APPROACHING ZERO DISCHARGE ON A MODERN MICROFILTRATION DRINKING WATER FACILITY IN NEW ZEALAND

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ABSTRACT

In May 2008 the township of Hokitika and Westland Milk Products started drinking and using water from a new Pall Microfiltration treatment plant. Lake Kaniere provides the source water which is filtered by the microfiltration membrane system and chlorinated using the existing chlorination system providing treated drinking water for Hokitika and Westland Milk Products. The plant achieves compliance with the Drinking-Water Standards for New Zealand 2005 and has a capacity of 7,000 m³/day.

The plant site is not connected to the town sewerage providing a key challenge for the plant to economically provide a waste disposal solution. The original treatment process comprised only chlorination and water storage with no need for wastewater disposal. Typical microfiltration systems require >3% of the feedwater for membrane regeneration including backwash and chemical cleans which would have produced more than 200 m³/day of wastewater for this plant.

The project was delivered via a lump sum turnkey Design and Construct contract. Various options were considered for wastewater treatment and disposal during the tender design phase including traditional settling ponds and construction of a wastewater pipeline for offsite treatment. However, included in the tender from the West Coast Water Joint Venture (WCWJV) was the most cost effective option, the inclusion of a "Wastewater Recovery" microfiltration membrane process. Conservative projections estimated that the Recovery microfiltration system would recover sufficient volumes to reduce the wastewater by about 93% to around 0.3% of the feedwater or approximately 20 m³/day. The wastewater is stored on-site until removal via a road-tanker for disposal at the existing municipal wastewater treatment plant.

The Westland District Council agreed with the "Wastewater Recovery" principle as being the most cost effective and backed the WCWJV to achieve the projections provided by awarding the contract. The WCWJV partners are Pall New Zealand and Marshall Projects who delivered and commissioned the plant in 8 months from award.

The "Wastewater Recovery" microfiltration system option had the lowest overall life cycle cost and was constructed as an integral part of the overall microfiltration treatment plant. The commissioned treatment plant utilises two identical Primary microfiltration units; with a single Recovery microfiltration unit providing an overall plant recovery in excess of 99.7%.

The upgraded treatment plant was commissioned in May 2008. This paper highlights the success in maximising the overall water recovery at the site. Operating data shows the achieved water recovery is greater than projected during the design phase, with the installation getting closer to the ideal 'zero-discharge' from the water treatment process. The cost benefits for many plants are real and perhaps with some additional innovation, complete on-site treatment could produce value added products and achieve the zero-discharge target?

KEYWORDS

Microfiltration, Drinking water, Zero discharge, Waste minimisation

1 INTRODUCTION

Three-quarters of the Earth's surface is covered by water. Incredibly, less than 1% of it is the fresh water agricultural, industrial and residential users depend on. Efficient use of this fresh water resource begins at the treatment plant. Water treatment processes that minimise and even recycle the wastewater generated within the process are an important development in meeting this goal.

There are a number of water treatment facilities that require upgrades to cope with increased demand or to ensure compliance with treatment standards that are becoming increasingly more stringent. Additional or improved filtration processes may be part of the process upgrade methodology. Regenerable filters such as membrane and media filters require a portion of the water supply for the regeneration sequences. Typically the wastewater from filter regeneration is discharged to;

- Surface receiving waters directly; or
- On-site settling pond systems prior to surface water discharge; or
- A Municipal wastewater treatment facility.

Discharge consents are often restrictive encouraging waste minimisation and waste recycling practices which inevitably must be considered.

Water used for regeneration sequences within a pressurised microfiltration (MF) plant is optimised with two goals in mind:

- Using sufficient water to ensure effective membrane regeneration to maintain plant performance, and
- Minimising wastewater produced by regeneration to increase the overall filtrate recovery generally measured as a percentage of feedwater.

Once the membrane regeneration is optimised, there is no further opportunity to reduce wastewater within the filter process itself. Water recycling strategies must therefore be employed to further reduce wastewater from the treatment process. This may simply involve returning waste to the plant inlet or adding another process to recover the wastewater stream.

This paper highlights the success in maximising the overall water recovery during the upgrade of the Hokitika Water Treatment Plant.

2 BACKGROUND

In 2007 the Westland District Council (WDC) and Westland Milk Products considered options to upgrade the Hokitika Water Treatment Plant (WTP). The plant supplies drinking water for the township of Hokitika, along with process water for the nearby Westland Milk Products processing site.

Raw water is supplied to the treatment plant from Lake Kaniere, situated approximately 14 km east of the Hokitika Township. The lake is surrounded by native forest except for two cleared areas containing farmland and two small lakeside settlements. The area is a popular recreational spot; common uses of the lake include boating, water skiing, swimming and fishing.

The existing treatment process consisted of chlorination followed by treated water storage. An improved process was required to achieve compliance with the Drinking-Water Standards for New Zealand 2005 (DWSNZ, MOH 2005) for both the township and milk processing site. The main requirement for the upgraded plant was compliance with DWSNZ protozoa removal requirements. Membrane filtration was selected by the WDC as the preferred process option.

Membrane filtration of water typically requires between 3 and 7% of the feedwater supply to be used for membrane regeneration sequences. These sequences consist of Reverse Filtration (RF) and chemical cleaning regimes, including periodic Cleaning in Place (CIP) routines and shorter more frequent Enhanced Flux Maintenance (EFM or mini CIP) procedures.

The WTP site did not have an existing sewer connection and therefore there was no existing infrastructure for disposal of the membrane regeneration wastewater. An important part of the overall process design was therefore the management of water produced from the regeneration sequences.

3 DESIGN AND CONSTRUCTION

The WDC and Westland Milk Products chose to adopt an Expression of Interest (EOI) process for the proposed WTP upgrade. The EOI stage was followed by selection of shortlisted tenderers for a Design and Construct (D&C) contract to deliver the WTP. Babbage Consultants were employed to assist during the EOI and tender phases.

The tendered design looked closely at the options available for management of the wastewater from filter regeneration sequences. Options assessed included;

- On-site settling ponds and decanting the supernatant back into the feedwater,
- Installing a connection to the sewer 2 km away from the WTP, and
- The selected option, to install a dedicated wastewater recovery MF unit and waste storage tanks, with wastewater ultimately transported by road-tanker to the wastewater treatment plant.

The structure of the tender process enabled and encouraged the tenderer to evaluate and provide options that were economic for the life cycle of the plant. The resulting option was based on achieving a feedwater recovery of 99.7%, allowing for 50 m^3 to be taken by tanker every 3 days during 'worst case' design conditions for feed solids loading and water demand.

The option to construct a settling pond system was complicated by the limited land area that was available. In addition the intense rain events that occur in Hokitika would have caused some management problems for a pond system. The pond design was not fully progressed, however initial estimates showed the costs to be similar to the Recovery MF option even before including an allowance for periodic desludging of the lagoon.

The option of installing a sewer connection was estimated to add between $150,000 to $200,000 in life cycle costs when compared to the Recovery MF option.

The successful tenderer was the West Coast Water Joint Venture (WCWJV) comprising the two partners of Pall New Zealand Limited and Marshall Projects Limited (MPL). Together Pall and MPL were able to provide a cost competitive tender with a high-recovery solution utilising a separate backwash recovery MF system.

4 MICROFILTRATION SYSTEM OPERATION AND REGENERATION

Each Pall Aria[1] AP Series MF 'skid' is composed of two parts; namely a valve part and a module part. The valve part or 'valve rack' contains all necessary valves, pumps, instrumentation, controls, motor drives and remote I/O. The module part or 'module rack' is equipped with Microza[2] MF modules and necessary piping.

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[1] Pall Aria is a trademark of Pall Corporation.

[2] Microza is a registered trademark of Asahi Kasei Corp., Ltd.

4.1 MICROFILTRATION MODULE

The Microza modules use proprietary poly-vinylidene-fluoride (PVDF) hollow fibre membrane technology with advanced bonding techniques for an exceptionally strong module design. The highly porous PVDF membrane is the heart of the system, and means a system can be designed at higher sustainable fluxes compared to other membranes, or it can be operated at lower fouling resistance and lower pumping heads, or with increased intervals between any regeneration sequences - all of which have substantial operational benefits including wastewater minimisation.

The uniquely designed filtration modules have a nominal pore size of 0.1 µm and therefore can remove the following contaminants from surface and ground water sources.

- Suspended Solids/Turbidity
- Viruses (partial removal)
- Bacteria
- Cysts and Oocysts
- Iron and Manganese
- Arsenic
- Organics

4.2 MICROFILTRATION SYSTEM OPERATION

4.2.1 FILTRATION (NORMAL PRODUCTION)

Feed water enters the bottom of the module and is distributed uniformly to the outside of the fibres. Since it is under pressure, the water passes through the hollow fibre membranes and filtered water exits from the top of the module. Under normal conditions, all of the feed water flows through the membranes and exits as filtered water. Depending on feed quality, a small amount of the feed water may be circulated past the outside of the hollow fibres. This flow prevents the accumulation of foulants and debris on the surface of the membrane and helps evenly distribute flow though the membrane fibres.

4.2.2 AIR SCRUBBING AND REVERSE FILTRATION

As water is filtered, rejected particulate accumulates in the module or on the membrane fibre's surface. The effect is a flow restriction in the module, resulting in an increase in trans-membrane pressure (TMP). TMP is the pressure difference from the feed side of the module to the filtrate side of the module. Air Scrubbing (AS) is a mechanical process to remove the debris from the module and decrease the rate of overall increase in TMP.

AS is usually initiated at a preset interval of time or water throughput, however as a secondary trigger, AS may be initiated if the TMP exceeds a specified maximum. The air injection valve opens and air is injected at low pressure into the feed side of the module. At the same time, filtrate that has been collected in the dedicated Reverse Filtration (RF) tank is pumped in the reverse direction through the module and out through the main system drain. The simultaneous AS and RF flow (SASRF) is then stopped after about 30 seconds. At this point, most if not all of the accumulated debris in the module has been swept to drain.

To complete the cycle, a Forward Flush (FL) is implemented, circulating feed water from the feed tank on the outside (feed side) of the membrane fibres at high velocity. This fast flow of liquid is directed through the excess recirculation port of the module to drain. This further dislodges and removes from the module debris that was captured by the membrane fibres.

This fully automated cycle is included in every Pall Aria System and occurs every 15 - 120 minutes, and stops filtrate production for about 1.5 - 2 minutes.

4.2.3 ENHANCED FLUX MAINTENANCE

To assure maximum efficiency and lowest total cost of ownership, Pall has developed techniques to keep the membranes free of fouling materials. EFM is a fully automated process that uses warm water with mild chemical solutions tailored to specific foulants that may be present in the application on a daily basis. EFM is used to reduce the times when a partially fouled membrane results in a system operating at less than peak efficiency.

The benefits to using EFM are a smaller system footprint by allowing the membranes to operate at high flux rates, which reduces floor space and facility costs, and a lower average TMP, which reduces pumping energy. The durable, strong and chemical resistant PVDF hollow fibre makes this possible - it can be subjected to thousands of EFM cycles with no reduction in service life.

4.2.4 CHEMICAL CLEAN IN PLACE

SASRF and EFM are designed to remove particulate matter and foulants. In most applications, it will occasionally be necessary to perform a complete CIP process. The CIP process is a 2-step protocol using an acidic solution and a caustic solution with chlorine. This process will return the modules to "nearly new" condition and can be performed hundreds of times over the life of the modules.

Due to the low frequency of CIP operation, the process is designed as a semi-automated process. The chemical and rinse cycles are programmed for manual initiation. This process requires minimal operator intervention to "setup" the system for CIP.

5 OVERVIEW OF HOKITIKA OPERATIONS

5.1 MF SYSTEM DESIGN

A basic process flow diagram for the MF system is shown in Figure 1. The key MF system design parameters for the Hokitika WTP are shown in Table 1.

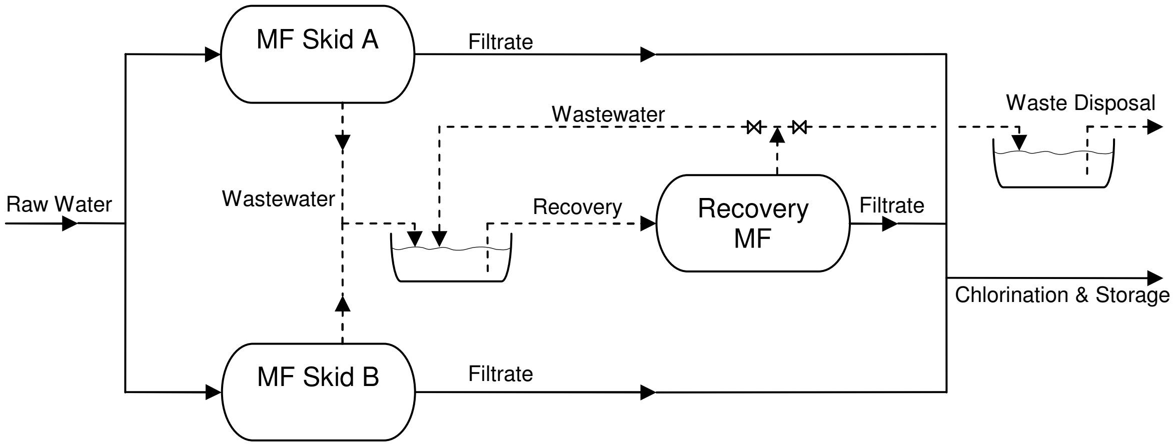

Figure 1: Hokitika WTP, MF process flow diagram

Raw water is supplied to the WTP from Lake Kaniere. The WTP design allows for the addition of water from the Hokitika River in the future to cope with times of peak water demand.

All wastewater from MF Skids A & B is collected in a covered waste sump located within the WTP building. This wastewater includes SASRF as well as chemical waste and rinses from the EFM and CIP processes.

The feed to the Recovery MF skid is taken from the waste sump. Filtrate from the Recovery MF is combined with the filtrate from MF Skids A & B prior to chlorination and treated water storage. The Recovery MF undergoes the same SASRF, EFM and CIP regeneration processes as the primary MF skids. All wastewater from the Recovery MF regeneration processes is returned to the waste sump, essentially concentrating the contaminants within the waste stream contained in the sump. Once the turbidity of the wastewater in the sump reaches 55 NTU, further regeneration wastewater from the Recovery MF will be diverted to the wastewater holding tanks for later collection by road-tanker and disposal at the municipal wastewater treatment plant.

Table 1: MF system operating parameters, design stage

	Primary MF	Recovery MF
Treated Water Capacity MLD	7.0	0.2
Flux Rate (LMH)	100	22
Number of Racks	2	1
Modules per Rack	34	10
SASRF Interval (min)	25	15
EFM Interval (Days)	1	1
CIP Interval (Days)	30	30

The Primary MF stage consists of two Pall Aria AP6 systems. Photograph 1 shows the valve and module racks for MF Skid A. The Recovery MF stage consists of a single Pall Aria AP3 system. Photograph two shows the valve and module racks of the Recovery MF skid. In both cases, spare module spaces were included in the initial phase to allow for future expansion of the WTP capacity.

The estimated design hydraulic balance for the WTP is shown in Table 2.

Table 2: WTP hydraulic balance, design stage

	Daily Volume (m^3/day)			Feedwater Recovery (%)
	Feedwater	Filtrate	Wastewater	
Primary MF System	7,218	7,000	218	97.0
Recovery MF System	218	201	17	92.2
Overall Plant	7,218	7,201	17	99.7

Photograph 1: Pall Aria AP6, MF Skid A

Photograph 2: Pall Aria AP3, Recovery MF

6 OPERATING RESULTS

The Hokitika plant has no redundant trains and is operating during peak demand season at the design capacity. This provides the opportunity to look at operation of the plant as it was designed without the use or availability of back-up resources.

The WTP design was based on limiting wastewater for disposal. Operational trials during commissioning were used to optimise the backwash recovery unit to further improve the feedwater recovery. During the optimisation exercise the following parameters were modified from the initial design expectation shown in Table 1;

- MF Skid A & B - SASRF interval increased to 30 mins
- MF Skid A & B – EFM interval increased to 2 days
- MF Skid A & B - CIP interval increased to 90 days
- Recovery MF - CIP interval increased to 90 days

The WTP feedwater characteristics are relatively consistent; Table 3 shows the WTP feedwater characteristics during May and June 2009.

Table 3: WTP feedwater characteristics

	Range	Average
Temperature (°C)	8.8 – 19.9	13.3
Turbidity	0.04 – 0.40	0.09
pH	6.1 – 6.5	6.3

Figure 2 shows the filtrate flow rate from each MF skid over a typical 24h operating period on 8 March 2009. The average filtrate production rates were 32.2 L/s, 32.0 L/s and 2.7 L/s for MF Skid A, B and the Recovery MF respectively. The plant produced approximately 5,200 m^3 of filtrate on this day; about 70% of the plant peak capacity. MF Skid B undergoes an EFM (no filtrate production) between 10:00 am and 10:51 am; the Recovery MF undergoes an EFM (no filtrate production) between 1:00 pm and 1:40 pm.

Figure 3 shows the feed water turbidity for the Recovery MF system over a typical 24h operating period on 8 March 2009. Figure 4 shows the filtrate turbidity from the Recovery MF system for the same period. The average feed water turbidity for the Recovery MF was >67 NTU (range 25 to >100 NTU). It must be noted that 100 NTU is the maximum scale value for the turbidity instrument, therefore there are some significant periods where the turbidity is >100 NTU. The average filtrate turbidity from the Recovery MF was 0.012 NTU (range 0.012 to 0.023 NTU).

Figure 5 shows the TMP for the Recovery MF system over a typical 24h operating period on 8 March 2009. The Recovery MF undergoes an EFM clean between 1:00 pm and 1:40 pm. The average TMP (excluding RF and any non-production periods) was 28.0 kPa. Prior to the EFM clean, the average TMP was 31.1 kPa; after the EFM clean the average TMP was 24.6 kPa (excluding RF and any non-production periods).

Figure 6 shows the daily filtrate production for each of the MF skids for the period 1/03/2009 to 22/03/2009. Figure 7 shows the waste tank volume for the same period in March 2009. Increases in waste tank volume correspond to wastewater transferred from the Recovery MF. Decreases in waste tank volume correspond to removal of wastewater from the site for off-site disposal.

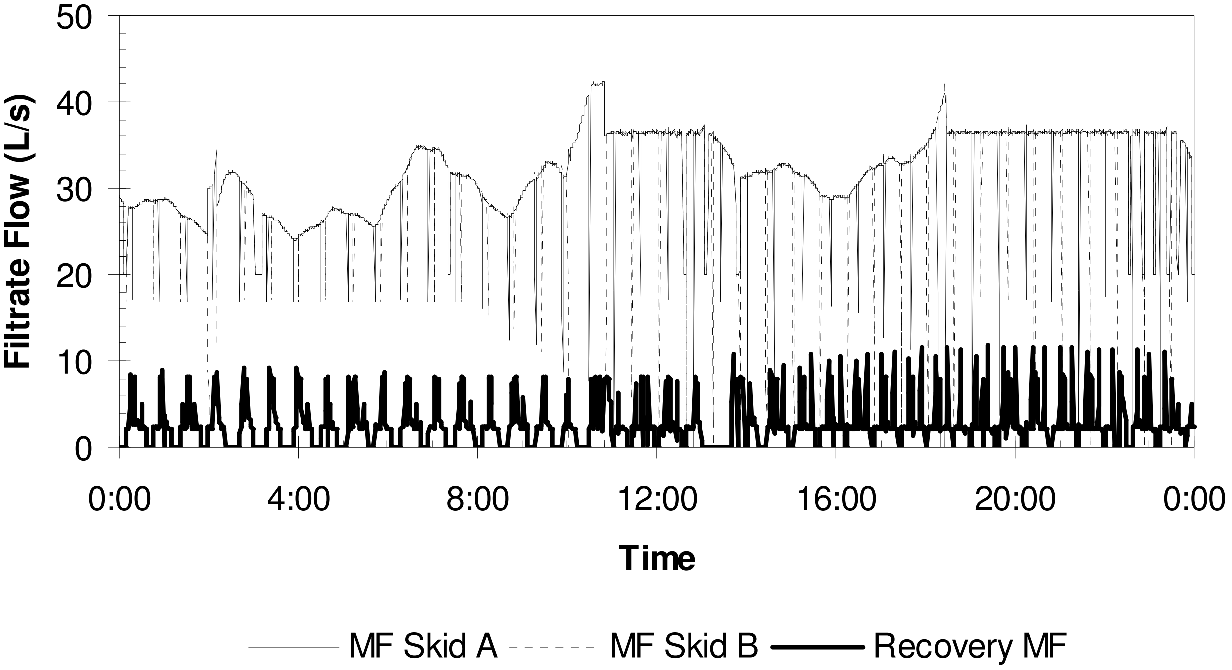

Figure 2: MF skid operating flow rates, 8/03/09

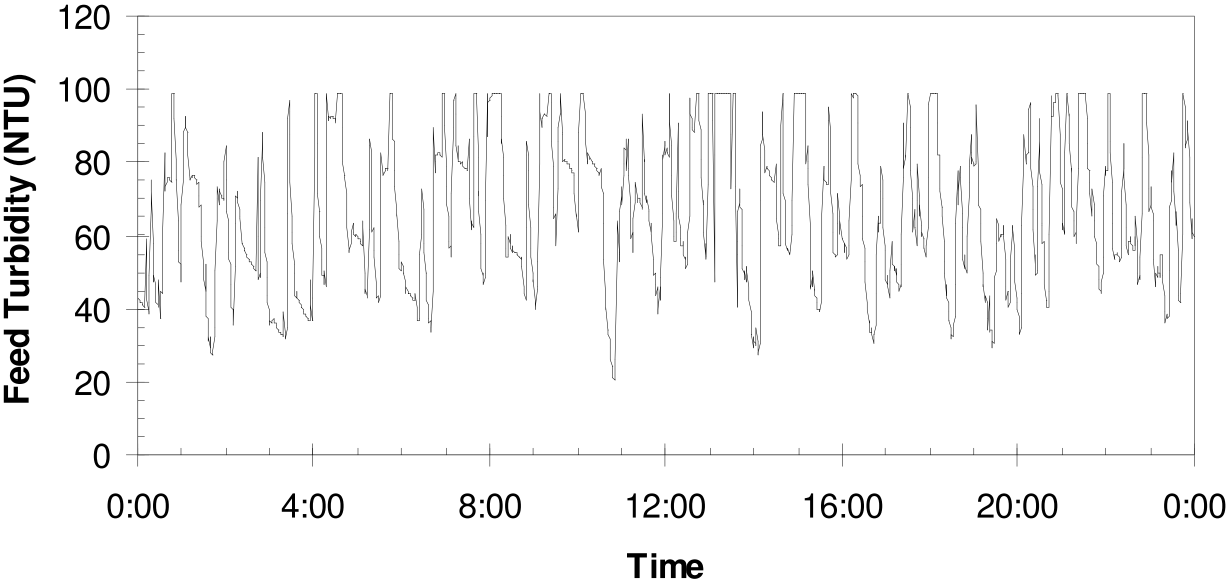

Figure 3: Recovery MF feed water turbidity, 8/03/09

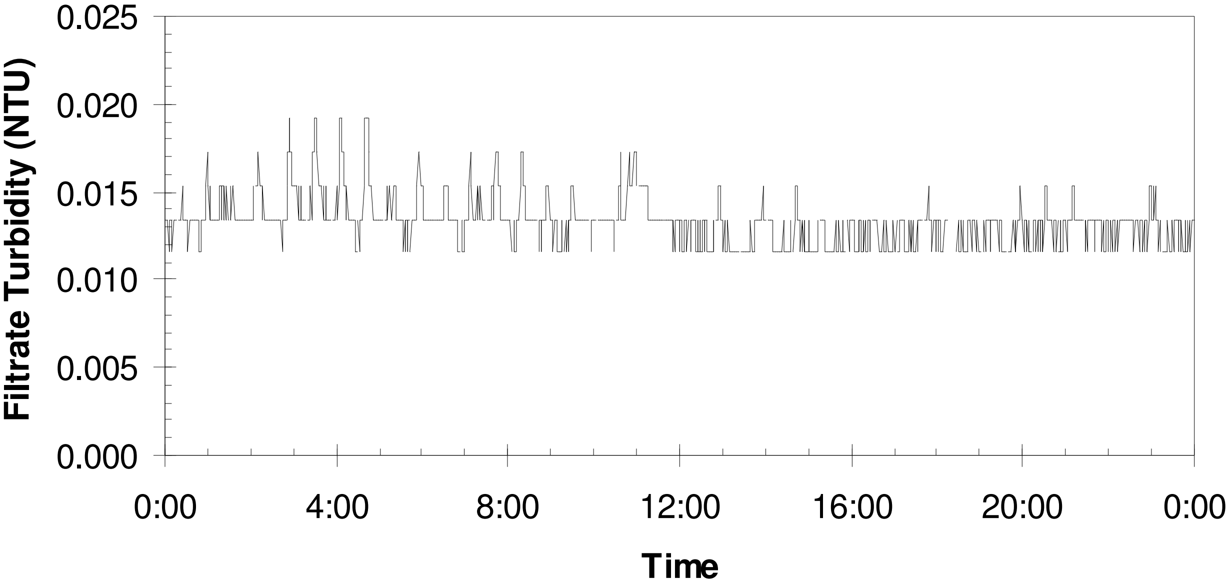

Figure 4: Recovery MF filtrate turbidity, 8/03/09

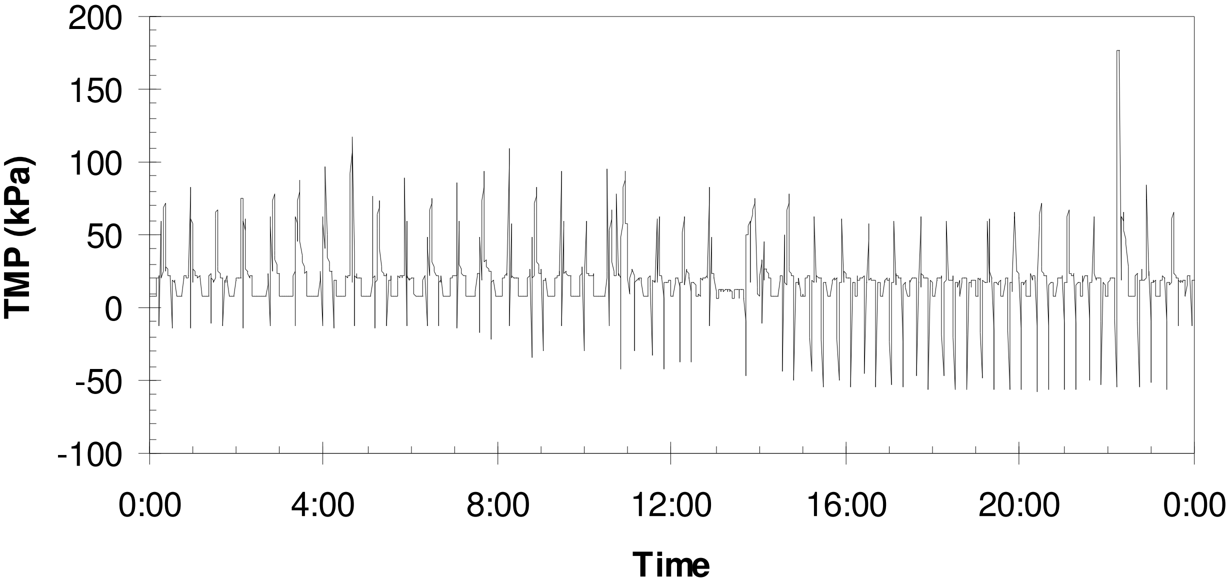

Figure 5: Recovery MF trans-membrane pressure (TMP), 8/03/09

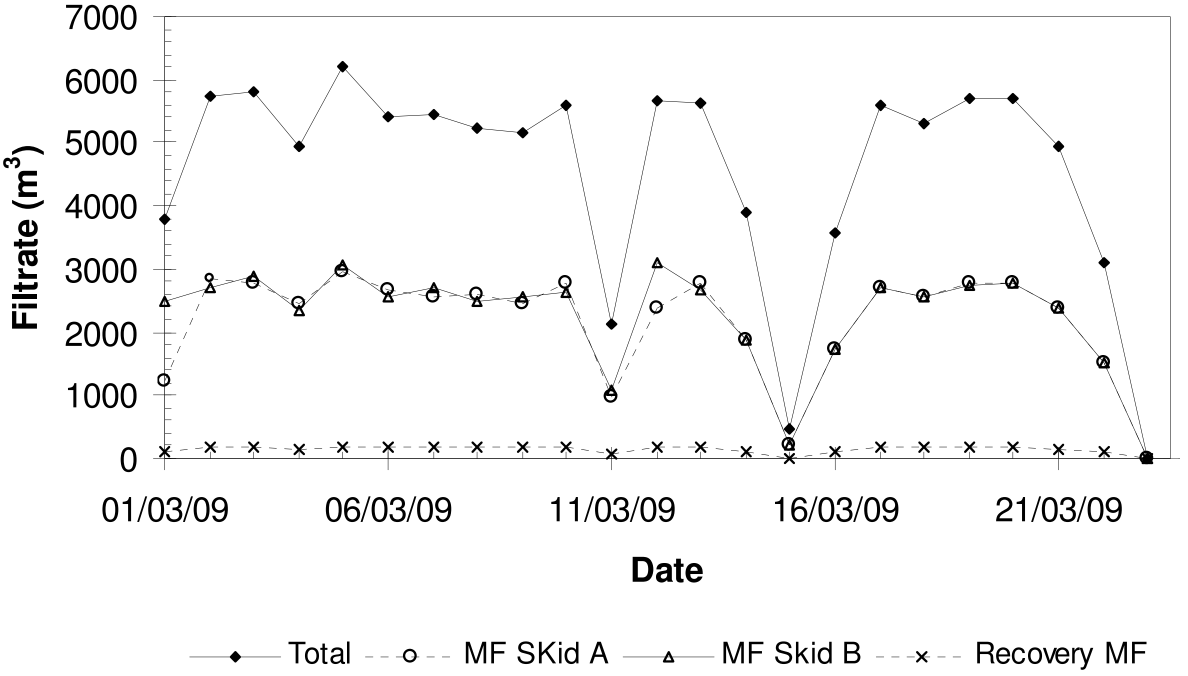

Figure 6: WTP water production, 1/03/09 - 23/03/09

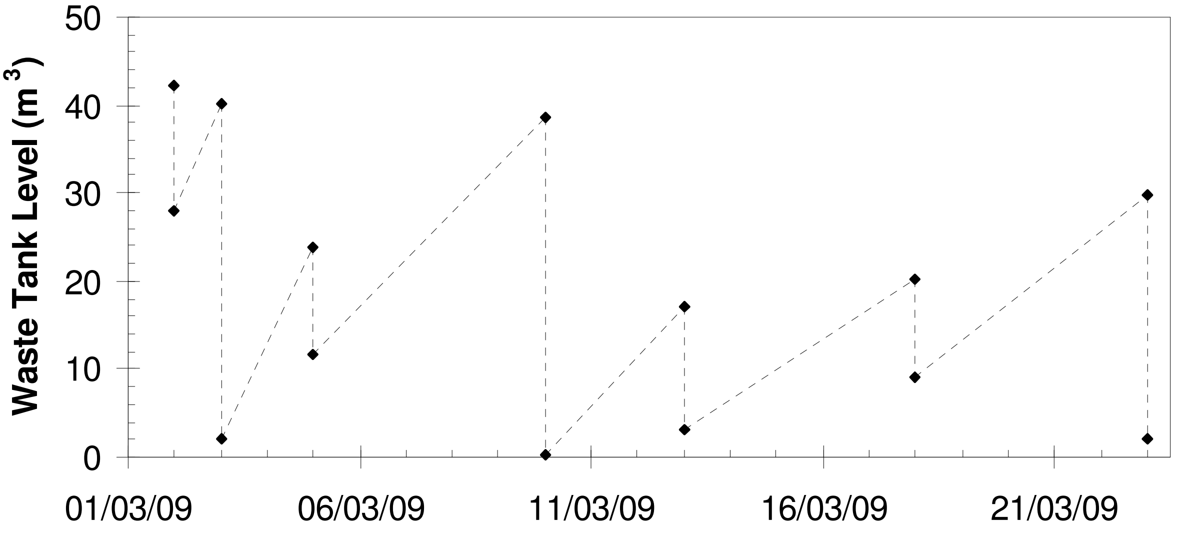

Figure 7: WTP waste tank level, 1/03/09 - 23/03/09

Equation 1 shows the method used to calculate the feedwater recovery for the membrane plant. The filtrate volumes from each MF skid are measured using a magnetic flowmeter installed on each skid. The waste volume for the entire plant is measured using a level transmitter in the waste storage tank. The tank has a working volume of 45 m^3.

Equation 1: MF system feedwater recovery calculation

$$V_{Feedwater} = V_{Filtrate} + V_{Waste}$$

$$R_{Feedwater} = \frac{V_{Filtrate}}{V_{Feedwater}}$$

Where;
V = Volume (m^3)
R = Recovery (%)

Table 4 shows the total filtrate, waste volumes and overall feedwater recovery for the WTP from 3/03/2009 to 23/03/2009.

Table 4: MF system filtrate and wastewater production, 3/03/2009 – 23/03/2009

	Primary MF	Overall Plant
Feedwater (m^3)	95,667	95,667
Filtrate Production (m^3)	92,517	95,552
Waste Production (m^3)	3,150	115
Feedwater Recovery (%)	96.71	99.88

A feedwater recovery of 99.88% would result in the concentration of a contaminant in the wastewater being 833 times greater than that of the feedwater. i.e. $\text{Concentration}_{\text{Wastewater}} = 1X / (1-0.9988) = 833X$, where X is the concentration of contaminant in the feedwater. This ratio assumes complete removal of the particular contaminant by the membrane system. On this basis, with an average feedwater turbidity of 0.09 NTU (Table 3), the theoretical turbidity of the wastewater from the Recovery MF would be 75 NTU (assuming the membranes remove all the turbidity). The results support the theoretical increase in solids loading of the waste stream, with an average wastewater turbidity from the WTP of >67 NTU (Figure 3). The data in Figure 3 only reads to 100 NTU and therefore the 67 NTU average is understated.

Whilst this theoretical calculation can only be used as an approximation, the correlation is amazingly accurate. Turbidity is a measure of light scatter and not a direct correlation of solids loading. What this correlation appears to indicate is that the solids in the water are all similarly sized for the above to equate to the recovery of the system.

The results therefore support an overall recovery of 99.88% based on volumetric analysis along with a crude approximation using turbidity data. The turbidity measurements indicate a corresponding increase in solids concentration in the wastewater produced in excess of 750 times the feedwater concentration.

Based on visual and physical inspection of the final wastewater prior to disposal, the solids removed are primarily organic in origin. The wastewater has a noticeable odour and an extremely “slimy” appearance and feel. The water source is a large lake surrounded by dense native forest with steep topography; the resulting expectation is that the solids delivered in the WTP feedwater would not be significant in size however would be primarily organic- based particulate matter that is not easily gravity-settled. While the turbidity of the feedwater is low by normal standards, the predominantly organic based solids in the feedwater can increase the propensity for organic fouling of the membranes. Inorganic-based inert particulate matter is generally removed by the membrane system without any residual fouling after SASRF.

The design flux of the Recovery MF is akin to that traditionally used for the treatment of secondary effluent which has turbidity in the range of 2 - 5 NTU. In addition, the fouling characteristics of the wastewater sent to the Recovery MF are not dissimilar to a secondary effluent application. However the feedwater to the Recovery MF at Hokitika is concentrated by up to a factor of 10 in comparison to a secondary effluent application.

7 CONCLUSIONS

As a D&C contract, the WDC and Westland Milk Products were presented with a tendered option that used membranes as a means of concentrating waste. This option reduced disposal volumes and ultimately for this plant reduced the costs of waste management. The D&C approach provided this solution where other procurement approaches may not have encouraged this option to be tendered in the design. The competitive D&C procurement methodology adopted by the WDC and Westland Milk Products allowed for innovation by the tenderer and ultimately resulted in the delivery of an extremely high-recovery plant.

The Hokitika WTP has been operating for 15 months with significant periods at or near design production rates. Operating results support the design assumptions and have shown for this feedwater that recoveries approaching 99.9% can be achieved. Based on the nature of the solids in the feedwater compared to a typical river based water source we are confident that similar recoveries could be achieved for river based water sources with significantly higher feed-solids loading.

Based on operating data, the Primary MF at Hokitika is operating relatively conservatively with regeneration sequences occurring less frequently than anticipated during the design phase. Of particular note is that the Recovery MF is operating with TMP consistently lower than half of the normal operating range. This plant operational data indicates that the recoveries being achieved are not only sustainable at Hokitika but would be with feedwater with higher particulate loadings. Whilst the Hokitika feedwater may be considered relatively easy to treat, there is significant room in the operational data to suggest that these recoveries are sustainable with feedwater more heavily laden with particulate matter.

The resulting plant installation is compact, negates the need for an overall settling pond with associated desludging/solids management needs and negated the need to install a costly sewer connection. Often in water treatment plants, solids management is costly and an “unwanted evil”. The approach shown at Hokitika provides a solution where solids management and on-site treatment is removed.

The authors postulate that in the future, this concentrated solids wastewater may be able to be further refined and produced into a saleable value-added product. Such a product may be suitable for fertiliser, or if the mind works hard enough, perhaps as a feed-source for hydroponics growing algae for methanol production? Engineers have throughout time taken many small steps to achieve amazing solutions. The results of the Hokitika WTP with a membrane backwash recovery unit indicates that the use of existing technology can bring us one step closer to achieving the ideal goal of a WTP without waste disposal but rather with all products being useful and profitable.

ACKNOWLEDGEMENTS

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REFERENCES

MOH (2005)
Drinking-Water Standards for New Zealand 2005. Ministry of Health, Wellington. August 2005.