“Untangling” Water Treatment using RSL Membranes™

David Bromley M.Eng., P.E, Chief Executive Officer, DBE Hytec Ltd.

Abstract

RSL Membranes™ have eliminated the need for pretreatment and post treatment to manage membrane fouling. This accomplishment provides simplicity in water treatment by eliminating process and chemical complexity due to membrane fouling. **RSL Membrane™** technology is one process unit that displaces all other technologies that are used to separate:

1. Suspended solids
2. Colloidal solids less than 0.45 micron
3. Some dissolved solids, and
4. Oil and grease

RSL Membranes™ are a scientific breakthrough technology that will provide the platform of one main and consistent process to use smart data analytics and create autonomous operations for water treatment facilities.

Discussion

Technology development for water treatment has been stagnant over the last 100 years. Membranes today are considered state of the art technology. Since their introduction in the 1960’s, membrane technology has become the foundational process for water treatment. Low pressure membranes (typically referred to as microfiltration -MF or ultrafiltration-UF membranes) took hold in the market in the 1990’s. However, since then, the use of low-pressure membranes has become complicated. The problem of continuous membrane fouling has led to two operational issues; pretreatment of the water prior to membrane treatment and post treatment cleaning of the membranes to manage fouling. These two operational requirements have created multiple complex treatment processes which impair the use of smart technology such as data analytics which can be used to create autonomous water treatment processes. Membranes have been touted as the barrier technology that makes drinking water safe however, due to the difficulty of managing membrane fouling, the technology has become entangled in the need to add numerous peripheral “support” processes. These peripheral processes are costly and inefficient, yet are required to pretreat the water with the intent to reduce fouling. When fouling does occur, there are additional add-on processes to clean the membranes which is essential to sustain operations.

Figure 1 below shows the impact of fouling on conventional UF membranes. In this figure, fouling increases consistently as the filtration cycles continue even with a 30 second backwash after each filtration cycle.

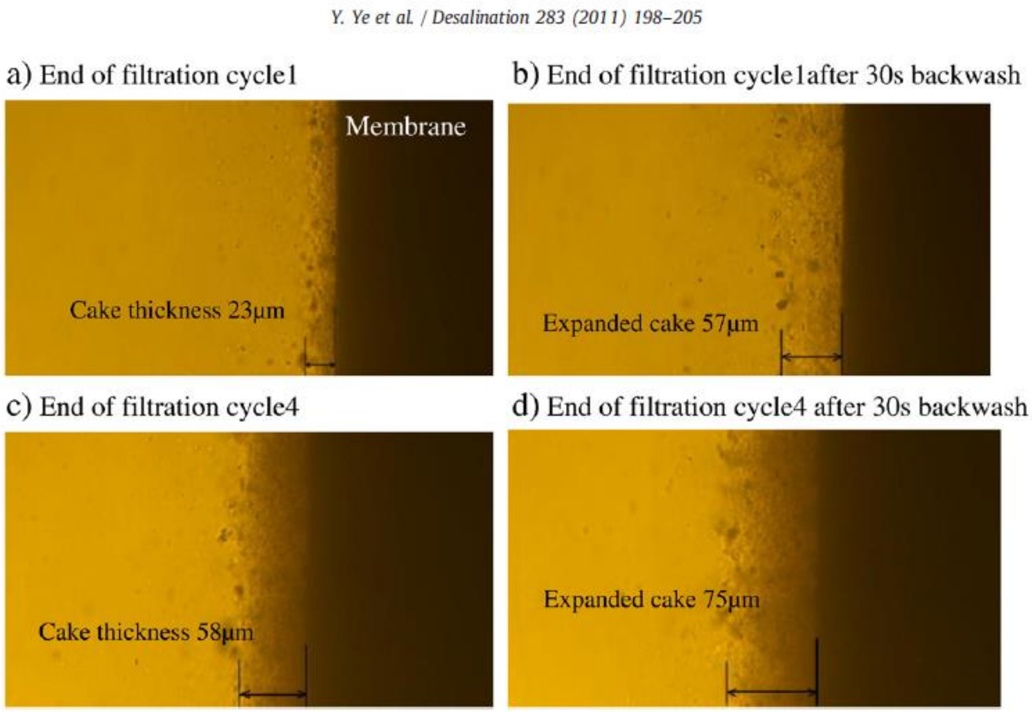


Figure 2 – Fouling cake at the end of filtration cycles, and after 30s backwash without air scouring. Filtration flux 50 l/m2-h, filtration duration 3570s, backwash flux 50 l/m2-h, backwash duration 30s. Feed solution: 50 mg/L bentonite and 50 mg/L alginate. (Ye et al., 2011)

To “untangle” water treatment and continue to rely on membranes as the heart of the treatment process, the pretreatment and membrane cleaning issues must be addressed.

RSL Membranes™ have addressed these issues as outlined below:

1. Pretreatment: Table 1 below identifies the manufacturer’s recommendations as to the limits of operating parameters for a conventional UF Membrane. The conventional UF membranes are listed as the hollow fibre, spiral wound, and ceramic tubular. Compare the operating conditions of the three UF membrane configurations to the **RSL Membrane™** operating parameters.

Table 4 Process Characteristics - Manufactuers Recommendations				
Operating Parameters	**UF Hollow Fibre**	**UF Spiral-wound**	**UF Ceramic Tubular**	**RSL Membranes™**
pH	2–13	2–11	3–7	2-13
Feed Pressure (psi)	9–15	<30–120	60–100	0-10
Backwash Pressure (psi)	9–15	20–40	10–30	air 75-90
Temperature (°C)	5–30	5–45	5–400	1-400
Total Dissolved Solids (mg/L)	<1000	<600	<500	<250000
Total Suspended Solids (mg/L)	<500	<450	<300	<5000
Turbidity (NTU)	<15	<1	<10	<3000
Iron (mg/L)	<5	<5	<5	no limit
Oils and Greases (mg/L)	<0.1	<0.1	<0.1	<2000
Solvents, phenols (mg/L)	<0.1	<0.1	<0.1	unknown

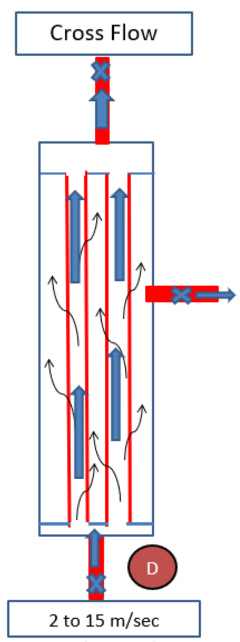
a. For Ultrafiltration (UF) membranes (Wikipedia-Ultrafiltration Membranes), treatment of feed prior to the membrane is essential to prevent damage to the membrane and minimize the effects of fouling. The parameters as outlined in Table 1 show the significant requirements for pretreatment of the water prior to using UF membranes. Types of pre-treatment vary depending on the type of feed and its quality. Not only are a variation in processes required but there also is a need for chemical pretreatment to manage organics and pH. For example, pre-treatment, which is common to many UF processes, includes pH balancing and coagulation. Appropriate sequencing of each pre-treatment phase is crucial in preventing damage to subsequent stages. As indicated in Table 1, the feed to a UF membrane cannot exceed 15 NTU. If the feed water is higher than 15 NTU, the pretreatment will typically involve clarification or flotation technology or a multimedia filter. If oil and grease levels are high then oil water separation technology is necessary such as dissolved air or induced gas flotation, oil coalescers, oil water separators and oil skimmers. The fact that operating a UF or MF Membrane requires a variety of pretreatment processes creates a complex operational procedure. These pretreatment complexities eliminate the ability to use smart data analytic technology. The latter is important in lowering costs and improving treatment as well as allowing for the development of semi or fully autonomous water treatment processes. Operation of MF or UF Membranes has become an ad hoc procedure.

b. **RSL Membranes™:** Pretreatment of the feed water is not necessary. RSL membranes™ are very robust and will treat waters with turbidity well in excess of 1000 NTU, TSS levels as high as 5000 ppm or emulsified oils as high as 2000 ppm. As a result, RSL membranes™ not only replace UF membranes but also replace all other methods of discreet solid and oil separation technology including clarifiers, dissolved air or induced gas flotation technology, multimedia filters, and oil water separators. In doing so, **RSL membranes™** simplify water treatment by reducing the need for process unit after process unit to treat a specific water. Simplifying water treatment by eliminating many process units is a breakthrough towards autonomous operation of water treatment facilities.

2. Membrane cleaning:

a. For MF or UF Membranes the common physical cleaning methods are cross flushing, backwashing, vibration, air sparging and sponge ball cleaning.

(i) Cross flushing: This approach to membrane cleaning occurs as the membrane is filtering. A high intensity flow rate is recirculated through the center of the membrane tube. Figure 2 shows the crossflow concept. The high flow rate up through the center of the membrane tube scours the inside of the membrane tube to release any build up of a filter caking on the inside of the membrane. The flushing occurs simultaneously with the filtration from the inside of the tube to the outside of the tube. To accomplish the simultaneous filtration, the valve at the top of the membrane is partially closed to create a back pressure. The result is the need for a large recirculation pump to create the cross flow which also consumes 90% of the energy required for the cross flushing system.



Conventional UF Membrane
High energy
Figure 2

(ii) Backwashing/Reverse flow cleaning: In MF and UF systems, especially in a dead-end filtration mode, the most adopted method for membrane fouling control is reverse flow cleaning, or backwashing/backflushing. After a certain time of filtration, a flow of clean water is pumped back through the membrane from the permeate side, thereby lifting foulants from the membrane surface and reducing concentration polarization near the membrane surface. There are two back pulse methods

- Water Pulse Backwash: Water is used in the reverse direction. The hydraulic back pulse releases and transport portions of the fouling layer away from the UF membrane surfaces and into the bulk fluid. However, a portion of the fouling layer (termed ‘hydraulically irreversible fouling’) remains and typically requires chemical cleaning for the irreversible fouling to be removed (Katsoufidou et al., 2005 and Katsoufidou et al., 2008). Backwashing UF membranes with the filtered water (permeate) has been used as a fouling control approach in seawater applications for many years (Li, et al., 2012).

The trials conducted by Li et al. (2012) produced relatively high fouling rates (0.28 PSI/hr) that required frequent clean-in-place (CIP) operations (approximately daily). Water back pulsing with the permeate will significantly lower the net permeate flux if it is applied for a large fraction of the filtration cycle. Typically, water back pulsing causes a 20% loss in the gross flux rate. Stronger amplitude, longer duration or higher frequency of back pulsing causes more permeate loss. Back pulsing with too weak amplitude, too short duration, or too low frequency is not effective to remove membrane fouling. The optimization of back pulsing conditions not only results in higher permeate flux, but also reduces the operating cost. (Yinghong 2019)

- Gas Pulse backwash (Air and Nitrogen): Instead of water, air or nitrogen are used for back pulsing. Although air back pulsing could avoid water loss of flux rate from water pulsing, it can lead to embrittlement and membrane integrity problems. It is also shown that water back pulsing is more effective than gas back pulsing to recover membrane permeability (Yinghong 2019). Yinghong reviewed a comparison of water back pulsing versus gas back pulsing on the net permeate flux in the cross-flow MF membrane of 100 mg/L carboxylate modified latex (CML) particles with polypropylene (PP) membranes of 0.3µm nominal pore diameter. The water back pulsing experiments were performed at a reverse TMP of 6.9kPa (1.0psi) for 0.15 seconds after every 4 seconds of forward filtration. For gas back pulsing, nitrogen was used. The operating parameters were almost the same as water back pulsing except for the pulse duration of 0.2 seconds. The results showed that for the long- term (i.e. fluxes at the end of 1 hour of filtration) the enhancement over filtration rate without back pulsing was 3.7-and 3.2-fold for water back pulsing and gas back pulsing, respectively. Yinhong referenced further research from Matsumoto et al with similar results about backwashing in the crossflow MF of yeast suspensions. Back-washing with permeate, supplied either by compressed gas or by a suction pump, gave a higher permeate flux than filtration with gas backwashing. It is important to note the difference between back pulsing and back washing. For example, a typical backwash will last 1 minute at 2.0 bar every 30/60 minute whereas the back pulsing would have a typical duration of 0.5 seconds at the amplitude of 7.0 bar every 5 minutes.

(iii) Vibration: The use of ultrasound or mechanical vibration is used to loosen the filter cake that builds on the surface of the tube. The best example of such technology was implemented by the VSEP membranes.

(iv) Sponge ball: This was one of the first methods used to clean a membrane tube where a sponge ball is run into and through the membrane tube to dislodge the build up of a filter cake.

(v) Chemical enhanced backwash (CEB): Yinghong also reviewed the use CEB. This backwashing method involves multiple adjustable parameters, such as duration, interval (time between backwashes), and intensity (reversed flow rate or TMP), affecting the removal efficiency. In most cases, the parameters are either “*ad hoc* “or based on a pre-investigation of a limited set of different durations and intervals.

Unnecessary backwashing wastes both permeate and filtration time, reducing the overall capacity of the filtration system. Consider the operation challenges with this type of backwash yet CEB has become the norm for most operational procedures on MF and UF Membranes.
A typical CEB, to provide a low fouling rate sustained over an extended period, would be a permeate flux of 17 lmh, CEB flux of 34 lmh-h, CEB duration of 5 minutes, CEB frequency of 2 hours, and NaClO concentration of 8-10 ppm. At this low fouling rate, the system could operate for approximately 4 to 30 months before reaching the maximum allowable TMP of 55 kpa (8 psi). Once at this level, a more extensive Clean in place (CIP) is required. The upper level of a CEB typically would be an Enhanced CEB with a CEB flux of 34 lmh, CEB duration of 15 minutes, and NaClO concentration of 150 ppm. (Beswick, 2011).

(vi) Clean in Place (CIP). MF or UF membranes never recover to their original clean TMP after a CEB. Typically, for a pressure UF membrane, once the residual TMP reaches 100-200 kpa (8 to 10 psi), a significant cleaning called a clean in place (CIP) is required. CIP is on demand, and frequency can range from 1 to 12-month intervals. The CIP steps are:

- Air scour + water backwash
- Drain by gravity
- Mix and heat chemical solution to 104°F.
    - Acid Cleaning – pH 2, for inorganic fouling
    - Alkali Cleaning – pH 12 for organic fouling (repeat entire procedure at high pH), or
    - Sodium Hypochlorite for organic fouling (repeat entire procedure)
- Recirculate chemical solution through the module 30-40 min., then soak 60 min., then recirculate again.
- Drain chemical solution, air scour, then backwash and forward flush.
- Purge modules with filtrate and return to service.

A typical schematic of a CIP system is shown in Figure 3.

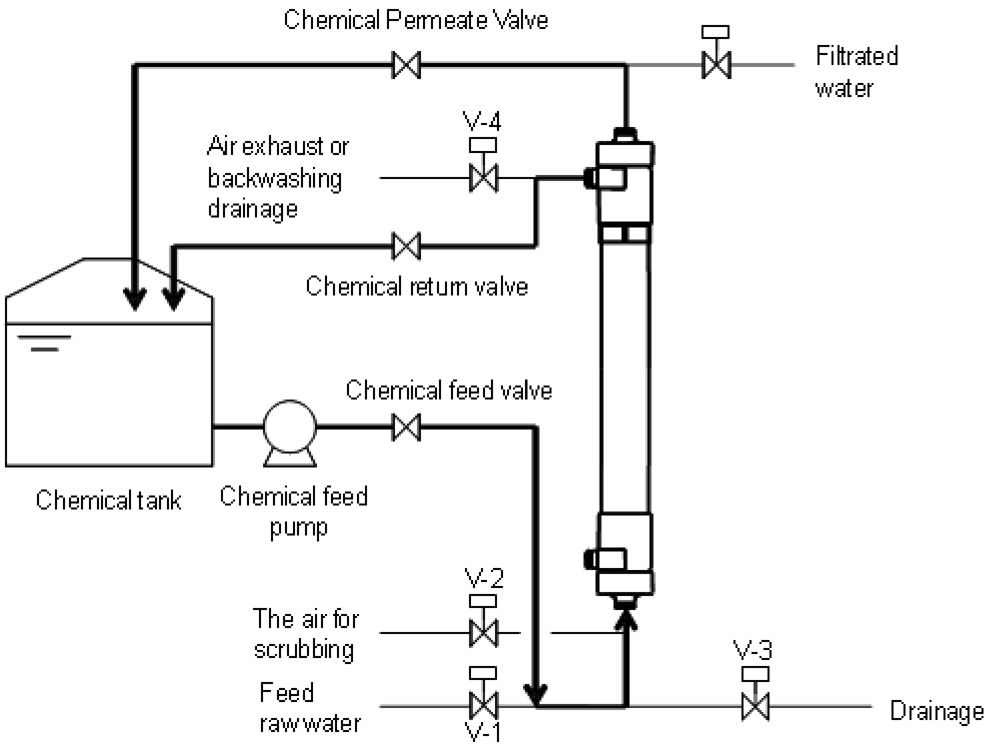


Figure 3: Clean-In-Place (CIP) Schematic

(vii) Wastewater from cleaning operations must be carefully managed. Typical chemicals used in CEB's and CIP's are shown in Table 2. The method of disposal is limited by the concentration of the chemicals in the wastewater. Each location uses a different approach to cleaning and is typically an *ad hoc* process. The management of this wastewater can be confusing and face regulatory hurdles. All of these issues add to the complexity of dealing with conventional MF and UF Membranes. More importantly, the literature clearly supports the fact that there is no consistency in applying these post treatment methods. The term "*ad hoc*" is used throughout the literature when discussing operational parameters. (Beswick, 2011)

Table 2 Summary of common types of fouling and their respective chemical treatments

Foulant	Reagent	Time and Temperature	Mode of Action
Fats and oils, proteins, polysaccharides, bacteria	0.5M NaOH with 200 ppm Cl2	30-60 min 25-55 °C	Hydrolysis and oxidation
DNA, mineral salts	0.1M – 0.5M acid (acetic, citric, nitric)	30-60 min 25-35 °C	Solubilization
Fats, oils, biopolymers, proteins	0.1% SDS, 0.1% Triton X-100	30 min – overnight 25-55 °C	Wetting, emulsifying, suspending, dispersing
Cell fragments, fats, oils, proteins	Enzyme detergents	30 min – overnight 30 – 40 °C	Catalytic breakdown
DNA	0.5% DNAase	30 min – overnight 20 – 40 °C	Enzyme hydrolysis

b. For **RSL membranes™**, all of the cleaning components as noted above are not part of the operational procedure. The benefit of **RSL Membranes™** is that the tubes are coated with a powder. The powder protects the membrane tube from exposure to fouling agents in Table 2. The powder is replaced after each filtration cycle where the filtration cycle lasts anywhere from 2 hours to 30 hrs. No hazardous chemicals are required for the replacement of the RSL powder. The RSL powder is NSF approved. The other major benefit is the size of the pores in the **RSL membrane™** tubes. These pores are 2.5 x 10^5 larger than the pores in a conventional UF membrane. If fouling were occurring on the membrane tube surface below the RSL powder skin layer, there would have to be significant fouling to cause a serious flow restriction on the membrane tubes. Nevertheless, **RSL membranes™** do have occasions when a CIP is necessary. In the event this occurs, the equipment, as outlined in Figure 3 above for CIP, is already part of the RSL system. The same equipment as used for CIP in conventional membranes is used for the **RSL Membranes™** to place the RSL powder on the membrane tube. If a CIP is necessary, a simple recirculation of the chemistry noted in Table 2 can be performed. Furthermore, there is no need for a CEB. As noted previously the optimum CEB would allow the membrane to operate for 4 to 30 months before requiring a CIP. The problem however with this optimum procedure is that the operating flux rate hast to be 17 lmh. **RSL membranes™** operate at a flux rate of 250 lmh to 800 lmh.

DAVID BROMLEY ENGINEERING LTD.

Summary: **RSL Membranes™** have eliminated the need for pretreatment and post treatment to manage membrane fouling. The technology provides simplicity in water treatment by eliminating process and chemical complexity due to membrane fouling.

RSL Membrane™ technology is one process unit that replaces all other technologies that separate:

1. Suspended solids
2. Colloidal solids less than 0.45 microns
3. Some dissolved solids, and
4. Oil and grease

RSL Membranes™ are a breakthrough technology that will provide the platform of one main and consistent process to use smart data analytics and create autonomous operations for water treatment facilities.

References

Yun Ye, Vicki Chen, Pierre Le-Clech, *Evolution of fouling deposition and removal on hollow fibre membrane during filtration with periodical backwash*, UNESCO Centre for Membrane Science and Technology, University of New South Wales, 2052 Sydney, NSW, Australia, March 31, 2011

Wikipedia Ultrafiltration Membranes

Yinghong Gao Jie Qin et al, B*ack pulsing technology applied in MF and UF processes for membrane fouling mitigation : A review;* **Journal of Membrane Science** Volume 587, 1 October 2019, 117136)

Michael Beswick B. Eng., University of Guelph, 2011 *Chemically Enhanced Backwash as the Only Ultrafiltration Fouling Control Approach in Seawater Applications*., University of Guelph, 2011)