LOW ENERGY MBR SYSTEMS – IMPLICATION FOR NEW ZEALAND WASTEWATER DESIGN

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ABSTRACT

The high quality product water produced by Membrane Bioreactor (MBR) systems has lead to it being increasingly adopted as a technology of choice in wastewater treatment and water reuse. For MBR systems, energy requirements are of primary interest; in particular aeration energy as it is the largest consumer of energy in the membrane treatment stage of the process.

Recent developments in low energy consumption for MBR design have further enhanced the technology as a relevant stand alone treatment. One development of note is the MemPulse system which has reduced air scour by 60% and total membrane system energy usage by up to 50%. This advance in reduced air consumption, coupled with the market trend for reduced capital costs, continues to increase the viability of MBR on a whole of life cost analysis. This paper reviews the design of MemPulse and operating plants with particular relevance to the NZ market.

KEYWORDS

Membrane Bioreactor, Energy, Membrane Scour Aeration

1 INTRODUCTION

The use of energy is inherent in the production of drinking water and the treatment of wastewater. In New Zealand, a 2004 study by New Plymouth District Council found that wastewater related assets were the major consumer of energy for assets owned by the Council (Macdonald, French, & Caroline, 2008).

New Zealand as a water market uses less energy per capita Australia; with the usage per capita being 40% less for major water markets (Kenway et al., 2008). While some of this difference may be related to population size, density and local topography, New Zealand has strong cultural, environmental & economic drivers to pursue sustainability. These have manifested themselves in various forms of legislation for the protection of the environment including the Resources Management Act (RMA) which emphasises sustainable use of resources and an effects based control approach to activities which impact the environment (Macdonald, French, & Caroline, 2008).

In Wastewater Treatment (WWT) these drivers often result in tighter regulation of discharges from treatment plants, driven by the nature of receiving waters or proposed usage of any recycled water. This translates to a requirement for a treatment process that can reliably and consistently meet the required effluent quality.

The drivers for the adoption of Membrane Bioreactor (MBR) technology have been well documented and include: stable high quality effluent; water reuse; reduced footprint and the elimination of a process unit when compared to Conventional Activated Sludge (CAS) treatment. (Daigger, Lozier, Crawford 2006, DeCarolis & Samer, 2007, DeCarolis et al., 2009, Drews, & Kraume, 2005, Melina, et al., 2006)

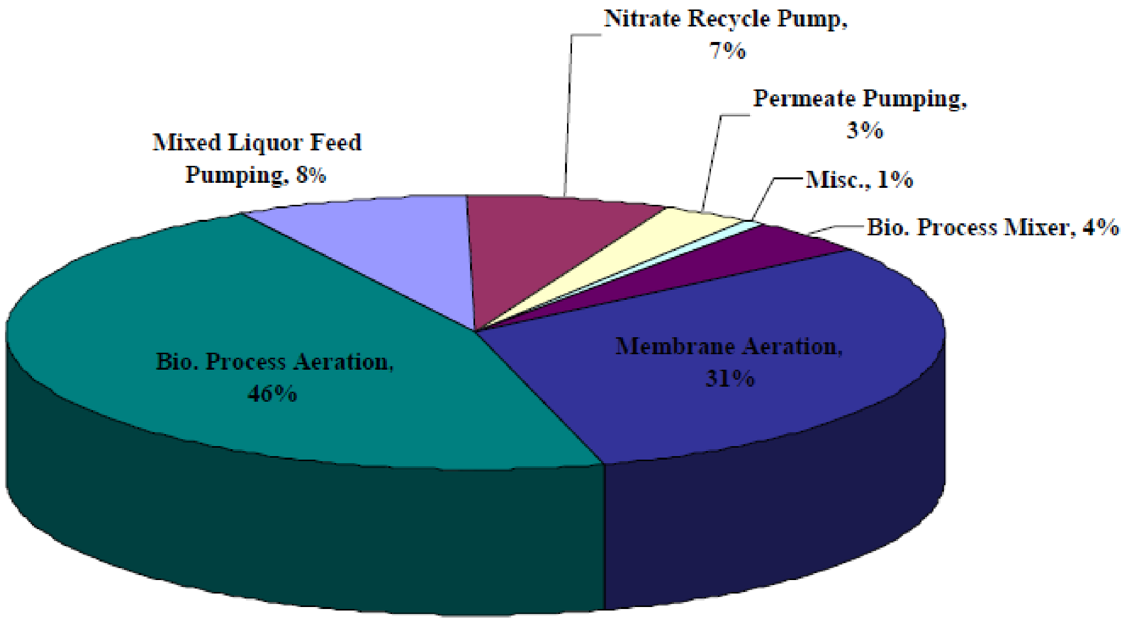
In has long been recognized that while the quality of the product water from an MBR system is a great benefit in the treatment of waste water, there is an increase in energy associated with MBR when compared to CAS. For advanced Biological Nutrient Removal (BNR) this difference is smaller as all treatment processes use more energy (Sen et al., 2008).

2 SLUG FLOW AIR SCOURING OF HOLLOW FIBER MEMBRANES

2.1 AIR SCOUR IN MBR SYSTEMS

For MBR systems, energy requirements are of primary interest. As shown in Figure 1, aeration energy is the largest consumer of energy on an MBR system. Aeration energy is used to both provide oxygen for biological nutrient removal, and scouring of membranes to control fouling.

Figure 1: Typical break-up of energy usage in an MBR system



Biological aeration can be optimized with automated Dissolved Oxygen (DO) control & effluent ammonia monitoring (Sen et al., 2008). However this optimization is limited to the control of excess DO, as most of the oxygen provided to the biological process is required for biological respiration.

In contrast, there is significant scope to reduce aeration energy used to manage membrane condition. MBR suppliers and universities are avidly researching the optimization of membrane air scour energy. As a result, various innovations have been brought to market over the past 10 years to decrease the air scour energy required in an MBR system. Air rates have dropped by 75% from 1.2 m^3air/m^3filtered to 0.3 m^3air/m^3filtered. (Judd, 2006)

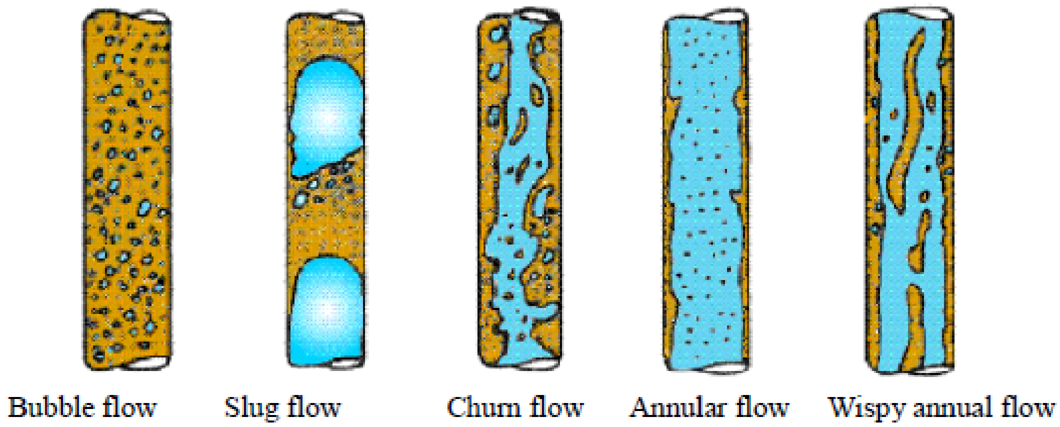
2.2 AIR SCOUR CONFGIGURATIONS IN MBR

Air scour energy in an MBR system gives high levels of turbulence at the membrane surface to remove solids particles that attach to the membrane. This maintains operating flux rates and guards against irreversible membrane fouling. Membrane fouling can cause reduced production capacity, shorten membrane life, and increases operational cost.

The use of two-phase (air and liquid) cross-flow has shown 20-60% performance improvement compared to operation with single-phase (liquid only) cross-flow (Kang et al., 2008).

Depending on the air and liquid flow rates and the properties of the liquid, the mixture of air-liquid can adopt a wide spectrum of flow patterns (figure 2). However, in MBR systems where the applied air flow rates are relatively low, the most likely flow regimes are bubble flow and slug flow (also known as plug flow)

Figure 2: Air-liquid flow patterns in a column (Cui et, al, 2003)



Slug air flow has been studied extensively through a tubular membrane. These studies have shown slug flow to provide the most effective air-liquid flow to maintain operating flows in the membrane systems studied. Slug or plug flow provides maximum efficiency due to three major factors (Judd, 2006):

- The moving bubbles generate secondary flows behind the initial bubble that assist in breaking up cake layers and subsequently promote local mixing near the membrane surface.

- A liquid film around the outside of the bubble can be a high shear region, promoting the movement of solids away from the membrane surface.

- The moving slugs result in pulsing pressure in the liquid around it, causing instability and disturbance near the membrane surface.

The outcome: by utilizing slug flow, an MBR system can require significantly less air for the same scouring efficiency. An immersed hollow fibre environment is different to a tubular membrane, air is introduced from the outside and there is lateral fibre movement. To date immersed systems have not harnessed the potential of slug flow and instead have continued to use bubble flow (with it's inherent high air demand) but have looked at ways to reduce aeration such as intermittent aeration (Judd, 2006).

2.3 PULSING SLUG FLOW MBR

In contrast to other MBR systems, the MemPulse membrane system uses the slug/plug flow regime to minimise air, and hence power consumption. The system is supplied with a continuous air supply that is accumulated in the base of the module (Photograph 1). It periodically releases irregular pulses of air to the MBR module, creating slug flow.

The slug flow generated by the MemPulse MBR system acts as an airlift pump, drawing mixed liquor from below the device through a suction pipe and into the module. The liquid helps to prevent solids accumulation as the mixed liquor on the membrane is continuously refreshed with new liquor.

Photograph 1: Rack of MBR Membranes with pulsed flow device below each module

2.4 ENERGY USAGE

The major difference between the MemPulse MBR system over traditional MBR systems is that the air supply to the system is up to 60% lower. Compared to a similar system with bubble flow regime, a comparable performance is achieved with half of the energy requirement.

This is shown in Table 1 where energy required for a typical 20MLD MBR system was reduced by 48% over a traditional MBR system:

Table 1: Comparison on continuous bubbling and plug flow for membrane air scour

Equipment	Continuous Bubbling MBR		Pulsing Slug Flow MBR		Savings
	Total Power Consumption	**Power Cost per Day**	**Total Power Consumption**	**Power Cost per Day**	
Filtrate Pump	405 kWh/day	$48.60	405 kWh/day	$48.60	0%
ML Feed Pump	786 kWh/day	$94.32	708 kWh/day	$84.96	**10%**
MOS Air Scour Blower	4,175 kWh/day	$501.00	1,670 kWh/day	$200.40	**60%**
Total Daily Power Consumption	5,366 kWh	$643.92	2,783 kWh	$333.96	**48%**
TOTAL ANNUAL POWER COSTS		**$235,030**		**$121,895**	**48%**

Assumptions:

- Calculated with 20 MLD average day flow (design for 34 MLD peak)
- Assumes NZD.12 / kWh
- Design with 4 membrane cells, no standby
- Does not include biological system

In addition to providing a large improvement in aeration energy, the pulsed flow system has other advantages over traditional MBR systems. Apart from the accumulation device on the base of the module, no additional equipment is required to produce the necessary air flow.

Traditional MBR systems often require cycling modulating valves or additional equipment to reduce the amount of bubbly flow supplied to the membrane modules while still maintaining a certain scouring efficiency. This equipment can require increased maintenance and care over the accumulation device, which has no moving parts. Further, systems relying on cycling air flow/distribution require complex control systems to monitor plant operation to determine periods when air flow can be adjusted. The MemPulse system does not require this complexity.

2.5 PROCESS DIFFERENCES

Another difference of a pulsed slug flow MBR is the low Dissolved Oxygen (DO) of the overflow mixed liquor (ML) from the membrane tanks. Conventional bubble MBR systems have a high residual DO level > 6 mg/L in the ML overflow, if this is returned to anoxic or anaerobic treatment zones the DO could potentially disrupt biological activity. As a result, the consideration of ML recycle flows is a critical part in the design of MBR systems. Solutions include returning the ML to the aerobic zone and adding an additional recycle stream or adding a de-aeration zone after the membrane tanks (Wallis-Lage & Levesque 2009).

Testing of the DO in overflow of pulsed slug flow MBRs has shown lower DO values of 2 -4 mg/L for a system with aerobic DO levels of 1 – 2 mg/L. This lower DO is achieved as a result of the lower surface area (per L of air) of large slug flow bubbles vs fine bubbles which minimises oxygen transfer. This simplifies the design of MBR systems by enabling a single recycle stream and/or reducing the size of the de-aeration zone (with a resulting capital cost saving).

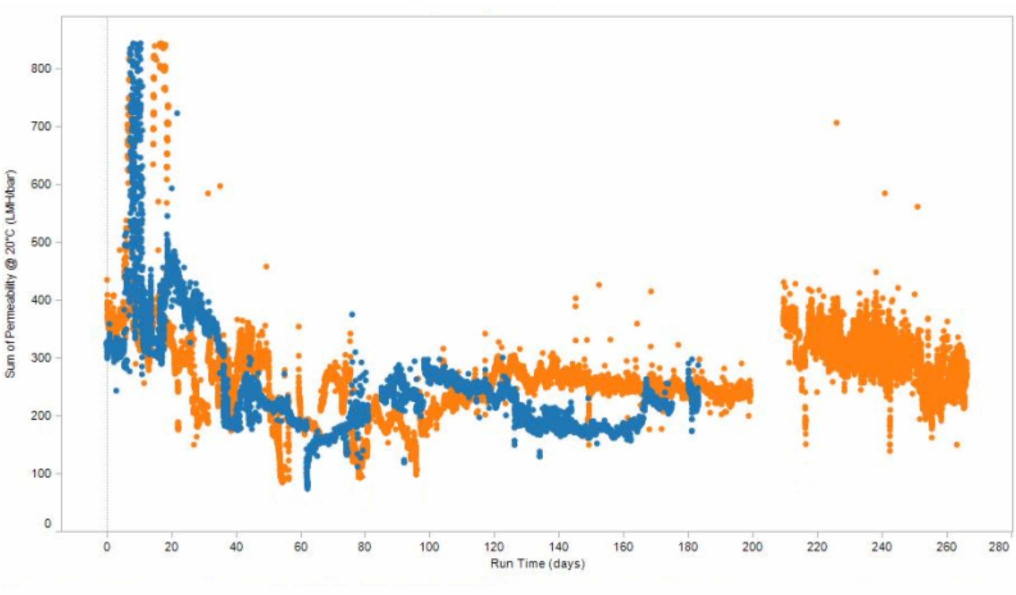
3 PLANTS USING PULSING SLUG FLOW MBR

Several operating plants have been upgraded to the MemPulse system, while others are in design or construction. Key drivers for the selection of the technology have been lower operation costs coupled with stable system performance.

Healdsburg is a city of 20,000 people in the Nappa wine region of Northern California. The area experiences large seasonal flow variations with a dry summer and a wet winter with sustained weather events. The plant is designed to treat 6 MLD average flow and 15 MLD wet weather peak for up to a week. The plant was commissioned in March 2008 with a bubble flow aeration system, but was progressively converted to MemPulse from June 2008.

Operation of the MemPulse tanks has resulted in membrane permeability vales equal to or higher than bubble flow system (Figure 1). The reduced air scour flow of the MemPulse has allowed the plant to run with one less membrane air scour blower operating with a resulting saving of ~NZD 325,000/year.

Figure 3: Operation of a MemPulse (orange) MBR tank in comparison to a bubble flow (blue) MBR tank



4 CONCLUSIONS

Over the past 30 years, there have been a number of breakthroughs in the MBR field that have seen the total system cost drop dramatically. This decrease in operating costs continues to make MBR a more sustainable choice for applications where the drivers for the use of the technology exist.

The MemPulse MBR system marks a breakthrough in the MBR market through the use of pulsed slug flow in submerged hollow fibre systems. The pulsed slug flow system, achieves reductions of up to 60% in air scour with an overall 50% reduction in the energy required to clean the membranes, though the use of the unique MemPulse device without the need for moving parts or complex control systems.

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