	0.978	16750	520	1.798	5	2.720	29	2.1

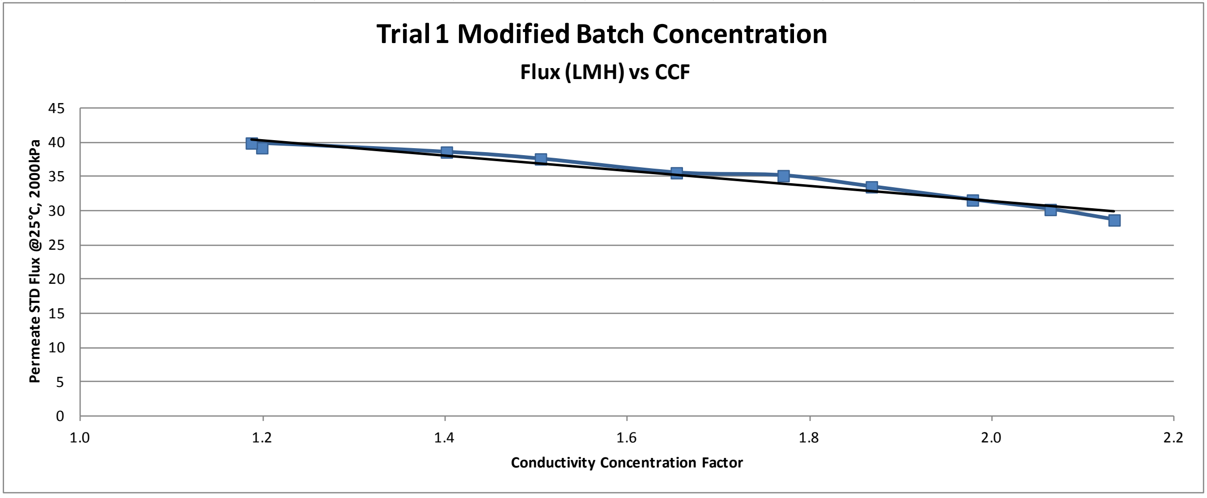


Figure 22. Trial 1 Modified Batch Concentration Mode – changes in permeate flux and conductivity.

Trial 2: By the ratio of permeate flux to retentate flux the system was operating in the range of 41% to 44% recovery during this trial. The permeate flux remained reasonably consistent through the trial after an initial decline, although the permeate conductivity slightly increased (Table 7). Compared to trial 1, the system produced a lower conductivity permeate at the equivalent system conductivity. The results are consistent with the operating recovery range of less than 50%.

Table 7. Results from Trial 2 Continuous Concentration Mode – permeate flux rates and conductivity.

Balance Tank Starting and Finishing Level (from top edge) = 235mm=145L, plant turned on at 3.45pm. 8800µs/cm, 25°C
VSD Set 500RPM = 64L/min, Back pressure Set 2000kPa
Constant Feed to RO balance tank
Feed source to balance tank 8560 µS/cm
Constant bleed of RO permeate and retentate
Start permeate bleed at 3.55pm, retentate bleed started 4.20pm

Time	Temp ◦C	TCF	Balance Tank EC µs/cm	Permeate EC µS/cm	Permeate Flux Minutes	Litres	Permeate Corrected Flux L/min	Retentate EC µS/cm	Retentate Flux Minutes	Litres	Retentate Corrected Flux L/min	Permeate Corrected Flux LMH	CCF	Perm Flux vs Retent Flux
4.00pm	25	1.000	8800	106	1.332	5	3.754	na	na	na	na	40	1.0	
4.10pm	25	1.000	11550	147	1.389	5	3.599	na	na	na	na	38	1.3	
4.20pm	start bleeding retentate													
4.30pm	25	1.000	14500	217	1.712	5	2.921	15000	1.340	5	3.731	31	1.6	0.8
4.45pm	21	1.098	14210	218	1.820	5	3.017	15140	1.355	5	4.053	32	1.6	0.7
5.00pm	20	1.125	14150	213	1.703	5	3.303	14830	1.256	5	4.479	35	1.6	0.7
5.15pm	24	1.023	14350	214	1.746	5	2.930	15090	1.500	5	3.411	31	1.6	0.9
5.30pm	23	1.047	14420	225	1.879	5	2.786	15000	1.420	5	3.686	29	1.6	0.8
5.45pm	23	1.047	14450	229	1.878	5	2.788	15040	1.359	5	3.852	29	1.6	0.7
6.00pm	24	1.023	14350	229	1.875	5	2.728	15060	1.503	5	3.403	29	1.6	0.8

Trial 3: The permeate conductivity increased by 7.8 times compared to an increase in volumetric concentration factor (VCF) of 2.9 (Figure 23). This permeate conductivity increase by a higher rate than the system VCF was particularly evident beyond a VCF of 2.0 (50% recovery), at which point the increase becomes higher and less linear. This indicates that more mineral is being passed through or past the membrane as the VCF increases. The permeate conductivity reaches mains water equivalence at a VCF of 1.7 (41% recovery). The permeate flux decreased steadily as VCF increased, after an initial in flux.

Closed feed to balance tank at 11.45am. Plant turned on at 11.35am. 8380µs/cm, 16°C
Balance Tank Starting Level (from top edge) = 235mm
VSD Set 500RPM = 64L/min, Back pressure Set 2000kPa
Start permeate bleed at 11.40am

			B/Tank Head Space	B/Tank Volume	Balance Tank EC	Permeate EC	VCF	Permeate Flux		Permeate Corrected Flux	Permeate Corrected Flux
Time	Temp ◦C	TCF	mm	L	µs/cm	µS/cm		Minutes	Litres	L/min	LMH
11.40am	16	1.243	235	145	8380	118	1.0	1.646	5	3.776	40
11.45am	20	1.125	235	145	8700	124	1.0	1.646	5	3.417	36
11.50am	21	1.098	320	121	9400	130	1.2	1.353	5	4.059	43
12.00pm	25	1.000	450	85	12800	196	1.7	1.392	5	3.591	38
12.10pm	27	0.956	540	59	18820	388	2.5	2.018	5	2.369	25
12.20pm	32	0.859	570	51	21600	925	2.9	2.361	5	1.819	19

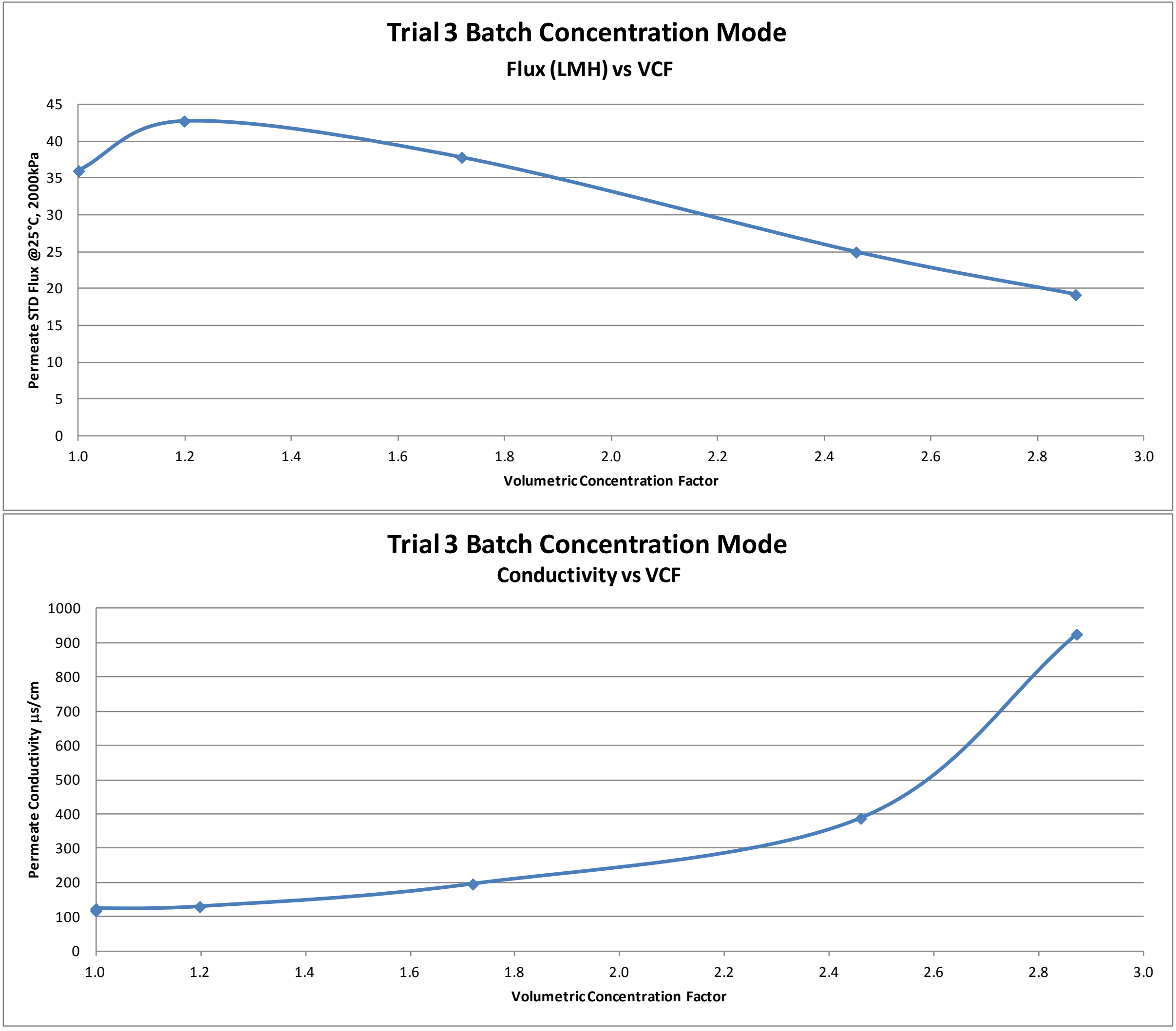


Figure 23. Trial 3 Batch Concentration Mode – changes in permeate flux and conductivity with Volumetric Concentration Factor (VCF).

Trial 4: The plant was operated in a continuous concentration mode so that the system was operating under reasonably consistent conditions while microbiological treatment and sampling was performed. The system behaved similarly to trial 2, except that the permeate flux was lower for the same time period (18%) and the conductivity considerably lower by 4.5 times (Table 8).

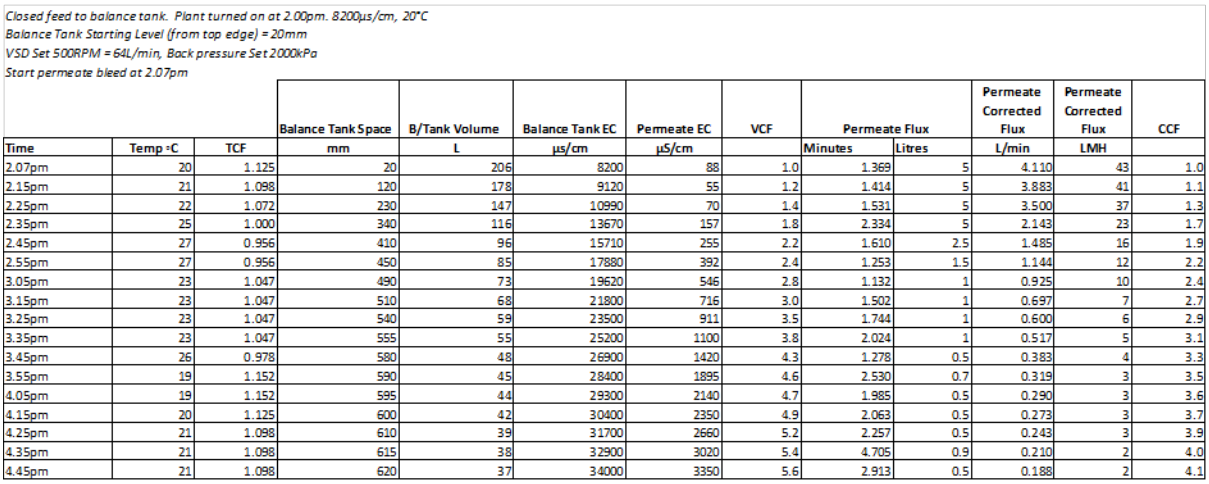
Table 8. Results from Trial 4 Continuous Concentration Mode showing lower permeate flux and conductivity.

Balance Tank Starting and Finishing Level (from top edge) = 235mm=145L, plant turned on at 11.45am. 8330µs/cm, 16°C
VSD Set 500RPM = 64L/min, Back pressure Set 2000kPa
Constant Feed to RO balance tank
Constant bleed of RO permeate and retentate
Start permeate bleed at 11.50am

			Balance Tank EC	Permeate EC	Permeate Flux		Permeate Corrected Flux	Retentate EC	Retentate Flux		Retentate Corrected Flux	Permeate Corrected Flux	CCF
Time	Temp ◦C	TCF	µs/cm	µS/cm	Minutes	Litres	L/min	µS/cm	Minutes	Litres	L/min	LMH	
11.50am	16	1.243	8330	21.2	2.149	5	2.893	8830	1.154	5	5.384	30	1.0
12.48pm	22	1.072	11750	47.8	2.047	5	2.619	12220	1.201	5	4.463	28	1.4

Stopped at 12.55pm after all final fully treated sampling complete

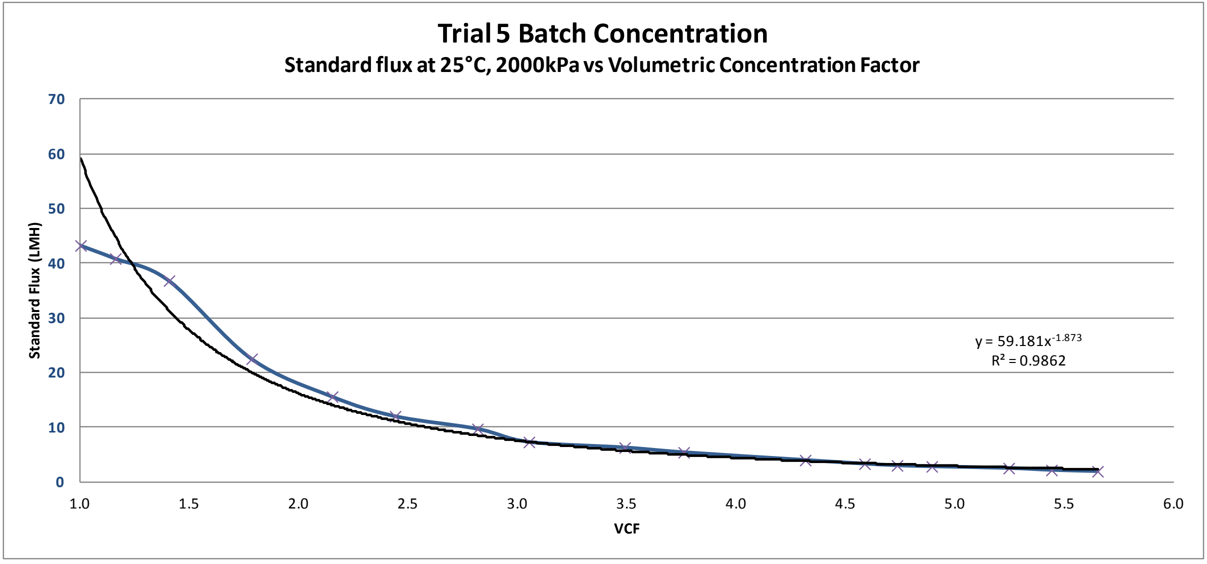
Trial 5: In batch concentration mode the flux decreased as VCF increased in a reasonably logarithmic trend, as shown on the graph (Figure 24). This smooth curve gives a good basis for design. When the flux concentration factor was compared with the conductivity concentration factor it was evident that the permeate flux factor was higher than the conductivity factor. This indicates that there was either permeation of salts across the membrane or there was a leak past the membrane.



Closed feed to balance tank. Plant turned on at 2.00pm. 8200µs/cm, 20°C
Balance Tank Starting Level (from top edge) = 20mm
VSD Set 500RPM = 64L/min, Back pressure Set 2000kPa
Start permeate bleed at 2.07pm

			Balance Tank Space	B/Tank Volume	Balance Tank EC	Permeate EC	VCF	Permeate Flux		Permeate Corrected Flux	Permeate Corrected Flux	CCF
Time	Temp ◦C	TCF	mm	L	µs/cm	µS/cm		Minutes	Litres	L/min	LMH	
2.07pm	20	1.125	20	206	8200	88	1.0	1.369	5	4.110	43	1.0
2.15pm	21	1.098	120	178	9120	55	1.2	1.414	5	3.883	41	1.1
2.25pm	22	1.072	230	147	10990	70	1.4	1.531	5	3.500	37	1.3
2.35pm	25	1.000	340	116	13670	157	1.8	2.334	5	2.143	23	1.7
2.45pm	27	0.956	410	96	15710	255	2.2	1.610	2.5	1.485	16	1.9
2.55pm	27	0.956	450	85	17880	392	2.4	1.253	1.5	1.144	12	2.2
3.05pm	23	1.047	490	73	19620	546	2.8	1.132	1	0.925	10	2.4
3.15pm	23	1.047	510	68	21800	716	3.0	1.502	1	0.697	7	2.7
3.25pm	23	1.047	540	59	23500	911	3.5	1.744	1	0.600	6	2.9
3.35pm	23	1.047	555	55	25200	1100	3.8	2.024	1	0.517	5	3.1
3.45pm	26	0.978	580	48	26900	1420	4.3	1.278	0.5	0.383	4	3.3
3.55pm	19	1.152	590	45	28400	1895	4.6	2.530	0.7	0.319	3	3.5
4.05pm	19	1.152	595	44	29300	2140	4.7	1.985	0.5	0.290	3	3.6
4.15pm	20	1.125	600	42	30400	2350	4.9	2.063	0.5	0.273	3	3.7
4.25pm	21	1.098	610	39	31700	2660	5.2	2.257	0.5	0.243	3	3.9
4.35pm	21	1.098	615	38	32900	3020	5.4	4.705	0.9	0.210	2	4.0
4.45pm	21	1.098	620	37	34000	3350	5.6	2.913	0.5	0.188	2	4.1

Cooling water turned on at 2.55pm



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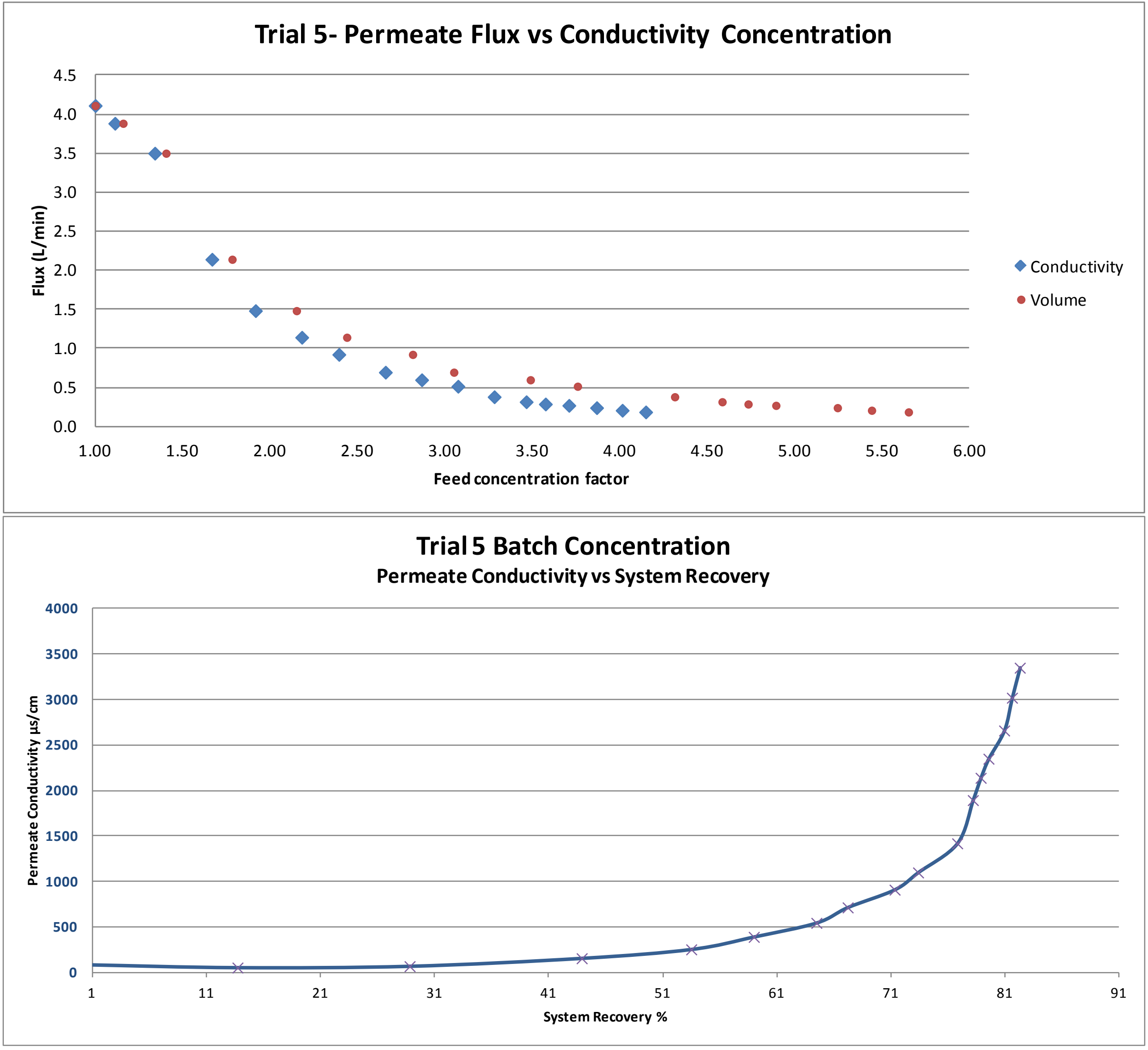

Figure 24. Trial 5 Batch Concentration Mode - flux decreased as VCF increased.

It should be noted that due to time restraints the membrane was left to soak with acid overnight after some of the trials. The pH may have been below the membrane pH tolerance for continuous operation and this may have impacted on the condition of the membrane and changed its permeability.

The RO trial produced process produced re-usable quality permeate at up to 50% recovery rate. Above 50% recovery the permeate quality was reduced due to elevated TDS, making it less suitable as recycled water. The end use of the permeate would determine the degree of treatment required. The Australian Drinking Water Guidelines TDS Fact Sheet states 0-600 mg/L TDS is rated as good for drinking water. Using the conversion factor of EC x 0.64=TDS, this is equivalent to 0-938 µs/cm electrical conductivity.

Conclusions

Overall the results give a good stable basis to design a full-scale RO plant that should operate at reasonable recovery rates. To produce water at greater than 50% recovery and with a conductivity equivalent to good by ADWG, or close to current mains water supply, the RO permeate would need to be further treated through a second RO. A one- or two-pass RO system operating at 70% recovery should be able to be operated without use of anti-scalants and without increased cleaning.

References

Australian Drinking Water Guidelines 6 (2011) Version 2.0 – Total Dissolved Solids Fact Sheet

Project team

Environmental management personnel at the DMS

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Nigel Goodman, Tim Muster and Kirthi Desilva, CSIRO for supply of final disinfection treatment and technical support.

5. Disinfection

Principal of operation

While reverse osmosis can theoretically remove almost all pathogens as well as salts nutrients, final disinfection of the treated water to control residual microbial activity is essential. UV disinfection and sodium hypochlorite addition was applied to the reverse osmosis (RO) permeate as combined disinfection has been shown to be more effective than each on their own.

Chemical processes / design basis

The UV light is a sealed unit and can be tested for operation by touching the outside stainless steel housing and noting warmth. RO product will first passes through this system.

The chlorination system is based on chemical doing of sodium hypochlorite. A 1:100 dilution of 13% stock will be required. Prepare 50 L of (0.13%) hypochlorite solution by adding 0.5 L of 13% stock to 49.5 L of deionised water.

A residual free chlorine concentration of between 0.5 and 2 mg/l (free chlorine), was maintained by calibrating the dosing pump to deliver a required volume of hypochlorite. (*Calculations in* Table 9 *are provided as a guide, but are based on 1 mg/L residual. The data below assumes 0.13% NaOCl and a flow rate of 2 L/min from the RO).*

Table 9. Calculations for NaOCl dosing (based on RO flow rate of 2 L/min and free chlorine residual of 1 mg/L).

0.13% stock	Required Volume	Final Concentration	RO Flow Rate
(mg/L)	(mL)	(mg/L)	(mL/min)
1300	1.54	1	2000
1300	0.77	1	1000
1300	0.38	1	500

The RO permeate had a pH of between 5.5 and 6.5 which was adjusted with lime $Ca(OH)_2$ to achieve a final pH of between 7.5 and 8. To do this approximately 10 L of disinfected water was collected in a jerry can and to this between 0.5 and 2 g of lime was added and the can well mixed (shaken). The ph was then measured and readjust with lime if needed. A high level of cleanliness was maintained throughout for sample collection and microbial analysis.

Specifications

A UV disinfection unit (WaterTec, model UV2A) rated to a maximum flow rate of 1.5 GPM /6 L/min) was used, followed by sodium hypochlorite (NaOCl) addition. Sodium hypochlorite (NaOCl) dosing was achieved using an Iwaki Metering Pump (Model EW-F10VC-20EPY3), dosing a 0.13 %w/w stock solution of NaOCl to achieve a final free chlorine residual between 0.5 and 2 mg/L. The NaOCl feed tank (Iwaki, CT-U50NR-3, 50 L) was new and constructed of high quality PVC to prevent contamination of the sample.

The UV disinfection unit was plumbed into the RO permeate. The UV light was a sealed unit and regularly checked for its effective operation by touching the outside stainless steel housing and noting warmth.

Sensors and Logging

Free chlorine residual was determined using a Grundfos DIT-B spectrophotometer (S/N 09/68929) according to the DPD (N,N-diethyl-p-phenylenediamine) spectrophotometric method. pH was measured using a hand held pH meter (Hanna Instruments).

Microbiological content within the samples was explored by testing for Coliforms (*E. Coli)*, *Enterococci* and *Heterotrophic* bacteria. Samples were collected post MBR (3 × 1 L), post RO (3 × 1 L) and post disinfection (3 × 1 L) on the 14th July 2014. The permeate flux at the time of sampling was 2.9 L/min. Post MBR samples were obtained by disconnecting the feed line from the balance tank.

Post RO samples were obtained by disconnecting the permeate feed line before the UV/chlorination system. Post disinfection samples were taken from pH adjusted bulk product water. Samples were shipped overnight at 4°C, received at CSIRO on the 15th July, stored at 4°C overnight and processed on 16th July. 300 mL aliquots were filitered through Advantec^R 0.45 µm, 47 mm diameter, white gridded membranes (sterile, individually wrapped), with the remaining solids plated using the following media:

- *Chromocult coliform* - Chromocult® Coliform Agar is a selective and differential chromogenic culture medium intended for use in microbiology laboratories analysing food and water. Within 24 hours, this medium enables the detection, differentiation and enumeration of *E. coli* and coliforms from drinking water and processed food matrices such as frankfurters, cooked chicken and non-fat dried milk.
- *Chromocult enterococci agar* – Chromocult enterococci agar (Merck) is a new medium for the detection of enterococci using a chromogenic mix in a selective agar. Enterococci cleave chromogenic substrates in this medium. This produces red colonies allowing an easy detection of enterococci.
- *R2A (total heterotrophic count)* - R2A Agar developed by Reasoner and Geldreich is a nutritionally reduced medium. It was demonstrated that using this medium and incubating for longer at lower temperatures enhanced the recovery of stressed and chlorine damaged bacteria from treated waters resulting in higher, more realistic bacterial counts.
- *Escherichia coli* Quantitative PCR Assay - The presumptive *E.coli* colony was picked from a Chromocult® Coliform Agar plate used for the detection, differentiation and enumeration of *E. coli* and coliforms from Post RO water samples from the DMS treatment plant. A PCR assay of 23S rRNA gene of *E. coli* was undertaken using previously published primers, TaqMan probes, and cycling parameters (Haugland *et al*. 2005; Chern *et al*., 2011) (see Table 9). E. coli ATCC 35150 DNA was used as a PCR positive control. The PCR amplifications were performed in 25-µL reaction mixtures using iQ Supermix (Bio-Rad Laboratories). The *E. coli* 23S rRNA gene qPCR mixture contained 12.5 µL of Supermix, 800 nM of each primer, 80 nM of corresponding probe, and 5 µL of template DNA. A negative control (i.e., sterile water) was included. The PCR was performed using the Bio-Rad iQ5 (Bio-Rad Laboratories).

Results

Both UV and disinfection units operated effectively throughout the trial period. The results from microbiological testing are provided in Table 10. A considerable number of *E.Coli* and heterotrophic bacteria are present in the water prior to RO. No Enterococci were detected in any of the samples received. Post RO, a presumptive negative result was obtained for *E. Coli* and qPCR results determined that the presumptive negative was a confirmed negative using conditions outlined in Table 11. Following disinfection a negative result was confirmed for *E. Coli*, however, there was a multitude of small, brown/tan colonies identified on the R2A plates which appeared almost as a monoculture. This highlights that there was potentially an issue with non-sterile samples lines or a contaminated sampling event. This is reinforced by the fact that heterotrophic counts were low after RO and before disinfection. Overall, the water quality post RO is of high quality as can be seen in Table 12.

Table 10. Results from microbiological testing.

	E. coli	*Enterococci*	Total Heterotrophs
Post MBR	>300	-ve	>300
Post RO	-ve†	-ve	Low numbers of mixed colonies
Post Disinfection	-ve	-ve	Low numbers yellow colonies; *very high numbers (TMTC) of small brown/tan colonies
Transit blank	-ve	-ve	-ve
Positive control	+ve	+ve	

† E.Coli was a presumptive negative based upon Chromocult coliform, but confirmed to be negative with PCR.

Table 11. PCR primers and cycling conditions used in this study.

Target	primer sequences[a] (5’-3’)	qPCR cycling param.	size (bp)	qPCR amp efficiency (%)
E. coli (23S rRNA gene)	**F: GGT AGA GCA CTG TTT TGG CA R: TGT CTC CCG TGA TAA CTT TCTC** **P: FAM-TCATCCCGACTTACCAACCCG- TAMRA**	**10 min at 95 °C, 40 cycles of 15 s at 95 °C, 60 s at 60 °C**	**87**	**102**

Table 12. External laboratory determinations of treated water quality.

Analyte	Level	Unit	Guideline values (NHRMC, 2013)
SS	< 0.1	mg/L	
TDS	35	mg/L	500
Conductivity	58	uS/cm	
Turbidity	0.20	NTU	5
pH	6.5		6.5 – 8.5
Total Alkalinity	9	mg/L	
Apparent Colour	< 2	Pt/Co	
True Colour	< 2	Pt/Co	15
Sulphate as SO4	< 2	mg/L	
COD	8	mg/L	
TOC	< 0.5	mg/L	
TKN	< 0.01	mg/L	
NO3-N	0.08	mg/L	50
NO2-N	< 0.001	mg/L	3
Total N	0.08	mg/L	
Total P	0.047	mg/L	
Chloride	9.7	mg/L	250
Reactive Silica (molybdate)	0.013	mg/L	
Transmission at 254nm	100	%	
Ca	1.7	mg/L	
Mg	0.03	mg/L	
Na	8.2	mg/L	
K	1.3	mg/L	
Total Hardness (CaCO3)	4.5	mg/L	
Fe	< 0.01	mg/L	0.3
Mn	< 0.01	mg/L	< 0.05
Al	< 0.01	mg/L	< 0.1

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Haugland, R. A.; Siefring, S. C.; Wymer, L. J.; Brenner, K. P.; Dufour, A. P. Comparison of Enterococcus measurements in freshwater at two recreational beaches by quantitative polymerase chain reaction and membrane filter culture analysis. Water Res. 2005, 39, 559−568.

NHRMC, National Health and Medical Research Council. Australian Drinking Water Guidelines, Version 2.0, Australian Government 2013.

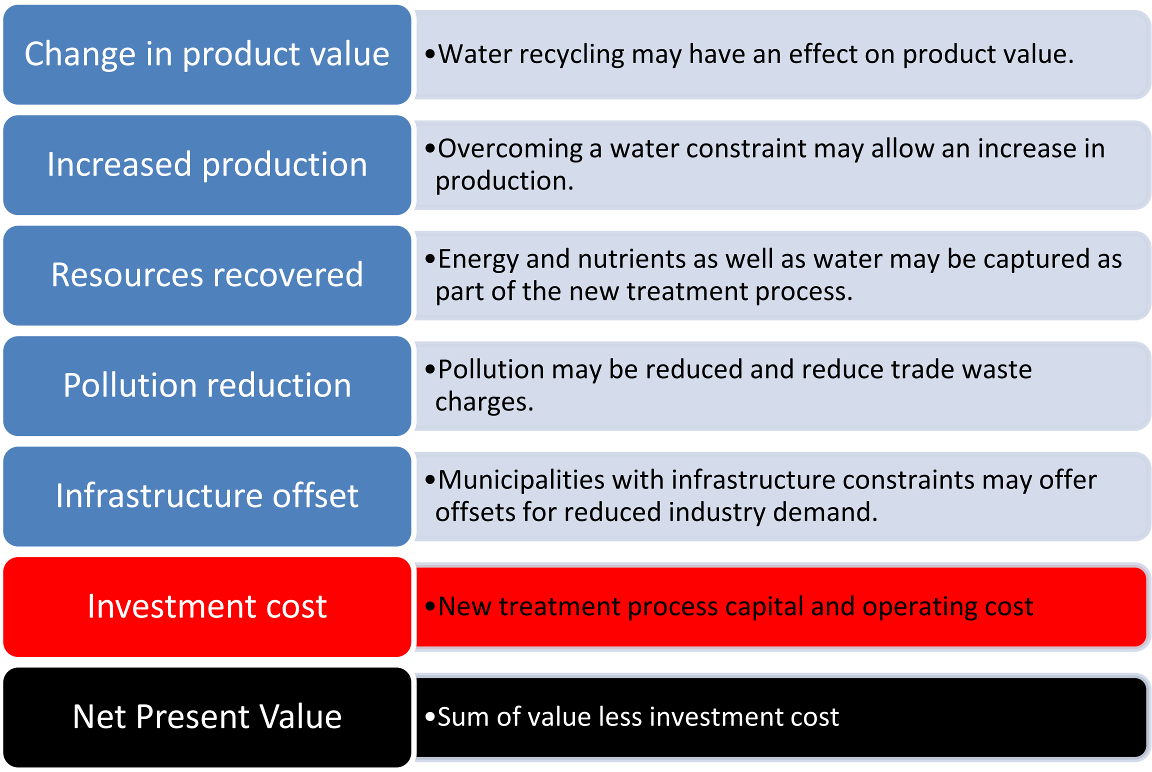
6. Value Proposition Tool Demonstration

Background

CSIRO is undertaking a project with the aim of supporting the reduction in fresh water use in the agri-food sector by increasing the amount of water being recycled. This section demonstrates a simple Excel-based tool developed by CSIRO for calculating the Net Present Value (NPV) of a water recycling investment. The 'Value Proposition' tool can provide a screening of investment options based upon site-specific factors such as the cost of water and wastewater disposal. Figure 25 provides the scope of factors that are considered in the tool.

Upper and lower range estimates can be entered for future water, waste and resource prices. The results identify the importance of each cost factor on the financial viability of a proposed project. This can be useful for testing the price of water or waste disposal that would be required to make the project viable. For example, if the results show that water costs are the most important factor for the NPV, then the results could be tested to find the price of water required to change the feasibility of the project.

The capability of the value proposition tool was tested using a wastewater option at the DMS. The demonstration illustrates the type of analysis that the tool is capable of and may provide a starting point for detailed financial analysis of options. It also highlights limitations of the tools capability and areas for further development.



Change in product value	• Water recycling may have an effect on product value.
Increased production	• Overcoming a water constraint may allow an increase in production.
Resources recovered	• Energy and nutrients as well as water may be captured as part of the new treatment process.
Pollution reduction	• Pollution may be reduced and reduce trade waste charges.
Infrastructure offset	• Municipalities with infrastructure constraints may offer offsets for reduced industry demand.
Investment cost	• New treatment process capital and operating cost
Net Present Value	• Sum of value less investment cost

Figure 25. Components of the value proposition for a water recycling investment.

Description of the Demonstration Option

The Value Proposition tool was trialled at the DMS with support from CSIRO. All data collection and entry was performed by the DMS personnel. Minor changes were made by CSIRO to the presentation of the results for the comparison of cost and value. This was a formatting and communication change rather than a change to the data.

Phosphorus and water recovery

This investment option considered the recovery of water and phosphorus from 3.8 ML/d feed. The phosphorus was precipitated in a form suitable for land application. The effluent after phosphorus recovery was adjusted for pH and sent to a Membrane Bio Reactor (MBR). The water from the MBR was treated to potable standards suitable for process washing. Refer to technical and regulatory framework reports for more details. Table 13 provides a summary of the financial variables and the mass flows of water and phosphorus.

Table 13. Summary of financial variables and material flows.

Variable	Value	Comment
Interest rate (%)	12%	
Period of analysis (years)	10 years	This was doubled for the sensitivity analysis
Volume of water reused (kilolitres per year)	511 000	This is the same as the volume of wastewater reduced.
Phosphorus recovered (tonnes per year)	115	

Analysis

The following analysis provides a summary of results from the value proposition tool. Results are generally presented in millions to reflect the accuracy of the results. The term ‘significant’ is used in a statistical sense in relation to a confidence interval. An overlap in the 95% confidence interval in a comparison suggests that the difference is not significant.

Figure 26 provides an overall comparison of costs and value to the DMS for the investment. The ‘most likely’ cost for the system for the assumed data was a Present Value of about $21 million over the period of analysis. The most likely value over the period of analysis was about $23 million. However, the overlap of the 95% confidence interval suggests that the difference in cost and value was not significant. For example, the 95% confidence interval for cost has a present value both above and below the interval for value. Reducing the uncertainty in costs would enable a comparison that was significant. The cost included capital of about $10 million and operating costs of about $11 million. The capital costs had an uncertainty of about 30% while operating costs had an uncertainty of about 10%. This uncertainty is not unreasonable for an initial screening of options. It highlights that further information, such as a detailed capital quote, is required to perceive a difference in value and costs. The results also indicate that a capital quote at the lower end of current estimate is required for the project to have greater value than cost for the DMS.

Figure 27 provides a breakdown of the components of value for the DMS for the investment. The greatest component of value for the DMS came from overcoming production constraints and the increased revenue from an expansion of production. Increase production gave a present value of about $9.5 million over the period of analysis and was about 42% of the total value to the DMS. The value of the reused water was about $6.6 million or 29% of the total value. Interestingly, the increased production and the water saved gave a value of about $16 million and an upper and lower 95% confidence interval of $17.4 and $14.9 million respectively. This shows that value from increased production and water savings is significantly lower than the costs (ie the upper estimate of value is lower than the lower estimate of cost in this case). This means that all value streams are required to ensure that value is greater than cost. Although only approximately 30% of the value, the reduced cost of wastewater disposal and the value of recovered phosphorus are important for the financial viability of the value proposition.

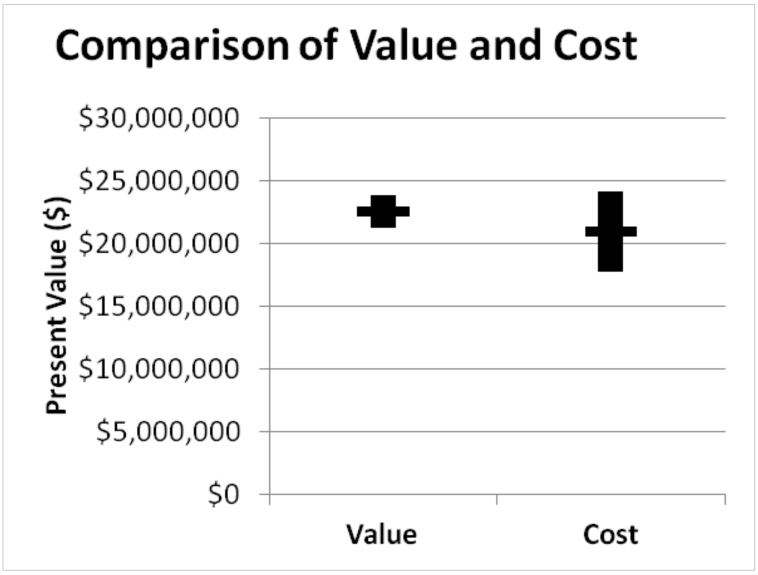


Figure 26. Comparison of value and cost.

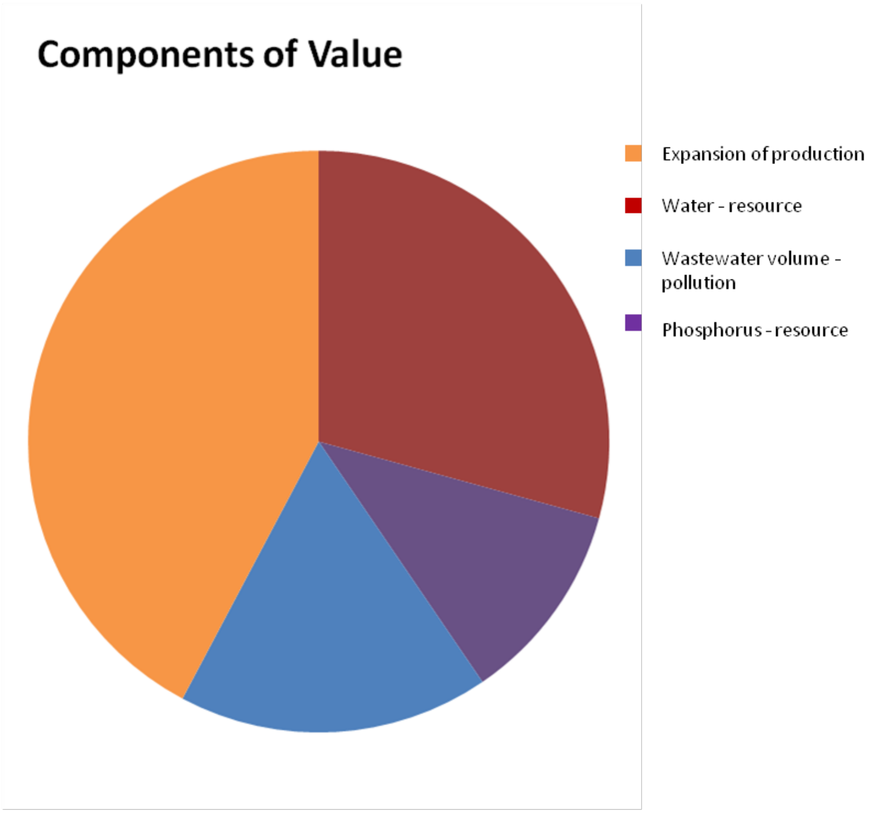


Figure 27. Components of value.

Sensitivity Analysis

Given the constraint of water upon the long term production at the DMS, a longer time period of analysis was considered as a sensitivity analysis. This was performed by CSIRO after the work undertaken by the DMS. Consequently, this analysis demonstrates the application of the tool but is not reflective of financial constraints chosen by the DMS. The discount rate was kept at 12% - which limits the effect of the increased time period but maintains the ‘time cost of money’ chosen by the DMS.

Figure 28 presents the comparison of value and cost for a 20-year period of analysis. The most likely value of the investment was about $32 million while the most likely cost was about $26 million. There was no overlap in the 95% confidence intervals which suggests that the difference was significant. Both value and costs increased due to the greater period of analysis. The relative importance of components of value was much the same as shown in Figure 26. However, operating costs become more important than capital costs which were about $10 and $15 million respectively. This also had an effect on the combined uncertainty of the costs and reduced the range of the confidence interval. This was because operating costs had a lower uncertainty and had a greater contribution to the total cost than the capital cost. This may also highlight that the uncertainty for operating costs may need to be reviewed given the longer time period. However, the effect of the longer time period, and any assumptions about future costs, is moderated by the discount rate. Although the time period was doubled, operating costs only increased by about half due to the effect of discounting to present values.

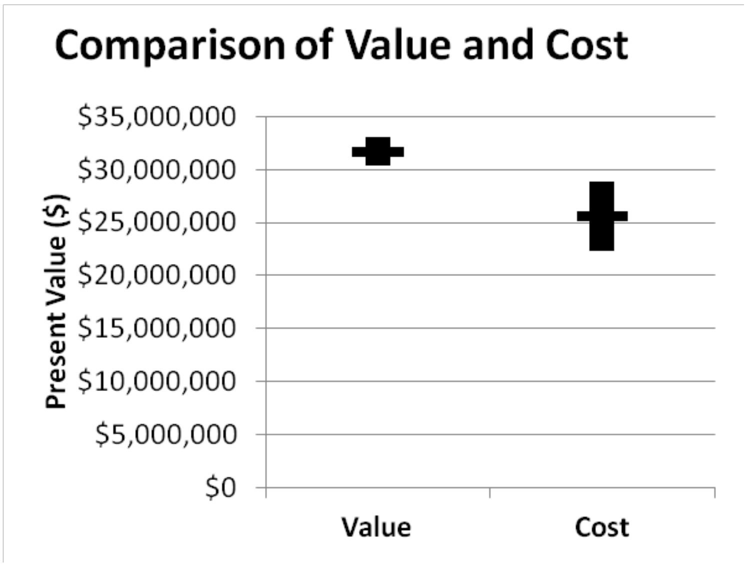


Figure 28. Sensitivity analysis using a double of the period of analysis for the comparison of value and costs.

Conclusion

The demonstration of the value proposition tool by the DMS provided valuable insight into the viability of a water recycling project. It highlighted that uncertainty in the estimates may make it difficult to discern a difference in cost and value. More detailed capital quotes may reduce the uncertainty and clarify any difference in cost and value. Nonetheless, the analysis provides an initial screening of an investment option and defines the range of capital cost estimates for a financially viable project.

The analysis also highlighted the need for water recycling projects to ‘bundle’ different components of value to gain the greatest value for the project. The value of the recycled water itself was only about 29% of the value of the project. The greatest value came from increased production by overcoming production constraints. Other values such as reduced wastewater and phosphorus recovery were required to make the value comparable to the costs.

The analysis focussed upon financial considerations for the viability of the project. A value proposition with a greater scope may also consider the value to the community – even if valued from the perspective of the DMS in terms of on-going community relations and corporate citizenship. The project also focused upon a short period of analysis which accords with a financial analysis with a relatively high discount rate. However, a strategic perspective may be warranted given the importance of water as a limiting constraint for production in the future. The sensitivity analysis doubled the period of analysis and suggested that value became significantly greater than the cost.

The DMS also provided valuable feedback for the value proposition tool itself. It was considered a ‘good aid particularly for waste water related calculations’. The modeling flexibility of the tool was also suitable for capital evaluations which are rarely the same. It was noted that the tool would provide an aid to in-house modeling that the DMS builds and tailors for each specific project.

7. Regulatory Framework for Water Recycling

A dairy manufacturing site is investigating the potential to recycle wastewater produced within the dairy plant to improve water sustainability, reducing their reliance on limited current supplies, and to ensure that they have security of supply in a changing variable climate. There are a range of reuse options available for the DMS, however, the company has elected to investigate the potential of recycling the produced wastewater to a potable standard to be able to use anywhere within the plant. To aid this decision, this assessment primarily focuses on the regulations and associated treatment requirements for potable recycling. The assessment also provides some information on alternative uses for the wastewater should a potable use not be required or it is decided to use some of the wastewater for non-potable purposes.

The ability to recycle wastewater produced by the dairy industry, either within the factory or externally for irrigation of green spaces, is reliant on meeting a number of requirements. One of the most important of these requirements is meeting regulatory requirements for the protection of human health and the environment. This assessment specifies the regulatory requirements that need to be considered in order for the wastewater produced within the factory to be effectively recycled.

There is already a national regulatory framework that incorporates federal and state regulatory agencies, dairy farmers, dairy companies and Dairy Australia. However, there is still a distinct lack of clarity surrounding the content of the regulations with very general descriptions such as ‘fit for purpose’ describing the proper use of water. Greater clarity and specificity in the regulations is necessary in order to make them easier to interpret and implement to assist the uptake of recycled water in the factory.

Regulations

As described in the information within the National Regulatory Framework from Dairy Australia (www.dairyaustralia.com.au) *‘The Australian and New Zealand Food Regulation Ministerial Council consisting of Health and Agriculture Ministers from the states and territories and the Governments of Australia and New Zealand sets policies for food production in Australia. The Food Safety Standards Australia New Zealand (FSANZ) use these policies as a framework to develop food standards. The international standards and codes of practice derived from the Codex Alimentarius Commission, World Animal Health Organisation (OIE), World Trade Organisation (WTO) agreements and World Customs Organisation (WCO) are also used and compared with guidelines for Australian food regulation.’*

For this study, the ANZFA Food Safety Australia guidelines, Phase 1 of the Australian Guidelines for Water Recycling and the Australian Standards for Cooling Towers were consulted for information relevant to water reuse and recycling within the dairy industry. The assessment was then divided into regulations pertaining to health and to the environment, as well as examining the implications of recycling the water within the factory or externally for green space irrigation.

The most relevant regulations for the DMS are the NSW State Food regulations, which like in all other states refer back to the ANZFA Food Safety Australia guidelines. The ANZFA Food Safety guidelines state that *“If a food business demonstrates that the use of non-potable water for a purpose will not adversely affect the safety of the food handled by the food business, the food business may use non-potable water for that purpose.*” The Food Safety guidelines also state that “*Businesses are permitted under subclause 4(3) to use non-potable water provided they can demonstrate to the appropriate enforcement agency that the water will not affect the safety of food produced by the business. It is the responsibility of businesses to provide evidence to an enforcement officer that the quality of the water and the use to which it is put will not affect food safety.*” It is therefore essential that the appropriate State regulators are consulted as early as possible in the design and set up of any recycling program, and involved in all stages of the scheme development.

It has been determined, however, that the ANZFA Food Safety Australia Standards provide only limited information relating to the recycling of water in a food production plant. Water recycling is mentioned in the Standards only to indicate that water recycling in food production facilities was permissible, but if the recycled water is to come in contact with food stuffs, then it is required to be treated to a potable quality. The Standards do state that it is possible to use non-potable water where there is no potential for contact with food, however, there is limited information on the required quality of any non-potable water, or the level of treatment that may be required. It is assumed in this assessment that recycled water not treated to potable standards can be considered as non-potable water. If there is no possibility for recycled water to contact food materials, we suggest that the Australian Guidelines for Water Recycling are currently a more appropriate source of guidance and could be used as a principal source of information. Where recycled water is employed for uses such as a cooling make up source or as a boiler feed source, it is recommended that the relevant standards such as the Australian Standards for Cooling Towers and similar should also be referred to.

As mentioned previously, specifics relating to the level of treatment required when recycling dairy factory wastewater are unclear. It is anticipated that treatment types and levels will vary according to the contaminants required to be removed. As expected, the sources of the wastewater will dictate what the potential contaminants will be, for example bottle wash water and whey produced during the dairy production would be anticipated to be reasonably free of microbial contaminants. The risks from exposure to the raw wastewater would be minimal as the pasteurisation and other dairy food production processes would result in the expected absence of microbial pathogens. Instead, the main focus should be on ensuring the removal and control of spoilage microorganisms and preventing post-treatment contamination. As well as determining the risk from microorganisms, the recycled water may also contain other contaminants such as cleaning chemicals used for cleaning equipment etc that can be present in the wastewater and would need to be removed prior to any potable reuse.

With regards to the quality of water used within the dairy factory, Section 3.2.3 “Food Premises and Equipment” of the Food Standards Code and the Australian Drinking Water Guidelines (NHMRC & NRMMC, 2004) for microbiological, chemical and physical properties, requires a food business to use potable (drinking quality) water, or else use water in a manner that will not jeopardise the safety and suitability of the food, and that the risk of contamination is minimal. The Standards and Guidelines also specify stringent food safety requirements where a food business is considering reusing water that will come in direct contact with food or food contact surfaces, dictating that all water used in direct contact with food or associated surfaces (whether reconditioned or not) must be of a potable (drinking quality) water quality. The Food Standards Code allows for the use of non-potable water in a food business, in situations where it will not impact the safety and suitability of the food. This can include water that is to be reused on non-food contact areas, as there is less risk of contamination of food in such processes. Examples where non-potable water could be used include the cleaning of non-food contact surfaces (eg yards, sheds, loading docks, and transport vehicles); water for flushing toilets; water for use in cooling towers and evaporative coolers. This does not restrict the possibility of a food business implementing the technology to recycle their wastewater.

Export and AQIS Requirements

The use of recycled water in facilities that are registered and approved for the export of food products, including dairy foods, is regulated by the Australian Quarantine and Inspection Service (AQIS). In addition to providing certification for exported dairy products, AQIS also assists with market access arrangements. AQIS requires that exported dairy products must meet the specified requirements of the importing country. This is regulated via the implementation of Export Orders, which in turn correspond with the Australian and New Zealand Food Standards Code. This code specifies that the use of recycled water is permitted as long as it is potable and that the water has been considered to be an input under the HACCP program. Currently, water recycling and reuse proposals are being considered on a case by case basis.

Proposed Recycling by the DMS

As stated above, the DMS is investigating recycling the wastewater produced in the plant to increase their water availability and security. To achieve this aim, the DMS is participating in investigations on treatment requirements and efficiency to treat the wastewater produced in the plant to a potable standard.

The proposed treatment train at the DMS includes a multi-barrier approach involving the use of Membrane Bioreactor (MBR) treatment, followed by Reverse Osmosis (RO) and then UV (with the possibility of a final chlorination step to prevent any regrowth). Based on the evidence of the treatment preliminary trial undertaken at the DMS, the treatment system appears to be operating to specifications and the quality of RO water produced should be able to be considered of potable quality following more validation testing (see Table 1 in Appendix A). Therefore, the specifications of the Regulations and Guidelines regarding the use of potable water within a food business should be easily met.

Potential uses for alternative non-potable recycled water

The potential options for use of recycled water within the dairy factory are varied as are the requirements for differing levels of water quality depending on the end use (see Table 14). As stated above, the DMS is considering direct contact with food, such as for the processing of milk and dairy products and for the washing of equipment and surfaces where there is the potential for contact with food products. In these instances, recycled water of potable quality is required according to the Food Standards. The quality of this water is monitored closely in order to ensure it does not have the potential to contaminate milk.

For use within the plant where there is no potential contact with food products (e.g. for use in plate coolers, cooling towers, heating) the water must be of a standard that is deemed ‘fit for purpose’, as dictated by the Food Standards. This means that the water does not necessarily need to be of potable quality, but must be of a quality sufficient to not cause any health, environmental or process risks. This level of quality can vary, depending on the use, the potential for contaminants in the water, and the potential for contact with people and environments that may be at risk.

The use of recycled water externally, such as for yard washing and irrigation, requires water quality of a level deemed ‘fit for purpose’ as determined by the Food Standards and the Australian Guidelines for Water Recycling. For example, yards and sheds can be washed using plate cooler water diverted into wash down or storage tanks with minimal treatment. Similarly, pre-cooler water can be reused for both washing and irrigation, warm water from the plate cooler and final machine rinse can be reused and/or recycled and final rinse water can be reused for the first rinse of the wash after the next milking. Additionally, yard wash water can be recycled and reused many times, for both yard washing and irrigation, with the use of suitable storage and any appropriate treatment to remove gross pollutants.

The provision of recycled water to external third parties also has potential, though it is imperative to also supply them with a contract specifying the quality of the water provided. The onus is then on the receivers to ensure that the quality of the water is fit for the purpose they wish to utilise it for, as specified in the Australian Guidelines for Water Recycling.

Recycled water may be utilised by third parties in a variety of ways, one of which is irrigation. Irrigation of green spaces such as gardens and parks can be a costly endeavour, and the use of recycled water provided by the dairy factory may help reduce the associated expense. In addition to this, dairy factory processes produce nutrient rich wastewater, the reuse of which may save 96% of the water and 98% of the nutrients in the wastewater (e.g. irrigation of pasture). These nutrients contained within the recycled water may be considered of value as fertilisers and soil conditioners, thereby potentially reducing the need for the addition of these products to green spaces, parks and gardens where recycled water is applied. The provision of recycled water for irrigation is also beneficial to the dairy factory as it reduces the expenses associated with other wastewater removal, such as the costs of discharge to sewer. A reduction in the environmental impacts of wastewater production and discharge are also important factors. Heaven *et al* (2012) found that the application of wastewater from the dairy factory can be relatively benign to the receiving green spaces, parkland and gardens, and any associated downstream environments. However, it was noted that an understanding of the potential sources of contaminants and their possible impacts on irrigation sites and associated environments is important.

Table 14. Water saving options and type.

Description of water saving option	Type
Re-use equipment cooling water (shrink tunnels) in boilers or for wash down	Re-use
Condense and re-use ‘cow’ water for wash down and staff amenities	Re-use
Re-use of ‘waste’ water such as seal water, bottle wash water for toilets, irrigation	Re-use
Internally recycle treated site wastewater	Recycle
Re-use water from the critical stage rinse in a less critical stage rinse (product flush water, CIP systems)	Re-use
Use of Class A recycled water in boilers, cooling towers	Recycle
Irrigation for farms, green spaces such as parklands, gardens, school ovals, wetlands, golf courses	Recycle

Risks to be considered

Key risks to be considered with regards to recycling water within the dairy factory are primarily potential health issues relating to non-potable recycled water, and the presence, type and number of microbial pathogens. Another issue requiring consideration is the potential for community members to be exposed to any pathogens that may be present in the recycled water. The Australian Guidelines for Water Recycling, and therefore State regulations, provides considerable information on controlling pathogens in recycled water and reducing exposure.

However, given the nature of the dairy factory, it is assumed that there would be no contact of the wastewater with human faeces. Therefore, the risk of contamination by human pathogens can be considered minimal (assuming usual hygiene practices are maintained around water treatment processes). Additionally, pasteurisation and food production processes will ensure that wastewater produced during dairy processing is free of pathogens. There is, however, potential for contamination by spoilage microbes where non-sterile fittings are used in the construction of the plants. An additional concern may be of the presence of cleaning chemicals used within the dairy, and what potential effects the reuse/recycling process will have on their concentration.

Any use of recycled water that can create a spray drift (eg, cooling towers), have the potential to pose risks from *Legionella* to the plant workers and closely neighbouring communities around the factory if the water is not treated to a sufficient quality for these purposes. Therefore, there is a need to control the BOD and nutrients to ensure that there is limited potential for growth of *Legionella* in these systems.

Referencing the Australian Standards for Cooling Towers (3666.3 -2011) there is a requirement that there is no *Legionella* detected in the water within the cooling towers (< 10 colony forming units/ mL) and that the Heterotrophic Plate Count (HPC) numbers are less than 100,000 cfu/ml. As the proposed increase in treatment of the final wastewater includes a disinfection stage (most likely UV treatment), this will control HPC numbers and significantly limit the potential for other microorganisms such as *Legionella* and other opportunistic pathogens (*Aeromonas* and *Pseudomonas*). Note that there would remain the normal requirement around maintenance and disinfection of cooling towers and other equipment that cause spray drift to continue to cover the normal risks from *Legionella*.

For the off-site recycling option, the people most at risk would depend on the potential for exposure to the recycled water. This would depend strongly on the application method of the water. Potential examples include green space irrigation (parks and gardens), dust suppression and 3rd pipe use in suburbs and buildings. Similar to the internal use, the major health risk for this recycled water would be bacterial pathogens capable of regrowing in the water (predominantly opportunistic pathogens such as *Legionella* and *Aeromonas*). Control of the regrowth issue for opportunistic pathogens would be through the level of treatment of the wastewater prior to the supply of the water to a third party. The proposed additional treatment which includes disinfection, particularly if disinfection is through UV, would remove any problem bacteria from the wastewater prior to supply for external recycling. This extra treatment should cover any health regulations pertaining to irrigation of recycled water. The only other issue that would be required to be demonstrated to the health regulators is the length of storage and the potential for the regrowth of nuisance microorganisms during storage. The additional use of chlorination also can be used to prevent regrowth of nuisance microorganisms.

Dairy factories should also ensure that third party users of the supplied recycled water are fully aware that they are responsible for ensuring that the location, manner and timing of use of the recycled water are appropriate and fit for purpose.

However, it is assumed that any chemicals used within the dairy are cleared for safe usage and covered under the Standards. It is important to note that recycling water may potentially increase concentrations of nutrients, farm chemicals and cleaning chemicals, therefore recycled water quality should be monitored closely to ensure that it is indeed fit for its intended use. Also of importance to note is that detergents designed for use within Australian dairies have not been registered for reuse purposes and consequently it is unclear as to whether they are in fact suitable for reuse applications (http://www.dairyingfortomorrow.com - 'Water in the Dairy' InfoSheet C1).

As stated in the 'Water in the Dairy' InfoSheet C1, there are a number of factors requiring consideration with regards to chemical and water reuse systems. For chemicals, these include: the monitoring of cleaning performance; the assessment of wash solutions' cleaning capability; health and safety aspects; the potential risks of cleaning chemical residues; any special handling or treatment of waste generated required.

Environment

Where the recycling and reuse of wastewater from dairy factories focuses on uses that involve potential environmental impacts, there are additional issues that need to be considered relating to the presence and concentration of various nutrients such as sodium, phosphate and nitrogen, and other factors including salinity and BOD.

Salinity levels of the raw wastewater of the DMS have been found to be in the region of 6000 µS/cm (EC). This is quite high when compared with the critical limits of 700 µS/cm set up by the Water Recycling Guidelines section on reuse for irrigation purposes, and as such, further treatment of the wastewater will be required in order to lower the salinity to a level acceptable for irrigation purposes. Treatment options include salt removal through RO treatment and dilution of the wastewater prior to use. It is important to note that when the critical level of 700 µS/cm is compared to the maximum EC tolerances of grasses, native plants and ornamental shrubs (provided in Appendix 5 of the Guidelines), it is found that generally the limits for most plants range in the 1000-2000 µS/cm (and often higher).

A secondary concern with regards to salinity is the potential accumulation of salt in the recirculation of recycled water. High salinity may not be an issue with reuse purposes such as dust suppression and wash down, but for irrigation purposes the concentration could be a potential issue. Levels would be required to be monitored and appropriate action taken to remove or dilute the salt content of the DMS wastewater prior to use.

Sodium can also have an impact on some soil types and cause sodicity issues. Sodium levels in the raw wastewater from this DMS were found to be 850 mg/L, which is quite a high value, and further removal or dilution of the wastewater would be required in order to render it useful for irrigation and other various purposes. This is the one environmental issue that may need to be investigated further to cover requirements within environmental regulations approval. This would need to be part of any discussions with potential third party users of the wastewater and a potential consideration regarding appropriate uses or site assessment of sodium impacts on the soil.

Nitrogen and phosphate in wastewaters are considered to have the potential of being used as a source of fertilizer for plants. The Guidelines do consider that these nutrients in the wastewater need to be used in place of, or in combination with, the use of commercial fertilizers. The amount of substitution will depend on the type of plants receiving the recycled water. Nitrogen levels in this DMS wastewater have been found to be approximately 13 mg/L, which is an acceptable level, with average concentrations found to be around 12 mg/L but sometimes as high as 50 mg/L. Phosphate levels have been found to be 86 mg/L, which again is quite high and would need to be addressed prior to use. The Water Recycling Guidelines and the scientific literature states that when recycled water is used for irrigation, any nutrients present in the water can be advantageous as a fertilizer replacement or supplement. The presence of phosphate in the wastewater, however, could still be a concern for waterways if the wastewater is allowed to enter a water body. This is an issue for the end user but would still need to be kept as a consideration for potential further treatment requirements.

A qualitative measure of consequence or impact (using Table 4.4 page 133 of the Guidelines) suggests that the current raw wastewater quality from this DMS should have minor environmental impact. If the treatment options suggested by the CSIRO assessment are also taken into consideration, then any further removal of nutrients achieved through enhanced treatment will reduce any potential impacts even further.

However, while the treatment options considered will reduce the nutrient load, it is likely that salinity concentrations will remain virtually unchanged. If there is a need to further reduce the salinity, a higher level of treatment such as nanofiltration or Reverse Osmosis (RO) would need to be considered. As RO treatment is a component of the proposed treatment train at this DMS, salinity levels should be reduced further to an acceptable level. Likewise, there also remains a need to assess if any more sodium issues exist outside of the general salinity issues (in particular soil sodicity issues). This strongly depends on where the water is used and the soil type at that location.

An assumption has been made that there are no toxic chemicals (organics, boron or copper) as the wastewater has generally come from processing food components. The potential exceptions to this are cleaning agents added to the recycled water through cleaning activities in the plant - these may contain chemicals that may impact the growth or health of plants irrigated with the waste water.

Any environmental impact of the final dairy factory wastewater will depend upon the intended uses of the wastewater; where the water will be used; and what material, plants or soil conditions will be in contact with the water (for much greater details see Box 4.1 on Page 123 of the Australian Guidelines for Water Recycling: Phase 1). The section in the Australian Guidelines for Water Recycling that describes the requirement for environmental controls predominantly considers wastewater that is sourced from sewage, stormwater or grey water as these are considered to be the most risk with the greatest range and levels of microbial and chemical contaminants. There is limited mention of the use of industrial water sources in the guidelines. Based on the information in the guidelines and the water quality data provided by the factories, it can be assumed that all of the water sources discussed in the guidelines can be considered to be much more likely to be contaminated than the wastewater from the plant would potentially be. This means that, with appropriate interactions with state regulators, there should be no major impediments to the plant wastewater being able to meet environmental regulatory requirements for reuse. In order for this proposal to be effective, it is of the utmost importance that the Australian Guidelines for Water Recycling are considered, understood and implemented with regards to any environmental impact/s.

Conclusion

There are a number of barriers to the uptake of wastewater recycling and reuse within dairy factories. More specifically, there remains a lack of clarity with regards to the regulations for water recycling. Greater clarity in and understanding of the regulations may assist in reducing the apparent reluctance of some companies to initiate investigations into implementing water recycling and reuse processes, technology and options. This provides scope for discussion and engagement with regulators. In addition to this, there is some difficulty in acquiring useful, detailed information regarding the value/costing of the implementation of water recycling and reuse processes, the technology involved and the potential end uses for individual companies and businesses. Often this information is only able to be acquired during consultation processes and associated fees may be prohibitive. The value proposition tool provided by CSIRO as part of this project can provide valuable assessment on the applicability and value of different reuse schemes and treatment methods.

The participation of the DMS in investigations focusing on the implementation of water recycling and reuse processes within their plant has provided us with greater insight into the efficiency and effectiveness of the recycling process via the specified treatment train. Initial testing of the recycled water produced by the treatment plant installed at the DMS indicates that the water produced by the plant is of high quality and comparable to town supply water quality. This initial testing has assessed the ability of the recycled water plant to produce water of an acceptable quality for use within the plant. Further testing will be required in order to validate and conclusively determine both the quality of the water produced and it’s suitability for use within the plant as a potable water source. If early indications are proven to be correct, then it is anticipated that the wastewater produced by the factory will be able to be safely recycled through this treatment train, and that this recycled water should be acceptable for use within the factory for both potable and non-potable applications.

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NHMRC and NRMMC (2004). National Health and Medical Research Council and Natural Resource Management Ministerial Council: The Australian Drinking Water Guidelines (2013) https://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/eh52_aust_drinking_water_guidelines_update_131216.pdf

Australian Quarantine and Inspection Service (AQIS). Australian Quarantine meat export information. http://www.daff.gov.au/biosecurity/export/meat

Other resources

Codex Alimentarius Commission http://www.codexalimentarius.org/

World Organisation of Animal Health (OIE) http://www.oie.int/

World Trade Organisation Agreements (WTO) http://www.wto.org/english/thewto_e/whatis_e/inbrief_e/inbr03_e.htm

World Customs Organisation (WCO) http://www.wcoomd.org/en.aspx

Appendix A: Jar Testing of Phosphate Precipitation

Objective and Experimental

Tests were carried out to define the chemical conditions required to lower soluble P concentrations in the anaerobic digester centrate by precipitating P, using either calcium (Ca) to form hydroxylapatite (HAP) or magnesium (Mg) to form struvite or magnesium phosphates. Stock solutions of 1M $CaCl_2$, 1M $MgCl_2$ and 2M NaOH were prepared using analytical grade reagents and were delivered to a 200 ml sample of treated effluent using a calibrated pipette. Mg and Ca ions were added independent of each other to achieve molar ratios of P as 1:1, 3:2 and 2:1. Defined volumes of NaOH stock solution required to achieve pH 8, 10 and 12 were added to each individual samples whilst stirring to allow rapid mixing. The solutions were then left undisturbed until 10 ml aliquots of the supernatant were removed at 30 min, 1 hr and 2 hrs and passed through a 0.48 µm syringe filter for ICP-OES characterization.

Results and Discussion

Jar testing demonstrated that the addition of Ca was more effective at lowering soluble P concentrations in the anaerobic centrate than Mg (Figure 1). In addition, soluble Ca levels could be controlled to below 50 mg/L when pH was increased to 10 or where higher Ca:P ratios were employed. Other studies have shown that Mg additions leading to struvite crystallisation have been more effective at lowering soluble P, however, despite ammonia levels in the centrate being stoichiometrically favourable (140 mg/L NH_3-N) for struvite formation, further investigations did not explore Mg additions.

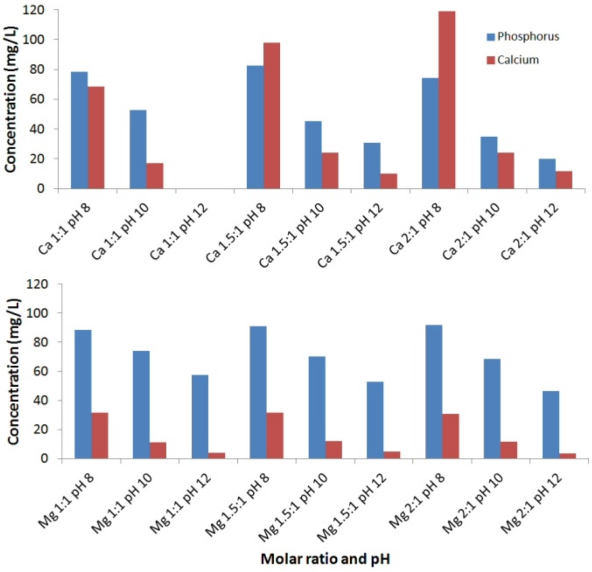

Figure 29. Jar test data - residual concentrations of Ca and P in anaerobic centrate after 1 hr settling.

Additional Information

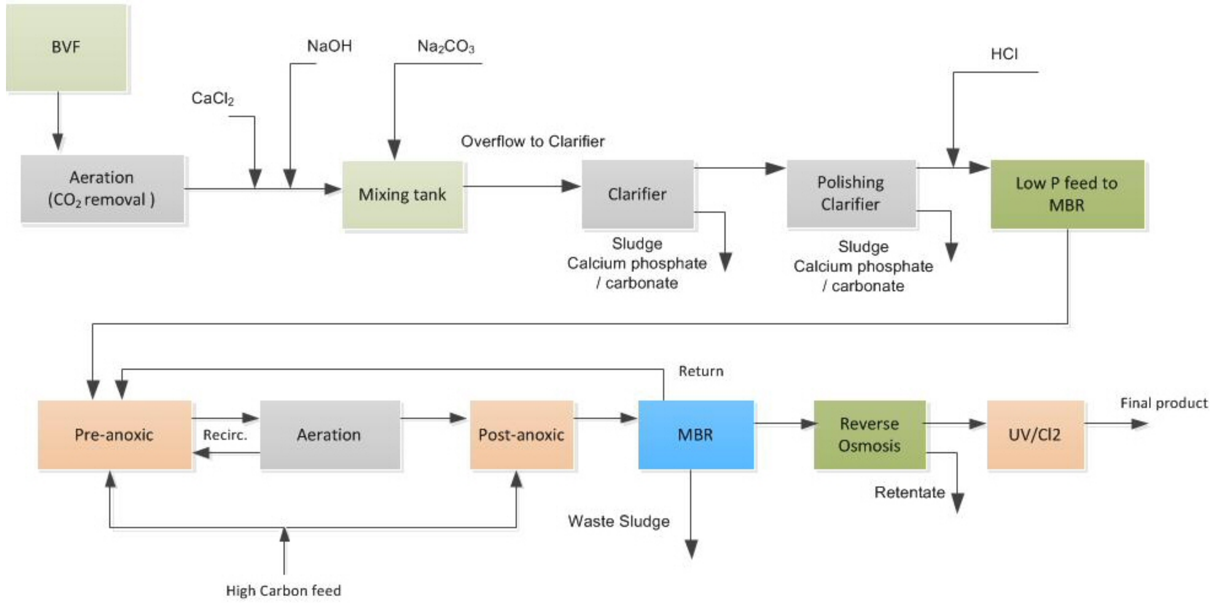

Figure 30. Schematic of the process train for the entire pilot trial.

Table 15. Agreed sampling regime for pilot trial.

Parameter	Influent	Membrane Tank	MBR Effluent	RO Effluent	Final effluent after disinfection
COD (mg/l)	3	--	3	--	
BOD (mg/l)	W	--	2	--	
TSS (mg/l)	3	3	3	3	
VSS (mg/l)	W	W	W	--	
DOC (mg/L)				3	
pH	3	3	3	3	
Total Dissolved Solids (mg/l)	3	--	3	D	
Temperature (°C)	D	D	D	D	
DO (mg/l)	--	D	--	D	
NH_3-N (mg/l)	3	--	3	3	
NO_3-N (mg/l)	W	--	W	W	
Total Phosphorus (mg/l)	W	--	W	W	
Sulphate (mg/l)	AR	--	AR	--	
Calcium (mg/l)	AR	--	AR	--	
Magnesium (mg/l)	AR	--	AR	--	
Iron (mg/l)	W	--	W	3	
Filterability (mL/5 min)	--	3	--	--	
Suction pressure (TMP)	--	--	D	D	
Total heterotrophic Plate Count (mg/l)					3
Thermotolerant coliforms (TTC)					3

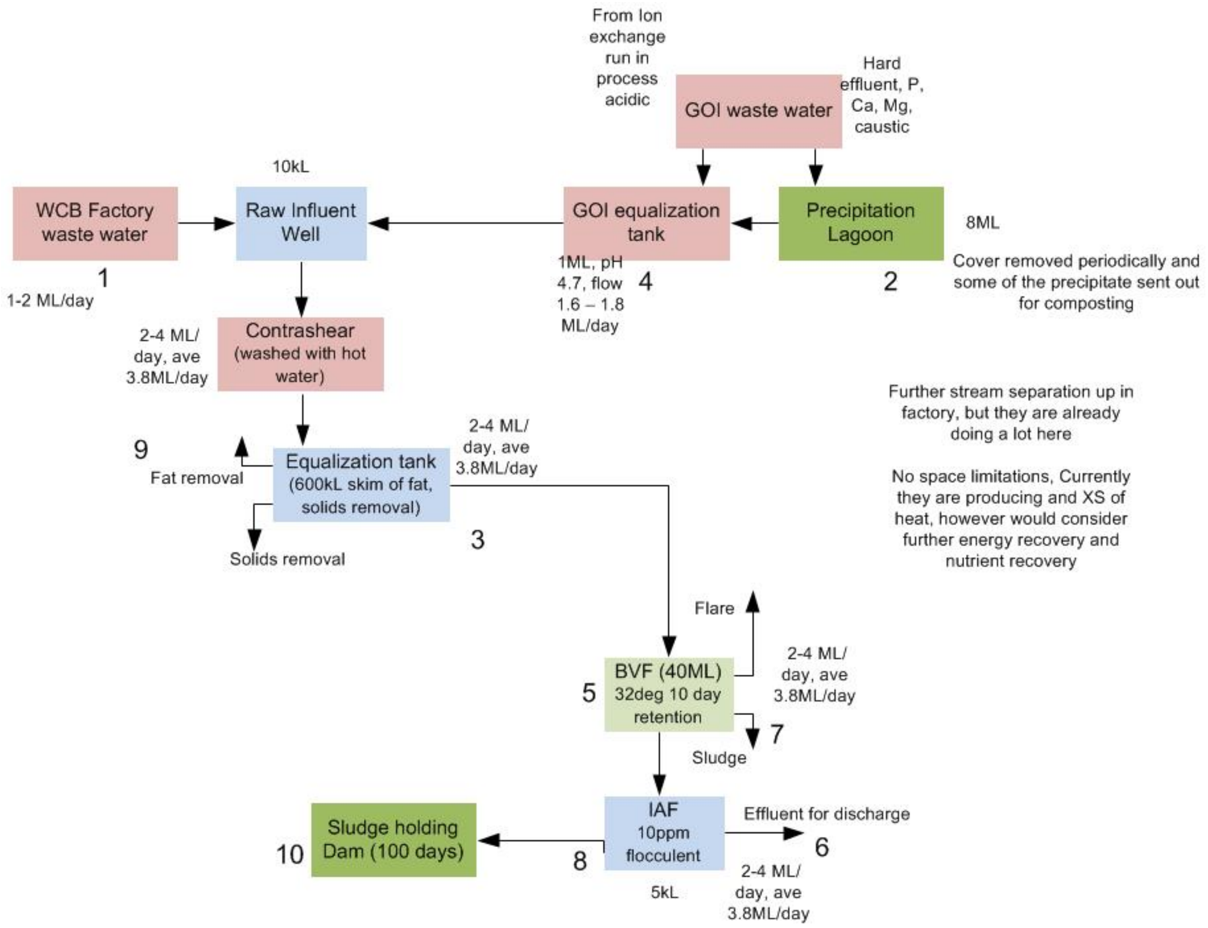

Figure 31. Process flow diagram for the DMS (August 2013).

Table 16. Chemical analysis of the DMS wastewater process.

	1	2	3	4	5	6	7	8	9	10
	DMS wastewater	**GOI Precipitation lagoon**	**Lagoon eq. tank**	**GOI eq. tank**	**BVF effluent**	**IAF effluent**	**BVF sludge**	**IAF sludge**	**Fatty solids**	**Lagoon sludge**
SS	2600	54	1200	170	180	12	49000	40000	660000	76000
TDS	3400	17000	5400	9700	4900	4900	4800	6100	5700	82000
EC	6000	28000	8300	9900	9800	9600	1000	11000	10000	17000
pH	11.6	12.7	4.4	4.7	6.9	7.2	6.9	6.9	4.5	7.7
Alkalinity	730	5400	<8	<8	1700	1600	2000	1600	3500	4100
COD	10000	6900	6500	3900	420	200	62000	57000	190000	97000
TOC	2800	2900	1800	1500	47	27	-	-	43000	-
NH3 N	2.8	22	96	69	140	120	220	220	390	950
Kj N	270	220	180	160	170	130	5400	4100	9800	11000
NO3	13	<1	<1	<1	<1	<1	<1	<1	<1	<1
NO2	0.24	<0.02	1	<0.02	<0.02	2.6	0.9	470	0.1	0.1
TP	86	240	100	100	92	89	450	470	280	760
Ortho P	63	180	69	84	89	87	200	130	230	230
Cl	550	2200	2100	4600	2100	2100	2000	2000	1100	1600
Na	850	4900	1700	2900	1700	1700	1700	1600	890	1500
Ca	77	0.97	56	39	48	43	120	65	540	80
Mg	11	2.9	11	12	11	10	16	12	55	17
K	120	1400	390	790	460	460	490	480	270	680
Tot S	<35	83	<35	<35	<10	<10	<89	<89	120	89
Turbidity						12				