# MEMBRANE PROCESSES:
## ADVANCEMENTS FOR DRINKING WATER TREATMENT

ROBERT C. ANDREWS, UNIVERSITY OF TORONTO

*Published May 2015*

Canadian Water Network

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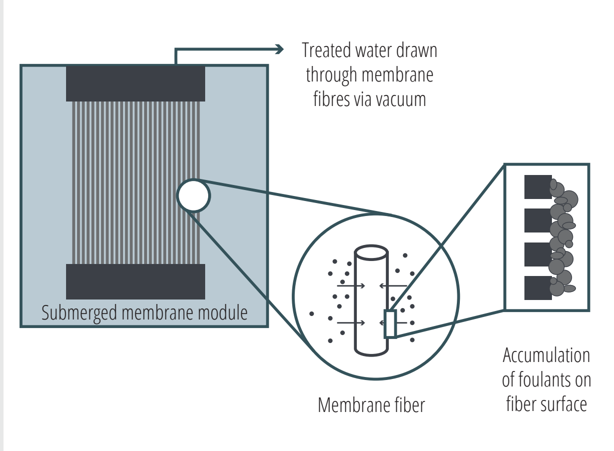
# RESEARCH BACKGROUND

The use of membrane filtration processes in drinking water treatment facilities has increased rapidly in the past decade. Ultrafiltration membrane systems typically consist of large bundles of hollow fibers submerged in the water to be treated. The water is drawn by vacuum through tiny pores in the membrane surface, which filter out undesirable particulates, bacteria and protozoa.

Membrane treatment produces water of high and consistent quality which is cost competitive when compared to conventional treatment options. As a result, many new and upgraded drinking water treatment plants are implementing this technology. However, despite these advantages, barriers remain to widespread adoption of the use of membranes in Canada. Generally, their application has been limited to low pressure membranes (mainly ultrafiltration) where source water quality is high. In contrast, high pressure membranes (such as reverse osmosis) are often used for the removal of salts (desalination).




Insert Figure 1. Membrane fouling

The primary barrier is fouling, which is the accumulation of material on the membrane surface. Certain components in surface waters (such as natural organic matter), build up on the membrane surface and create resistance to the flow of water through the pores. As a result, more energy is required to pull water through the membrane, which increases operating costs. Research is needed to identify and target those specific components of source waters that are known to foul membranes and to develop strategies to minimize membrane fouling.

Drinking water treatment plant operators and consumers have expressed concerns over the potential health implications of pharmaceuticals and other emerging contaminants present in surface waters, particularly estrogens and endocrine-disrupting compounds like bisphenol A. It is not clear whether membranes are able to effectively remove these smaller-sized components from water. Therefore, it is important to increase understanding of how membrane processes may be optimized in this regard.

This research was conducted with the overall goal of improving membrane performance for drinking water treatment in Canadian utilities and focused on two main themes:

### 1. FOULING ABATEMENT STRATEGIES

Rather than target organics in water as a total group, this research focuses on identifying and targeting specific fractions of organic matter present in surface waters that cause fouling of membranes.

### 2. INTEGRATING MEMBRANE SYSTEMS TO MEET MULTIPLE WATER QUALITY OBJECTIVES

The integration of membranes with established yet complementary technologies such as the use of coagulants and adsorbents prior to membrane filtration may serve to target the removal of specific membrane foulants, as well improving the removal of emerging contaminants.

# RESEARCH METHODS

Several related projects were conducted with the goal of optimizing existing membrane processes for drinking water treatment. The investigations involved data collection from studies performed at the University of Toronto, where a range of treatment scenarios were examined using small membrane modules (Figure 2) with automated operation to mimic treatment at full-scale plants. Several natural source waters representing a range of characteristics were studied. Membrane fouling was assessed, as well as the ability to remove emerging contaminants. In addition, concentrations of several emerging contaminants including pharmaceutical compounds and endocrine disrupting compounds were measured in raw source waters at the intakes to several drinking water treatment plants.


Figure 2. Image of the small-scale membrane modules used during laboratory studies as part of this research.

## FOULING CONTROL STUDIES

- Research was conducted to identify major membrane foulants from three Canadian source waters: Lake Ontario, Lake Simcoe and the Otonabee River.
- Coagulation was investigated as a complementary process to membrane filtration in order to target these specific foulants.
- Different types of coagulants at varying dosages were applied prior to the membranes to determine the impact on membrane performance and operating and maintenance costs.

## REMOVAL OF PHARMACEUTICAL COMPOUNDS

- Research was conducted to investigate the removal of pharmaceutical compounds through membrane filtration, when coupled with complementary pre-treatment processes of coagulation and an adsorbent (powdered activated carbon).
- Up to 24 different pharmaceutical compounds were added into source waters and measured during different treatment scenarios.
- Further studies investigated how these contaminants were rejected in the membrane process, based on the characteristics of the compounds studied, as well as the properties of the membrane and the source water.

# RESEARCH FINDINGS

The major membrane foulant identified from the Canadian source waters examined was large-sized organic matter known as biopolymers. Biopolymers are present in most surface waters at relatively low concentrations (< 0.5 mg/L and typically < 10% of the total organics), but cause the majority of membrane fouling. Coagulation with aluminum sulphate (alum) or polyaluminum chloride (PACl), both of which are commonly used in drinking water treatment plants, was effective at removing biopolymers from surface waters.

A low coagulant dose (0.5 mg/L) was identified as optimum for biopolymer foulant removal and decreased membrane fouling when compared to membranes operated without coagulant pre-treatment, as well as membranes operated with a higher coagulant dose (15 mg/L), which is more typical of current treatment practice (Figure 3). At higher coagulant dosages, the coagulant itself was found to be fouling the membrane. There is potential for significant cost savings (up to $1 million/year for a 100 MGD treatment plant) with the application of a low coagulant dose (0.5 mg/L). This estimate is based on savings associated with lower chemical requirements and less residual waste, as well longer membrane run times and increased water production.

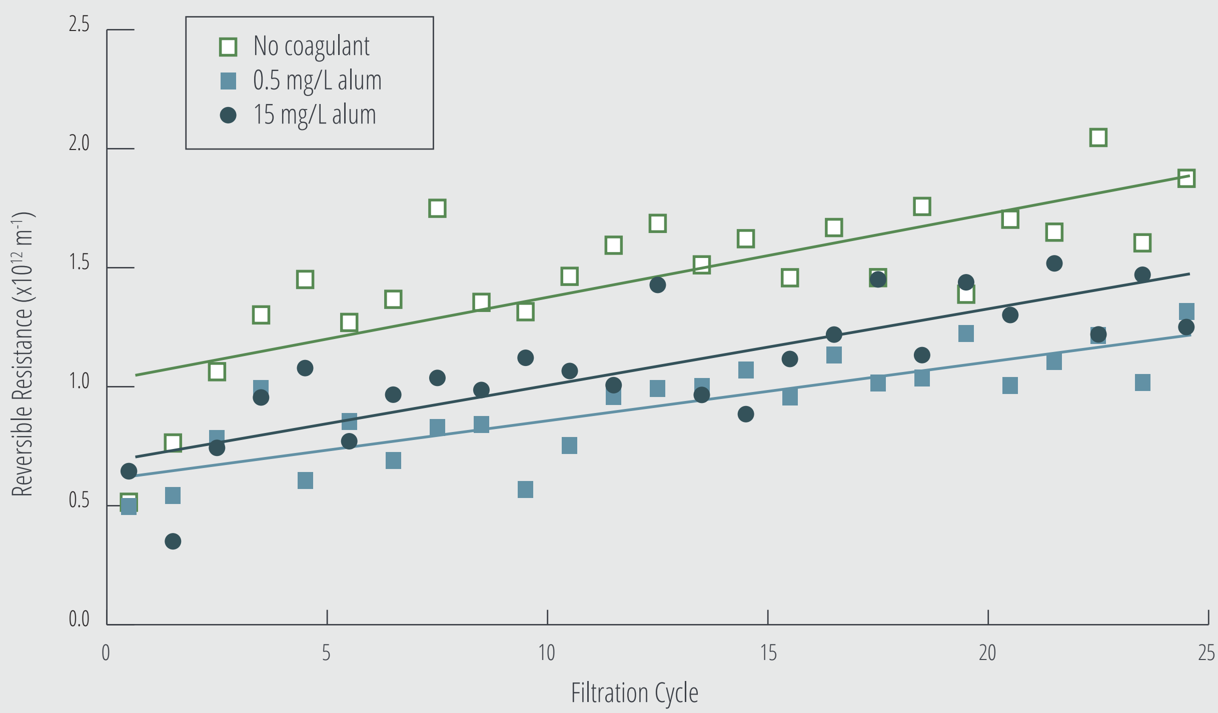



Figure. 3 Fouling (y-axis) over filtration time with no coagulant and with the application of a low (optimized) dose of 0.5 mg/L and a more typically-applied dose of 15 mg/L.

Membranes typically employed in Canadian drinking water utilities (i.e., ultrafiltration) are generally ineffective at removing pharmaceutical compounds (< 20% removal) (Figure 4). The exception to this trend was for hormonal compounds such as estrogens, which demonstrated up to 50% removal by membranes alone. Removal of pharmaceuticals in this manner was mainly attributed to adsorption to the membrane surface.

In addition, the presence of higher concentrations of organic matter (and therefore membrane foulants) in the water increased the retention of many pharmaceutical compounds. This was attributed to adsorption of pharmaceuticals to organic matter in the water, which is then removed by the membrane.

The addition of coagulant prior to ultrafiltration membranes was generally not effective at improving the removal of pharmaceutical compounds from surface waters when compared to removals observed with the membranes alone.

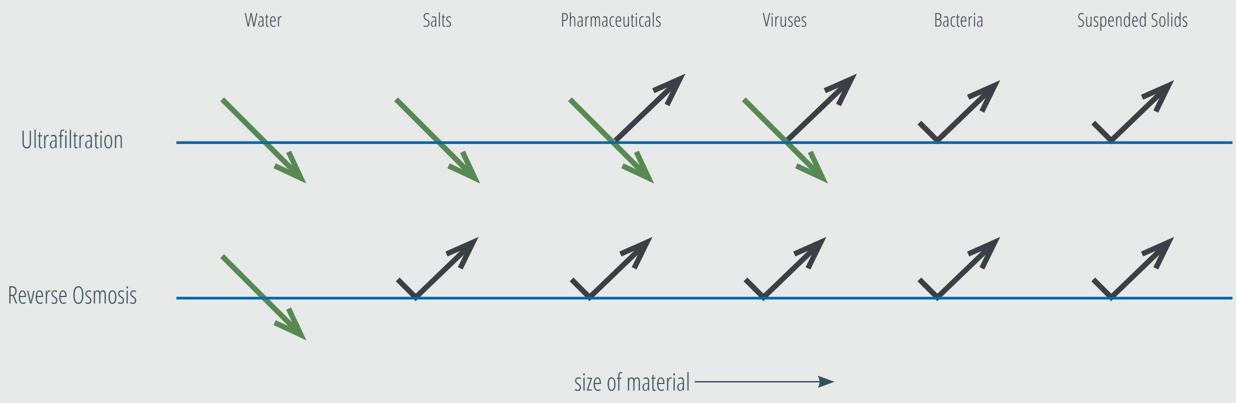



Figure 4. Summary of different membrane types and the compounds retained by each

However, the use of an adsorbent (powdered activated carbon) prior to the membrane showed improved removals of several pharmaceutical compounds. An average compound removal of >60% was observed in membrane systems with 5 mg/L of powdered activated carbon adsorbent applied as pre-treatment.

Hormonal compounds demonstrated the highest removal by the membranes and adsorbents (up to 97% removal). However, the presence of higher concentrations of organic matter in water generally caused a decrease in the efficiency of the adsorbent to retain pharmaceutical compounds, likely because organics present in the water were competing with pharmaceuticals for adsorbent sites. The only membrane systems investigated that provided consistent efficient rejection of pharmaceutical compounds when applied without any pre-treatment were reverse osmosis processes (> 90% retention) (see Figure 4).

In practice, installation of high pressure membranes for drinking water treatment of already high quality surface waters may not be feasible, based on high capital and operating costs of these systems. In addition, analysis of surface water sources used for drinking water in Ontario indicated that very few emerging contaminants were actually detected in raw waters, and at very low concentrations (Table 1).

| COMPOUND | MDL (ng/L) | LAKE ONTARIO | LAKE SIMCOE | OTONABEE RIVER |
|---|---|---|---|---|
| Carbamazepine | 26 | nd[a] | <MDL[b] | nd |
| Ketoprofen | 24 | <MDL | nd | nd |
| Naproxen | 17 | nd | 112 (±105) | <MDL |
| Pentoxifylline | 15 | <MDL | <MDL | <MDL |
| Sulfamethoxazole | 10 | <MDL | 26 (±23) | 15 (±8) |
| Sulfamethizole | 6 | 10 (±17) | nd | 8 (±19) |
| Sulfachloropyridazine | 32 | <MDL | nd | <MDL |
| Acetaminophen | 35 | 66 (±114) | nd | <MDL |
| Bisphenol A | 57 | <MDL | nd | <MDL |
| Clofibric acid | 22 | nd | nd | 73 (±45) |
| Diclofenac | 37 | <MDL | nd | 51 (±12) |
| Diethylstilbesterol | 61 | nd | nd | <MDL |
| Estriol | 52 | nd | nd | nd |
| Estrone | 67 | nd | <MDL | <MDL |
| Gemfibrozil | 51 | nd | nd | nd |
| 17β-estradiol | 90 | nd | <MDL | <MDL |

[a]not detected
[b]detected at a concentration less than the method detection limit

Table 1: Concentrations of organic micropollutants measured in raw surface waters, collected from the intakes to water treatment plants; values represent mean concentration ± the standard deviation of three separate samples

# IMPLICATIONS FOR MUNICIPALITIES

This research examined ways in which municipalities can improve the efficiency of membrane processes for drinking water treatment while meeting multiple water quality objectives:

- Large-sized organic matter (biopolymers) present in surface waters is mainly responsible for membrane fouling.
- Pre-treatment to target foulants is recommended.
- A low dose of coagulant may serve as an excellent pre-treatment strategy to target foulants.
- Significant cost and energy savings may result from reduced coagulant usage, reduced residual waste and improved membrane performance.
- Higher pressure reverse osmosis membranes or the addition of adsorbents may be required to remove pharmaceuticals from surface waters during membrane treatment.
- Pharmaceutical compounds were generally not detected (or were detected at trace concentrations) in the source waters examined in this study.
- If risks associated with emerging contaminants are deemed to be low, implementing advanced processes may not be practical, given the capital and operating costs involved.

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