IMPROVING THE EFFLUENT DISCHARGE FROM OXIDATION PONDS IN NEW ZEALAND WITH MEMBRANE POLISHING

S. Towndrow[1], G. Truscott[2], R. Butler[1]
1. Siemens Water Technologies (Memcor Australia Pty. Ltd), Windsor, Australia
2. Mason Engineers Ltd. Auckland, New Zealand

ABSTRACT

Many of New Zealand's Waste Water facilities are faced with the prospect of having to upgrade their existing treatment plants to meet higher influent flows and stricter effluent quality guidelines to obtain resource consent for their effluent discharge. Their challenge is to find innovative solutions that work with their existing plant equipment. Many facilities already use oxidation ponds to reduce the biological loads and suspended solids levels in the effluent, but seasonal variations in flow can have a large impact on the effectiveness of these ponds. Additional filtration is required to improve the solids removal. Traditional water filtration methods, like sand filtration, are not sufficient to meet the stricter guidelines in variable conditions and often require large amounts of space that are not available at existing treatment facilities. Two New Zealand plants, at Hikurangi WWTP and Dunedin Airport, have met this challenge by complementing their oxidation ponds with low-pressure membranes. This paper explores the innovative engineering designs employed to upgrade their existing equipment, and the motivations and results for choosing a low-pressure membrane solution to reduce the impact of the effluent discharge on New Zealand's natural water resources.

KEYWORDS

Membrane filtration, low-pressure membranes, waste water, oxidation ponds, wetlands, trickling filter, faecal coliforms, suspended solids, algae, discharge consent, Hikurangi, Dunedin Airport, design, micro-organisms

1 INTRODUCTION

Oxidation ponds are a widely used method of waste water treatment in New Zealand. They are a proven waste water treatment solution with low capital and operating costs. The low operation and maintenance requirements mean they are particularly suited to treating waste water in small rural communities. However, they can also be used to treat larger flows, Christchurch WWTP being an example.

Many of the pond systems throughout New Zealand have been in use for a long time. As communities have grown, these assets are required to treat increasing volumes of waste water whilst also meeting more stringent effluent quality consent conditions. This poses a challenge for local authorities, particularly in small or remote communities; how to meet more stringent effluent discharge standards and can existing assets be utilised?

There are a range of technologies which can be used to increase the capacity of oxidation pond systems and to improve the final effluent quality. Low-pressure membrane filtration is one such technology and has already been applied to a number of pond systems in New Zealand. This paper examines membrane filtration technology and its application to pond systems.

.

2 OXIDATION PONDS AND MEMBRANE FILTRATION

2.1 MEMBRANE FILTRATION OVERVIEW

Over the past 20 years, membrane technology and manufacturing processes have advanced significantly. Where membrane filtration was once confined to niche applications, this technology is now competitive with comparable conventional technologies and can provide significant operational and performance advantages. Figure 1 shows how the installed capacity of low pressure membrane systems has increased globally since 1990.

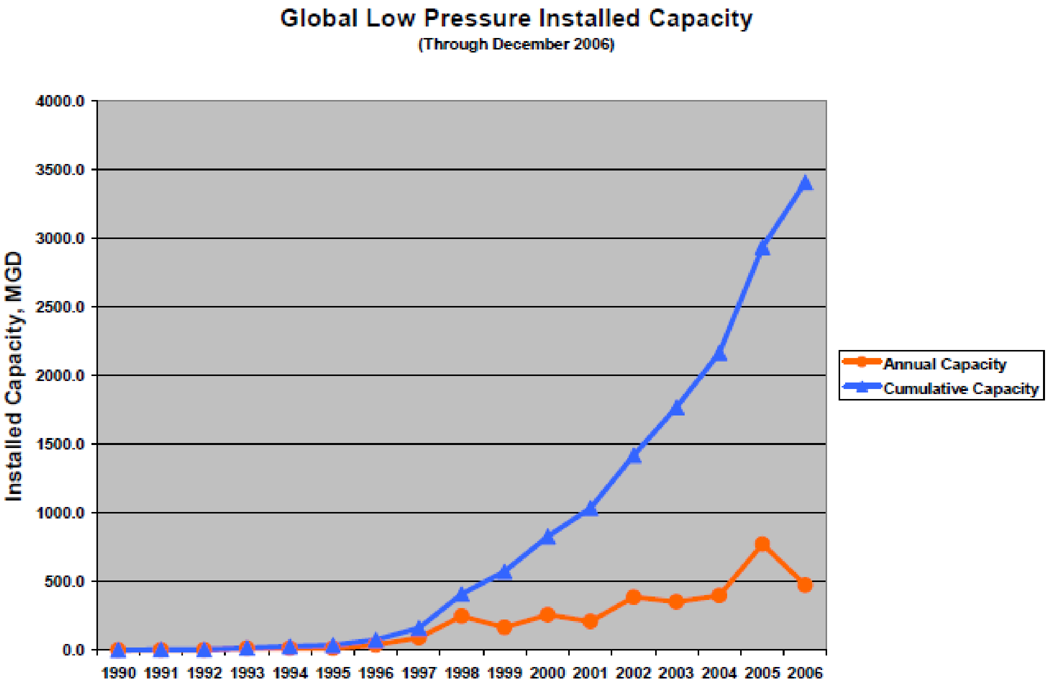
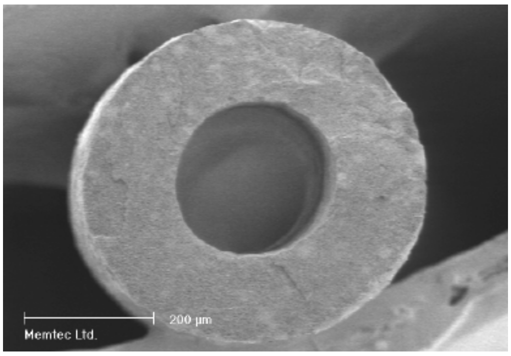
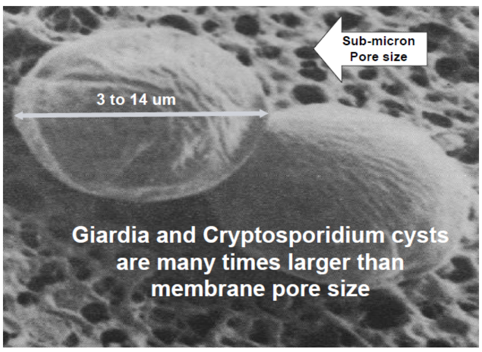


Figure 1 - Global low pressure membrane installed capacity (2)

The mechanism by which membrane filtration removes suspended solids is very different to those at work in traditional treatment systems. The pores in the membrane fibres are so fine that the membrane presents a complete barrier to micro-organisms and particles and hence membrane systems produce a consistent filtrate quality independent of a number of feed water parameters. Photographs 1 and 2 below show the hollow membrane fibre and pore size relative to giardia and cryptosporidium cysts.



Photograph 1: A slice through a hollow fibre membrane



Photograph 2: Close-up of Giardia and Cryptosporidium cysts on the surface of a membrane fibre

Membrane Filters remove solids at their surface to form a filter cake, irrespective of the nature of the solids removed. The membrane is a positive barrier to contaminants and in waste water treatment, coagulation is typically not required.

Media filters remove solids throughout the filter bed and rely on attractive forces far more than "sieving" effects

Clarification devices rely on chemical addition to form large flocs that can be readily separated by gravity.

Both media filters and clarification devices are susceptible to process upsets which result in variable and inconsistent effluent quality over time. Membrane filtration however, has the ability to produce consistent high quality filtrate, independent of variable feed parameters. Figure 2 shows the typical performance of a membrane filter during a turbidity event and is one of the reasons this technology continues to grow in popularity across all sectors of the water industry; drinking water, waste water polishing, waste water recycling and indirect potable reuse and as pre-treatment in seawater desalination applications.

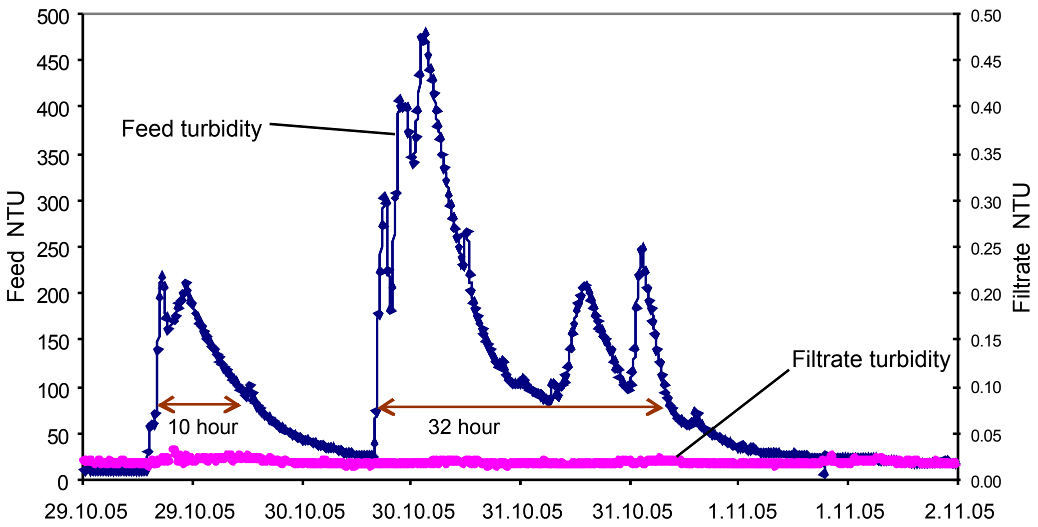


Figure 2 - Membrane Filter typical performance during turbidity events (3)

2.2 APPLICATION TO OXIDATION POND SYSTEMS

Oxidation ponds are passive systems which rely on natural processes for breakdown and removal of nutrients and organic pollutants. Combining multistage ponds with aeration lagoons and wetlands can further improve effluent quality through natural filtration and UV disinfection. These systems have been popular in New Zealand and around the world for many years, one of the key reasons being their low operating cost.

Many of New Zealand's pond systems have been operating successfully for decades. As populations grow however and influent flow and biological loading increases, many of these systems will begin to struggle to maintain consistent effluent quality. Pond systems rely largely on detention time for the natural oxidation and nutrient removal processes to work. This makes their treatment performance susceptible to storm water flows, particularly when already operating under increased effluent flow and loading rates.

While New Zealand does not have any national effluent quality standards, the Resource Management Act (1991) requires that adverse environmental effects are avoided, remedied or mitigated, and that the life supporting capacity of ecosystems is sustained. Through recognition that significant degradation of natural water bodies from diffuse sources of agricultural run off has occurred, strong environmental, social and cultural drivers mean that new effluent consent requirements are increasingly demanding while fewer excursions are being permitted. This creates a challenge for local authorities; how can they increase plant capacity and improve treatment quality whilst ensuring that the process is robust enough to withstand process upsets without consent excursions?

Dunedin International Airport and Whangarei District Council (Hikurangi WWTP) have both faced this issue. Their adopted solutions are discussed below.

2.2.1 DUNEDIN INTERNATIONAL AIRPORT

Dunedin International Airport operates a small waste water treatment plant which treats waste water from the airport and a nearby cluster of residential dwellings. The plant was required to comply with a new discharge consent which came into effect at the end of June 2007. This consent has a 20 year term and requires the plant meet a higher discharge quality standard. The consent conditions are outlined in Table 1 below.

Criteria	Value	Units	Compliance Level
BOD	10	mg/L	12-month geometric mean. Not to be exceeded
TSS	10	mg/L	12-month geometric mean. Not to be exceeded
NH3	10	mg/L	12-month geometric mean. Not to be exceeded
Total P	8	mg/L	12-month geometric mean. Not to be exceeded
Faecal Coliforms	260	MPN/100mL	90 percentile. Not to be exceeded.

Table 1: Consent Conditions, Dunedin International Airport

The existing treatment consisted of an Imhoff tank for primary settlement of solids followed by a 4-stage pond system. To meet the new biological and nutrient removal standards, the biological capacity of the plant needed to be improved. This was achieved with the installation of a trickling filter down stream of the Imhoff tank to reduce the biological load onto the pond system, enabling the biological and nutrient removal requirements to be achieved.

To ensure that the suspended solids and faecal coliform discharge requirements could be achieved, a low pressure membrane filter was then selected in an effluent polishing role. As a complete barrier to particulates down to microbial size, the membrane system provided surety that suspended solids and faecal coliform levels would be achieved irrespective of process upsets such as algal blooms or solids wash out through heavy rainfall.

The membrane filtration system is housed in a small building adjacent to the oxidation pond system and draws effluent from a sump in the final pond. The building also contains the ancillary equipment required to operate the filtration system. Effluent is drawn from the pond into the filtration system and the filtrate is discharged into the Main Drain culvert which feeds Lake Waipori. All rejected particulates are returned under gravity to the trickling filter recycle pump station during the membrane filter backwash process.

Since commissioning, the membrane filtration system has maintained effluent suspended solids and faecal coliform concentrations at a consistent level, significantly below the consent requirements of 10 mg/L and 260 mpn/100mL respectively (refer to Figure 3).

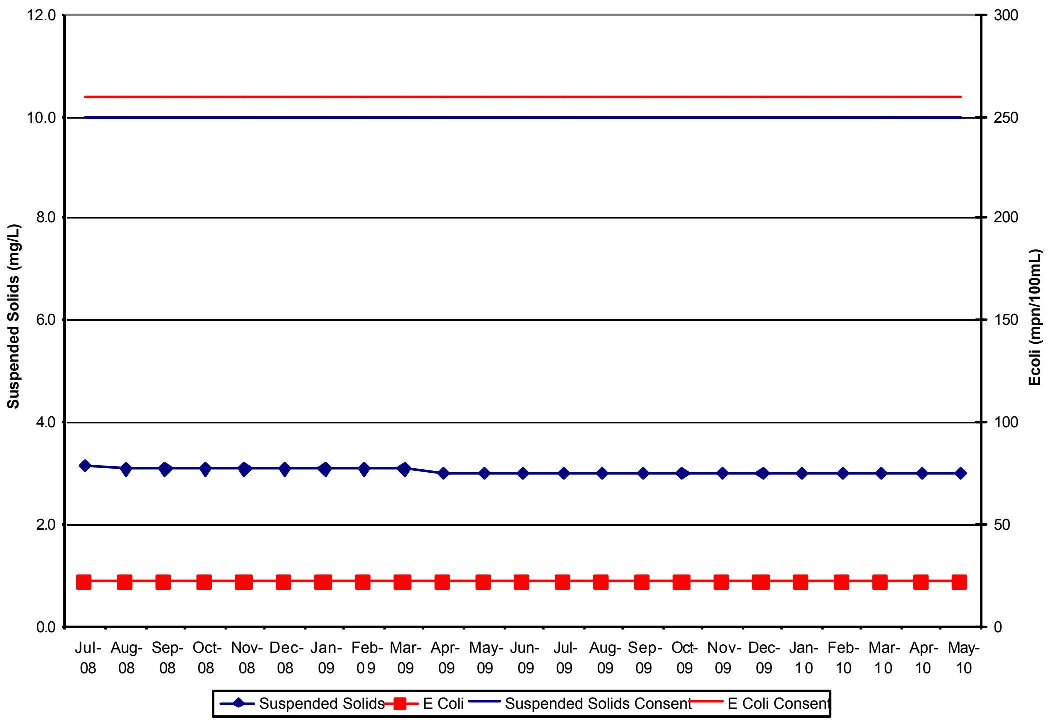


Figure 3: Dunedin Airport WWTP Effluent Suspended Solids and EColi Sample Results

2.2.2 HIKURANGI WWTP

Hikurangi WWTP is another oxidation pond system which utilises membrane filtration as the final effluent treatment stage. As with Dunedin International Airport, the reason for selection is the high degree of suspended solids and bacterial removal which can be achieved with a single stage process.

Hikurangi WWTP is located approximately 10 km north of Whangarei and is operated by Whangarei District Council. The plant is located in a rural area receiving primarily domestic influent flows which increase significantly during wet weather periods through storm water infiltration. To meet the conditions of a new discharge consent, the plant was upgraded in 2008. The membrane filtration plant is required to meet the standards as set out in Table 2 below.

Parameter	Max. allowable median concentration for flows less than 10.5 L/s	Max. allowable 90th percentile concentration for flows up to 1200 m^3/d (13.9 L/s)
BOD_5 (mg/L)	10	20
TSS (mg/L)	10	20
Faecal Coliform (cfu/100mL)	200	500

Table 2: Hikurangi Effluent Polishing Plant Discharge Requirements

The plant consists of a primary pond, a secondary oxidation pond fitted with surface aerators and a wetland. As part of the upgrade, in addition to increasing plant biological and hydraulic capacity, a membrane polishing plant was installed to ensure consent compliance with respect to suspended solids and micro-organisms.

The membrane filtration system is located in a building between the primary pond and the wetland and is fed from a pump station located after the wetland. Prior to filtration, the feed passes through two 400µn parallel strainers which remove any coarse material or particulates that might damage the membrane fibre.

During filtration, rejected particulates accumulate on the membrane surface. These solids are removed periodically during the backwash process and drained by gravity back to the primary pond. The filtered effluent is pumped to a filtrate storage tank from which it then flows under gravity to the point of discharge. The filtrate storage tank supplies the water used by the membrane filter during the backwash and chemical cleaning processes.

Figures 4 and 5 show sampling results for the membrane filtration plant feed water quality and final effluent discharge quality over a 6 month period. Figure 4 shows that suspended solids in the final effluent are consistently at or below 2 mg/L, irrespective of the feed water suspended solids concentration. Similarly, BOD_5 is consistently below the consent requirement. As the membrane filter can only remove particulates, the difference between inlet and outlet BOD_5 concentrations is all associated with filterable organic solids. Dissolved organics will pass through the membrane. Figure 5 shows the membrane filter feed water and final effluent faecal coliform sampling results. It shows that faecal coliforms are consistently approaching limit of detection and two orders of magnitude below the maximum median consent limit of 200 cfu/100mL. As discussed previously, the reason for this is that faecal coliforms are larger than the membrane pore size; they are filterable and therefore retained at the membrane surface.

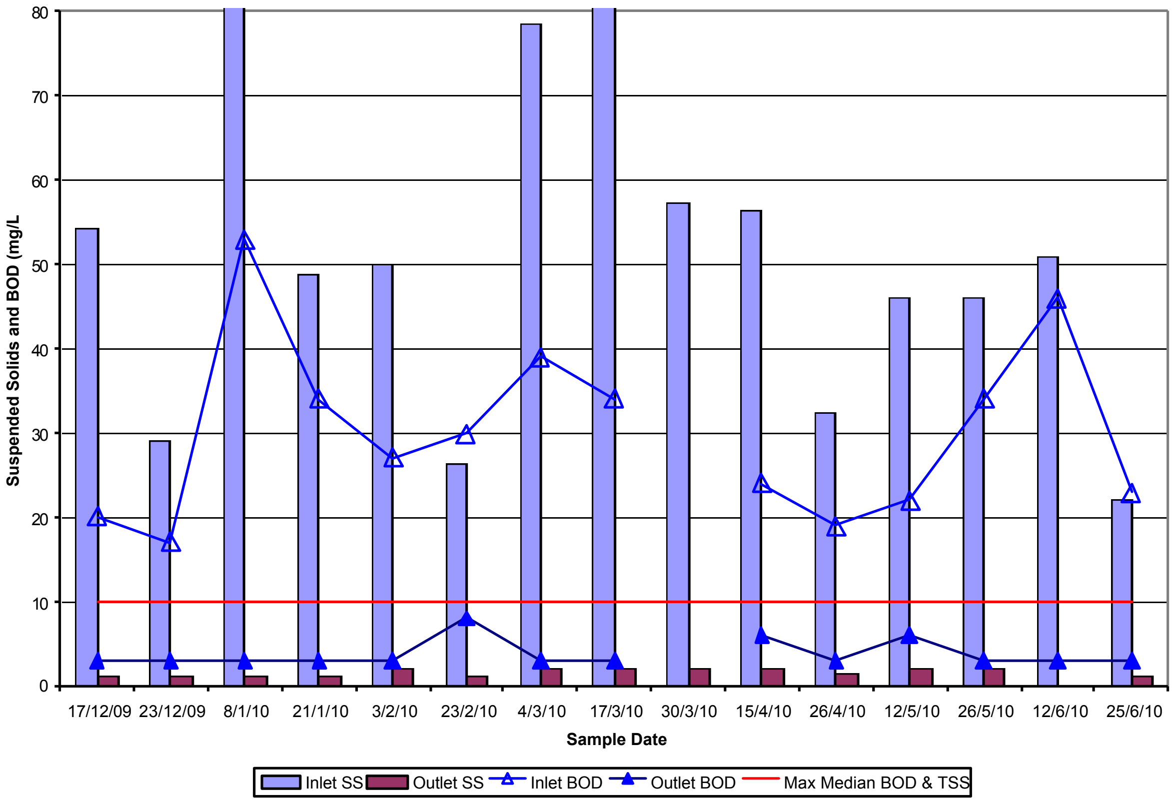


Figure 4: Hikurangi WWTP Suspended Solids and BOD_5 Sampling Results

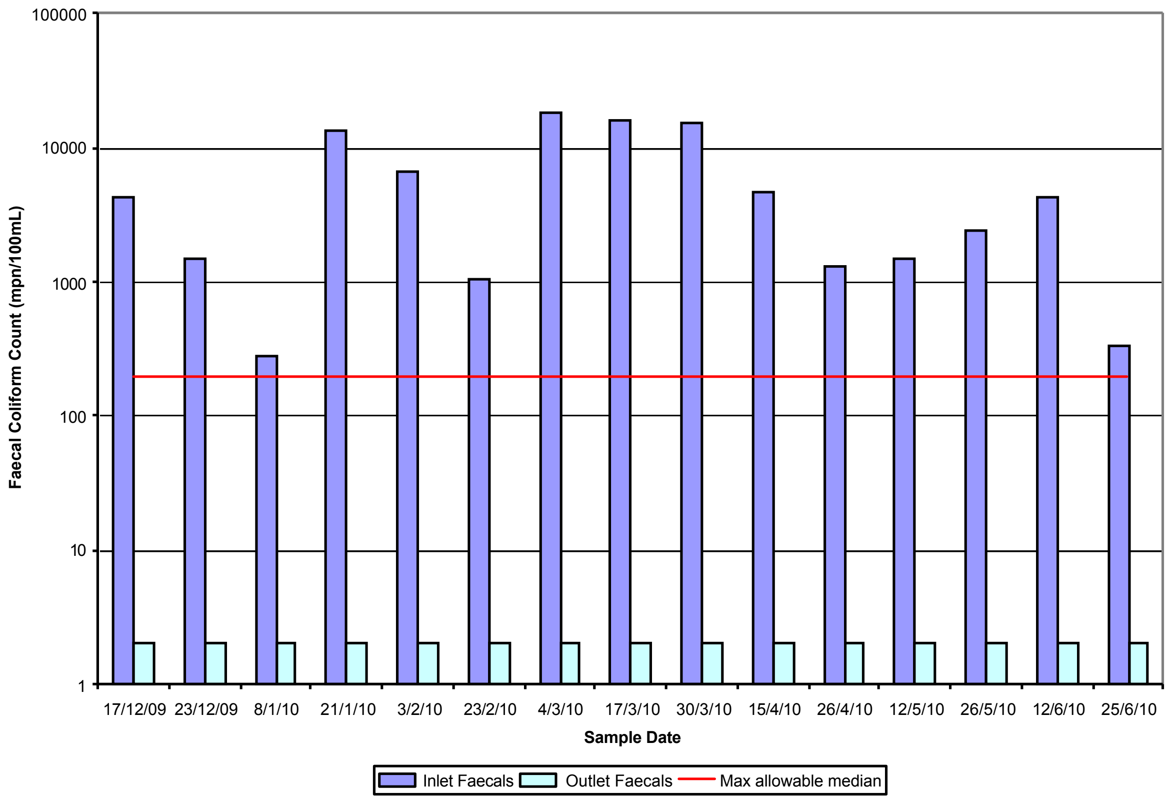


Figure 5: Hikurangi WWTP Faecal Coliform Sampling Results

2.3 MEMBRANE SYSTEM OPERATION

The driving force for producing filtrate is the Trans-Membrane Pressure (TMP). TMP is the differential pressure between the feed side and filtrate side of the membrane. This driving force is usually provided by a pump. A positive pressure is required for pressure driven membrane systems, whereas a vacuum (negative pressure) is require for immersed (or submerged) membrane systems.

A linear relationship exists between TMP and the filtrate flow rate (and equally the filtrate flux). Water temperature affects the TMP required for filtration as a result of the water viscosity. For a fixed TMP, higher temperatures will result in a higher flow, or at a fixed flow, a higher temperature will require a lower TMP.

As an absolute barrier to particulates, a filter cake develops on the membrane surface during filtration operation. This cake increases the resistance to filtration flow and will be seen as an increased TMP for a constant filtration flow. Through the backwash process it is periodically removed and the TMP will be reduced. Low-pressure membrane systems typically operate with a TMP range of 20 – 100 kPa.

During a backwash, filtration flow is stopped. Low pressure air is used to scour the membrane surface and at the same time a reverse flush takes place, washing the filter cake from the membrane fibre. This procedure typically lasts 60 seconds at the end of which, the backwash liquid containing all the removed suspended solids is drained from the membrane system. In waste water pond applications, it is common for the backwash waste to be returned to the primary pond. The overall backwash down time is 2-3 minutes, after which, the system returns to filtration. In waste water applications, filtration intervals can vary between 10 and 45 minutes depending on the feed solids load.

Over time, organic and inorganic fouling accumulates at the membrane surface which is not entirely removed during the backwash step. To overcome this, periodic chemical cleans are required. The clean-in-place (CIP) cycles typically use chlorine or acid to dissolve the fouling and return the membrane to its clean condition. The CIP process can last 3-6 hours. Therefore, to keep the frequency to a minimum, maintenance washes (MW) are also employed. A maintenance wash is similar to a CIP only the duration is shorter (typically 45 minutes) and the chemical concentrations are lower. A typical membrane filtration cycle between CIPs is shown in Figure 6.

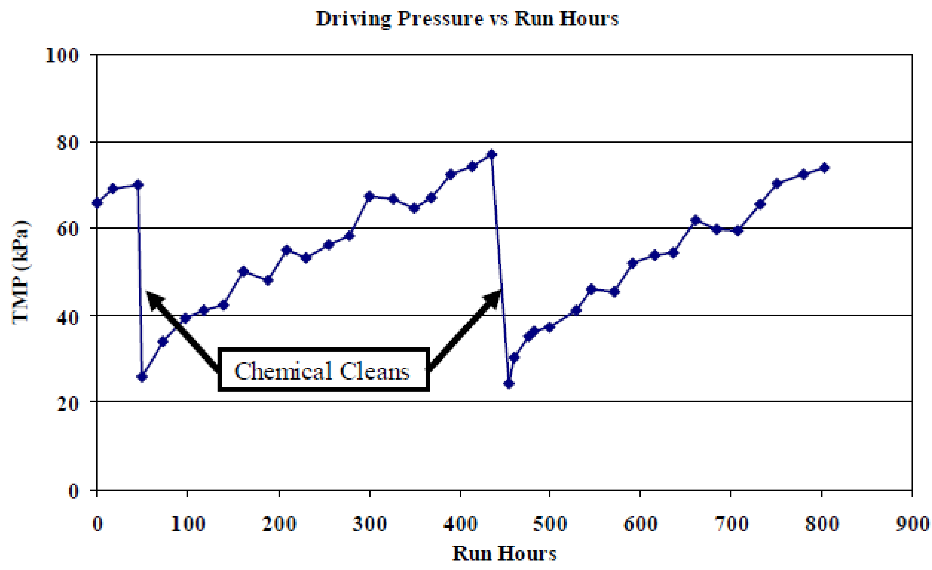


Figure 6: Typical Membrane Filtration Operating Profile between Chemical Cleans (3)

In addition to automatic cleaning operations, low pressure hollow fibre membrane systems can automatically test the system integrity through a pressure decay test. This pressure decay test can be used to calculate a cryptosporidium log reduction value (LRV). The test is highly sensitive and can measure defects as small as 3 microns. It not only provides the operator with a means to measure and track the system performance and plan maintenance, but in the case of an effluent polishing application, it also provides confidence that the system is meeting consent with regard to filterable particulates and organisms.

2.4 DESIGN CONSIDERATIONS

When reviewing membrane filtration as part of an upgrade to waste water pond systems, there are a number of key process and operational issues which should be considered:

Membrane System Feed Characterisation: The membrane will remove suspended solids and colloidal matter from the effluent. The Feed Fouling Index (FFI) is a test used to quantify the fouling impact of these materials on the membrane system. The FFI test is very similar to the Silt Density Index (SDI) test used to quantify the amount of silt and its impact on a reverse osmosis system. Detailed design of a low-pressure membrane system design should consider: the feed water FFI; water temperature variation; variability in feed water quality (such as seasonal algae events, turbidity spikes due to effects of heavy rain); and if there are any flow rate variations over the seasons.

Of these parameters, a key determinant in the sizing of the plant is the concentration and nature of suspended solids in the feed stream. Particularly important in sizing for an effluent polishing application is algae. Waste water high in algae will have a high FFI reading.

Membrane filters are very effective in removing algae and many membrane plants operate with a seasonal challenge which is fully rejected with a manageable level of fouling. However, the impact of algae on a membrane filter is significant. Algae forms a highly compressible filter cake which is resistant to flow. It is readily removed in the backwash process however will generally result in much shorter filtration cycles during periods when algae numbers are high.

Membrane Filter Feed System: Filtration operation is halted during cleaning processes. During chemical cleaning, the filter will be offline for between 1 and 6 hours. When operating with a single membrane filtration system, this operational characteristic needs to be considered in the design of the feed system. The buffer capacity offered within pond systems can be used to readily address this issue.

Designers should also consider membrane system pre-screening requirements. Fine screening to less than 500µn is required to protect the membranes from particulates which might otherwise cause damage during filtration or backwash operations. An effective coarse filtration system on the outlet of the pond or wetland system should also be considered to prevent grass and weeds from entering the feed system and blinding the pre-screens. If the membrane plant is fed from a wet well, ensure that it is covered to minimise growth of duckweed or algae.

Backwash Waste: Following a backwash to remove accumulated solids, the backwash waste needs to be drained from the membrane filtration system. In pond applications it is commonly returned to plant inlet or the primary treatment pond removing the need for a separate solids handling system. In small or single pond systems, it is important to ensure that the backwash waste is returned to the treatment process in such a way that short circuiting cannot occur.

Maintenance Wash: Periodically, the filtrate flow is stopped and a dilute chlorinated or acidic solution is injected into the membrane system and recirculated briefly. The maintenance wash dissolves organic and inorganic build-up on the membrane surface that is not removed entirely during backwashing. This can occur every 24 to 48 hours and is only 30-45 minutes in duration.

CIP: The CIP process consists of recirculating a dilute sodium hypochlorite or acidic solution through the membrane system and allows sufficient time (typically 3 to 6 hours) and chemical solution strength to remove all the foulants (whether they are organic or inorganic) from the surface of the membrane. For waste water applications, the CIP process consists of a chlorine clean followed by an acid clean. Typical concentrations of the cleaning solutions are 500 ppm of sodium hypochlorite and 0.5% citric acid, adjusted to a pH of 2.0 with a mineral acid such as sulphuric acid. Once the clean is complete, the waste chemical solution is commonly returned to the plant inlet or primary pond.

3 CONCLUSIONS

Low-pressure membranes utilised in effluent polishing roles, have demonstrated their ability to provide consistent effluent quality, independent of a number of feed water parameters. This characteristic makes them particularly suitable to applications with stringent discharge consent conditions which require consistently low suspended solids and microbial contaminant concentrations. In a single stage process, membrane filtration is able to achieve an effluent quality that would require multiple stages if using alternate and more traditional technologies.

Some of the key considerations when applying this technology include:

- Utilise the inherent buffering capacity of the pond system and design the membrane filtration system for average flow conditions.

- Clearly define feed water parameters, with particular regard to suspended solids and algae. Accurately establishing baseline and peak conditions will ensure that the membrane filtration system is not undersized and can maintain stable hydraulic performance under event conditions.

- Dissolved contaminants will not be removed by low-pressure membranes. Biological load and nutrient removal must be addressed with upstream treatment processes.

- Backwash and chemical cleaning waste is commonly returned to the plant head works or primary pond, removing the need for a dedicated treatment and disposal system. If taking this approach, ensure the pond system has sufficient capacity to accept this waste load without compromising performance.

ACKNOWLEDGEMENTS

The authors wish to thank Whangarei District Council and Dunedin International Airport Limited for provision of operating data from their respective waste water treatment plants.

REFERENCES

1. Australian and New Zealand Environment and Conservation Council (2000). Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 1

2. Furukawa, David H. (2008). A Global Perspective of Low Pressure Membranes, National Water Research Institute

3. Layson, Andrew. (2009). Introduction and application of advanced water treatment with membrane filtration in Europe, Australia and NZ, Water Institute of South Australia Conference (WISA) 2009

4. Layson, Andrew. (2010). Membrane Filtration – Current Know-how and Future Directions. Water Institute of South Australia Conference (WISA) 2010

5. Macdonald G, French C and Crosby C (2008). New Zealand Wastewater Utilities – the Path to Energy Sustainability under New Government Policies. WEFTEC 08