Research Update

Membranes

Introduction

The need for new water sources to help meet growing water demand, coupled with increasingly stringent regulatory environments, have been strong drivers for investment in membrane research.

Research has improved membrane performance, process design, chemical and energy use, and made membrane technology an economically competitive technology with widespread application.

WaterRA and its predecessors have contributed to these outcomes with a strong focus on operational issues associated with membrane technology. These include membrane integrity monitoring, membrane bioreactor (MBR) robustness (particularly associated with the removal of micro-contaminants), membrane ageing and chemical pre-treatment for high pressure membranes. Previous work has also covered the application of ultrafiltration membranes in point of use applications.

It is relatively easy to identify some of the significant benefits of investment in membrane research for the water industry. For example, the cost of treating water through reverse osmosis membranes is approximately one tenth of the cost it was in 1978. Similarly, the energy requirement is approximately one quarter of that used in 1980 to treat the same volume of water through reverse osmosis membranes. As a result in these dramatic reductions in the cost and energy required, the adoption of reverse osmosis globally as a water treatment process has accelerated exponentially over the last few decades.

This document outlines a recent selection of WaterRA projects in Membrane research.

Development of predictive tools for membrane ageing

Project 2008/09 - Completed

Static and consecutive ageing tests were used to investigate the degradation/ageing mechanisms occurring on porous membranes used in the water and wastewater industries. The aim was to better predict the loss of membrane integrity in large scale plants.

The project comprised 4 parts; (i) critical assessment of characterisation techniques, (ii) static accelerated ageing, (iii) consecutive accelerated ageing, and (iv) consecutive ageing of industrial membranes.

The extent of the apparent membrane degradation varied due to the history of the membrane sample. This revealed a number of limitations with regards to the prediction of membrane ageing, with the following variables all having a significant impact on the results:

- The nature of the cleaning agent(s) used
- The type and maximum concentration of cleaning chemical used during accelerated membrane ageing studies
- The lack of information regarding cleaning protocols used by industry, including the exact chemicals, the concentrations used and the cleaning frequency.

Future studies should focus on the effect of membrane degradation on product water quality by assessing the relative impact of fouling and ageing on membrane rejection performance.

Project Leader: Pierre LeClech, UNSW
Low maintenance, chemical-free recycling of effluent by ceramic membranes

Project 3017/11 - Underway

This project explored the cost, reliability and treated water quality of recycling secondary effluent water using a combination of ceramic membrane filtration and an ozonisation advanced oxidation process.

A pilot plant was established at the Eastern Treatment Plant in Victoria. The equipment, supplied by PWN Technologies, was set up in two shipping containers. The plant’s process control computer enabled automatic, unattended operation with logging of all process sensors.

The structured experiments undertaken examined four distinct pre-treatment options. The hybrid ceramic membrane/ozonation process tested on secondary effluent, while controlling many operational parameters, found a demonstrable increase in plant performance over a ten month trial period.

This project supports the hypothesised performance benefits of ceramic membrane technology combined with ozone. High flux operation of challenging waters - such as secondary effluent - and enhanced disinfection are unique attributes of this approach.

The potential for reduced chemical cleaning exists but the ceramic membrane’s features of robustness and longevity can most likely be better exploited through a smaller plant size with greater operational freedom.

Project Leader: Mikel Duke, VU

Real time integrity monitoring for high pressure membrane systems

Project 2018/10 - Underway

The ability to demonstrate the integrity of high pressure membrane systems is critical to verify and maintain the quality of water production. The best available online monitoring technologies can only measure up to 2 log treatment, necessitating membrane modules to be taken offline for more thorough assessment.

This project aimed to identify a suitable non-microbial virus surrogate, develop a protocol to test for the surrogate in permeate samples as part of a challenge test, and to establish this as a real-time, online technique.

A range of non-microbial surrogates were examined including soluble food dyes, fluorescent dyes and fluorescent nanoparticles.

To rigorously assess the efficacy of each approach a series of key selection criteria were established. These included parameters such as the particle size, adsorption, toxicity, detection limit, cost, availability and storage stability.

The project has successfully identified a nanoparticle coupled to a sensitive detection system that, in laboratory and pilot scale systems, could detect a pin-hole membrane failure.

The successful approach demonstrated in this project requires pilot scale testing to rigorously assess the application of this measurement in industrial systems.

Project Leader: Stephen Gray, VU
Membrane integrity testing for virus particle removal

Stage 1 Project 2006/08 – Completed
Stage 2 Project 2013/09 - Completed

An important aspect of the membrane filtration process is the development of reliable techniques to monitor the integrity of the membrane to verify the removal efficiency claimed for target contaminants.

In light of the growing importance of microporous and semipermeable membranes in the Australian water industry, in stage 1, this project aimed to:

- Review the literature on pathogen and indicator removal efficacy for synthetic membrane processes
- Consolidate standing protocols and techniques for synthetic membrane processes
- Review failure modes, likelihood of failures and plant reliability
- Identify novel integrity test methods that have the potential to detect virus sized breaches.

In stage 2, citrate stabilised silver nanoparticles were developed as a non-microbial alternative to bacteriophage, for the purpose of intermittent challenge testing for membrane validation. These nanoparticles are spherical, zerovalent, negatively charged and highly stable.

The effectiveness of intact UF membranes to remove virus sized particles was established up to 3 LRV using nanoparticles as an alternative to bacteriophages, without affecting the hydraulic performance of the membranes.

Project Leader: Greg Leslie, UNSW

Protocol for developing chemical pretreatment for high pressure membranes

Project 2009/09 - Underway

Scale formation and subsequent performance decline still remain a challenge for RO systems in spite of the availability of a suite of scale prediction tools and a range of scale mitigation measures practiced in the water treatment industry.

This project reviewed various aspects of scale formation and related issues including, mechanism of scale formation, prediction, control and detection. Managing scale formation relies on understanding the chemistry of the scale, judicious system design, appropriate chemical application and early detection.

A rapid screening test was proposed for the evaluation of antiscalants to control various scale types, applicable for both alkaline and non-alkaline scales.

Also, an in situ real time monitoring technique using electrochemical impedance spectroscopy was developed and evaluated for the functional and structural characterisation of RO systems. Conductance of six specific frequencies in the range of $10^1$ to $10^5$ Hz were obtained and compared with flux decline. By observing the change in conductance signal at low frequency (38 Hz), which relates to the membrane coating layer, the EIS technique was able to signal the early stages of scale formation. Therefore, attaching EIS as a side stream to a full scale module may provide early warning of scale formation, well before permeate flux decline is observed.

Project Leader: Greg Leslie, UNSW
Resilient desalination pre-treatment of secondary effluent by ceramic membranes

Project 3020/12 - Underway

The use of ceramic membranes as an alternative to polymeric membranes has gained interest in water/wastewater treatment due to their superior life, durability and integrity. It is well known that very high flux performance can be achieved with ceramic membranes by pre-treating the feed water with coagulation and ozone.

This project explores ceramic membrane performance coupled with a range of pretreatments, including coagulation/ozonation, and the more novel ultraviolet/hydrogen peroxide (UVH) treatment. The downstream effects of fouling the RO membrane were also investigated.

The project confirmed that ozone and coagulation led to high fluxes in the ceramic membranes, and found that the UVH pretreatment also enhanced ceramic membrane flux.

The UVH pretreatment delivered the lowest NDMA formation, which may be of significance in plants with higher levels of NDMA.

With regard to pretreatment impacts on downstream fouling of RO membranes, enhanced biodegradable dissolved organic carbon (BDOC) was observed after ozone, ozone/coagulant, UVH and UVH/coagulant pre-treatments. This finding suggests increased fouling potential for those pretreatments. In contrast, the BDOC did not change after coagulant pretreatment only, suggesting it should have minimal impact on RO membrane fouling.

Project Leader: Mikel Duke, VU

Evaluation of integrated membranes for taste & odour and algal toxin control

Project 1003/08 - Complete

This project determined the most effective integrated treatment system for source waters subject to a range of cyanobacterial contamination, which included evaluation of ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) membranes.

Laboratory studies indicated that an NF membrane as the final stage of an integrated membrane system (IMS) may be the best method for maximising removal of extracellular cyanobacterial metabolites. Selection of the correct NF membrane was essential. The most efficient removal of cyanobacterial metabolites was achieved with a polyamide NF membrane with MWCO of ~100Da. This membrane should also be hydrophilic for the best retention of flux.

A UF membrane incorporating coagulation and powdered activated carbon (PAC) addition is also a practical treatment train. Aluminium chlorohydrate (ACH) is the best readily available coagulant for removal of intracellular cyanobacterial metabolites. ACH may also be a better coagulant for UF-IMS in remote locations as lower doses are required for flux retention.

Water authorities should be confident in using an UF-IMS incorporating PAC addition and coagulation as part of a multibarrier approach for the removal of cyanobacterial metabolites to concentrations below the suggested guidelines.

For all membranes a cleaning process should be undertaken after a cyanobacterial bloom to remove NOM foulants.

Project Leader: Gayle Newcombe, AWQC