TWENTY YEARS OF MBR DESIGN AND OPERATION: WHAT HAVE WE LEARNT FROM DELIVERING 27 MBR PROJECTS?

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EXECUTIVE SUMMARY

Membrane Bioreactors (MBRs) are now an established technology for wastewater treatment and water recycling. Since the first tentative steps were taken in the early 2000's the use of MBR technology in Australia has evolved to now encompass projects with design dry weather flows of more than 25 MLD and peak flows of over 100 MLD. Reductions in membrane unit prices and improvements in efficiency mean that MBRs, for some years now, have often been a more cost-effective approach to both brownfield and greenfield upgrades than conventional treatment processes. What have we learnt from the design, construction and operation of over 27 such treatment plants in Australia?

INTRODUCTION

The first municipal wastewater treatment MBR in Australia was a relatively small (<1 MLD) system built on Magnetic Island, Queensland, circa.1997. The second MBR was a 5 MLD plant designed and constructed in 2003/2004 at Victor Harbor in South Australia. Both these ground-breaking plants utilised flat sheet membrane technology. Developments in membrane technology, specifically hollow fibre membranes adapted to wastewater conditions, have subsequently seen considerable advancements made in plant design, in the application of membranes and in reduced capital and operating costs. This paper discusses advancements in the technology and key lessons learnt with reference to select case studies.

HIGHLIGHTS

- A review of 20 years of design, construction and operational experience across 27 MBR plants in Australia.
- Improvements in technology and operation.
- Integration into water recycling schemes and use of renewable energy.
- Key lessons learned in design and operation.

SYNOPSIS

Membrane Costs, Warranty, Lifetime and Performance Improvements

Membrane costs continue to decline as manufacturing capacity has expanded. On an index basis, the cost of membranes per m^2 of installed area in 2025 is approximately 0.3 relative to an index value of 1.0 in 2005. Moreover, the increase in civil and structural works for larger footprint conventional plants has seen the unitised membrane solution become more economical than material and "labour-centric" concrete structures such as secondary clarifiers and media filters (Figure 1). Warranties have improved with suppliers now offering 8-10 years (pro-rata) compared to 3-5 years initially. Actual membrane lifetimes in excess of 10 years have been demonstrated, providing more certainty in whole-of-life cost assessments.

In terms of aeration scouring requirements, membrane technology in general has become more energy efficient, mostly due to improved aeration nozzle design, targeted aeration scouring and better membrane element arrangements. This has seen a reduction in membrane scouring air flow rates from >0.8 $Nm^3/m^2/h$ to as little as 0.1 $Nm^3/m^2/h$, allowing MBR plants to compete on an operational cost basis with conventional treatment plants with media/ultra-filtration (Figure 2).

Applied membrane flux rates have settled into a practical range after a period where suppliers sought to out-compete one another with claims of achieveable flux rates that proved to be too high for reliable performance. Whilst guarantees of higher operating fluxes will reduce membrane area requirement and therefore reduce the initial installed membrane cost, they come at the cost of operational robustness or membrane life. A conservative approach to installed membrane area incurs a marginally higher upfront capital cost but may save much more in terms of operational performance issues during peak flows and overall NPV with an extended membrane life.

Membrane Selection Criteria

The membrane system is integral to the performance of the biological nutrient removal (BNR) process and not simply a non-reactive solids separation system in the way that a traditional secondary clarifier may be considered. By their nature membrane systems introduce process changes and it is necessary to account for these process impacts in the overall design. From a practical operational viewpoint, the proven operational life of the membrane and the ability to reliably air scour, de-sludge and chemically clean the membranes is, in our experience, the most critical aspect of an MBR installation. Our key membrane process selection criteria are considered to be: resilient membranes materials, resistence to ragging and sludging, low air scouring requirements, sustainable flux rates, demonstrated operational life, commonality and upgradability.

CASE STUDIES

Cost Effective Upgrades for Existing Plants

By way of examples, membrane bioreactor (MBR) technology was used to increase the capacity of the existing Yeppoon Sewage Treatment Plant (Queensland) by 48% from average dry weather flow of 4.2 ML/day to 6.2 ML/day (Figure 3) and the Sunbury Recycled Water Plant (Victoria) by 53% from 6 ML/day to 9.2 ML/day (Figure 4). The upgrades addressed a number of challenges including; reducing operational costs, efficiently reusing the existing site space, and maintaining recycled effluent quality whilst taking major process units offline to be repurposed for the upgrade. These projects, and others, have demonstrated how membrane technology can provide a more sustainable alternative for sewage treatment plant upgrades in areas with rapid population growth; especially where stricter treated effluent licence conditions are being imposed by regulators, and available plant area is scarce. It also demonstrates how an MBR upgrade can reuse existing assets, reduce the plant footprint, and provide improved recycled water quality.

Treated Effluent Quality

Treatment plant upgrades are now regularly targeting 50%ile treated effluent quality of TN<3 mg/L, TP<0.1 mg/L and TSS <2 mg/L to ensure compliance with environmental licences. These licences have been steadily tightened from typically <10 mg/L TN in the 1990's to less than 5 mg/L TN in the 2000's to now <3 mg/L TN or lower. Membranes have also demonstrated bacteriological removal to <5 cfu/100 mL (or below detection), often removing the requirement for traditional disinfection processes after secondary treatment.

Integration with other technologies

Examples include the use of MBR with Ultra-Filtration (UF) for water recycling, MBR with Reverse Osmosis (RO) for industrial wastewater treatment and re-use and MBR with a wetland (Cedar Grove, Queensland) for environmental discharge of exceptional quality treated effluent (TN<1 mg/L, 50%ile) (Figure 5, Figure 6). Renewable energy technologies are also being integrated, for example at Rubyanna WWTP (Queensland) (Figure 6) and Cedar Grove STP, where on-site solar provides over 40% of the daily electrical energy required to operate the treatment plants.

Key Design and Operating Lessons Learnt

- Achieving robustness of inlet screening has seen a change in the types of screens that have been adopted and the screen aperture. Screening is a critically important feature of MBR design.
- The impact of the design and operating concentration of mixed liquor suspended solids (MLSS) on aeration efficiency.
- Propensity for membrane module sludging and the importance of membrane aeration nozzle design.
- Intermittent bioreactor aeration approaches for improved nitrogen removal to TN <2 mg/L
- Staging for extended capacity reach (i.e. down-tuning to 20% initial load).
- Adapting MBR operation to solar power to provide a practical and relatively inexpensive renewable power offset.

CONCLUSION

The application of MBR technology has generally been successful in Australia and its adoption is continuing to expand. Although the technology has been applied for some 20 years, learnings continue to be gained from real-world, practical operating experience.

FIGURES:

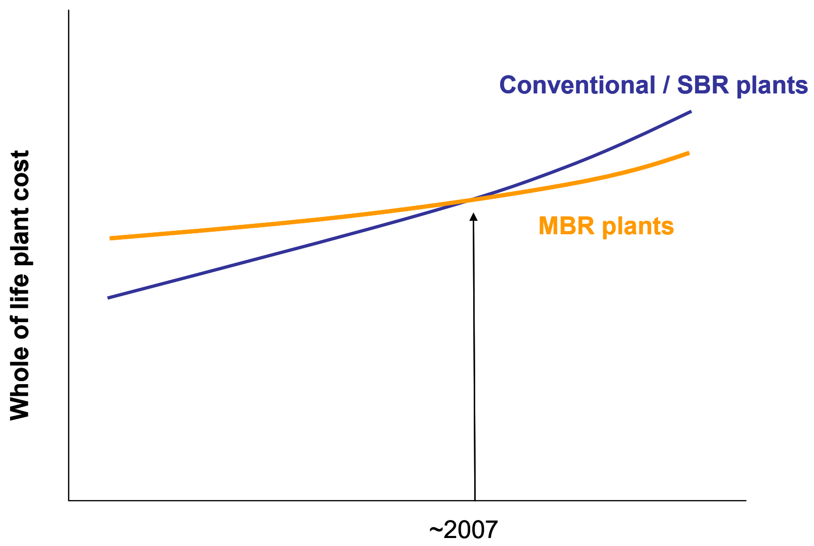

Figure 1: Relative whole of life costs for a 5 ML/day (peaking 25 ML/day) wastewater treatment plant

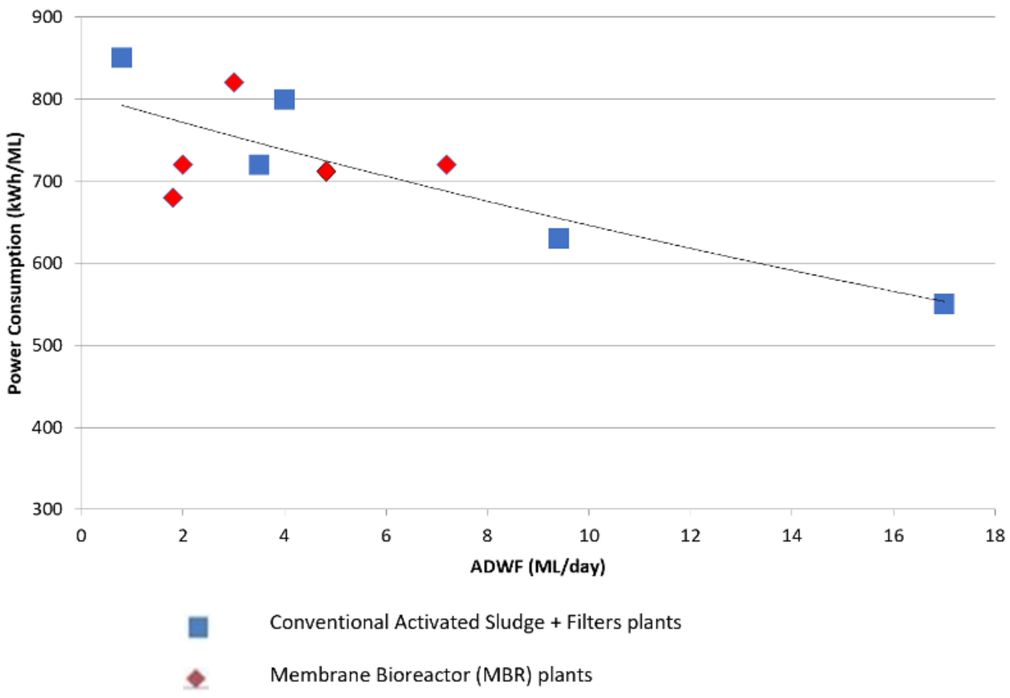

Figure 2: Comparative whole-of-plant power consumption for MBRs and Conventional AS Plants

Figure 3: Yeppoon STP upgrade, Queensland, 2019

Figure 4: Sunbury RWP Upgrade, Victoria – 2018

Figure 5: Cedar Grove Environmental Centre, MBR + Wetland

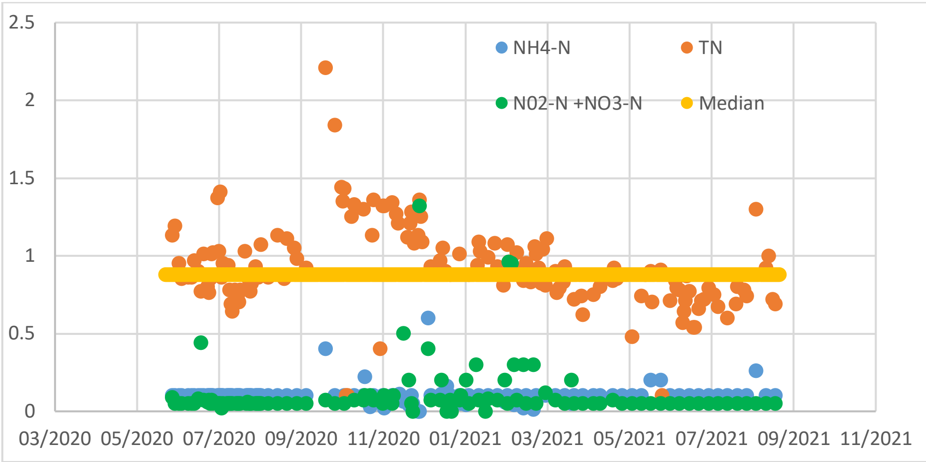

Figure 6: 15 months of nitrogen removal performance data from Cedar Grove MBR-wetlands system

Figure 7: Rubyanna WWTP, MBR with solar – 2019

Figure 8: Winmalee STP, New South Wales. SBR plant converted to MBR in 2024.

West Camden WRP, New South Wales. Upgraded with dual MBRs to replace IDALs - commissioned 2025

Loganholme WWTP, Queensland. MBR upgrade to augment existing oxidation ditch plant