dbe DAVID BROMLEY ENGINEERING LTD.

The differences between Conventional Low-Pressure Membranes and RSL Membranes™

The Science and Technology

Conventional low-pressure membranes are known as Microfiltration (MF) and Ultrafiltration (UF) Membranes. Both MF and UF membranes use the same technology to remove colloidal solids or oil from water. Specifically, pressure drives the water through the membrane pores while pollutants larger than the pore size are separated from the water passing through the pore. This is called a barrier method of filtration. UF membranes will provide a smaller colloidal particle separation (0.01 to 0.05 micron) than MF membranes (0.1 to 0.5 microns- µm). A MF membrane will reject particulates, including bacteria, suspended solids and colloidal solids while the UF membranes can reject these solids as well as some macromolecules including emulsified oils. To put this in perspective, a person with beautiful full hair has a hair diameter of 60 micron (µm-1/1000 of a millimeter) and a person who is losing their hair may have a hair diameter of 30 µm. Removal of a colloid or an emulsified oil constituent at the size of 0.01 µm is very small. These particulates will cause a cloudiness in the water but are not distinctly visible to the naked eye. The intention of the conventional low-pressure membranes and the **RSL Membranes™** is to remove these colloidal and nano size particles from the water.

Photo 1: This is a raw water sample from a refinery coker wastewater which is first treated with a flotation technology. The middle sample is the effluent from the flotation technology. Note the cloudy appearance of the water. The cloudy appearance is due to emulsified oil and colloidal solids. **RSL Membranes™** removed the oil and particle colloids. The permeate is the left sample.

There are two basic designs of UF/MF systems: pressurized systems and immersed membranes. Compared with pressurized membrane systems, submerged membrane processes have significantly lower operating costs.

MF or UF Submerged membranes

The reason for this significant operating cost difference is due to energy consumption and cleaning intervals for submerged membranes. Submerged membranes rely on a low differential pressure across the membrane to cause the water to pass through the membrane. For typical submerged membranes, the wastewater flows from the outside of the membrane tube to the inside. A vacuum is used to draw the water through the membrane to the inside of the tube and then to the treated water discharge. Treated water from a membrane is called permeate. A suction is placed on the inside of the membrane tube causing the water to permeate through the pore from the outside of the tube to the inside of the tube. For submerged membranes, the maximum flux rate is 25 to 30 litres/m2/hr (lmh) (S. Sadr et al, 2015). However, to accomplish this flux, there is a common requirement to back pulse the membranes every 15 seconds with the treated water which results in the back-pulse water being added back to the water to be treated on the upstream side of the membrane. This back pulsing causes a significant net flux reduction of approximately 20% less than the feed flux rate. If the feed flux rate is 25 lmh then the net flux rate would be 20 lmh. In addition, submerged systems rely on a maximum pressure differential (commonly called trans membrane pressure-TMP) of 70 to 85 kpa (10 to 12 psi) due to the limitation of a vacuum. With this TMP, energy consumption is very low compared to conventional pressure membranes but membrane area for submerged membranes is very high. Membrane area affects capital costs and major cleaning or replacement costs if necessary.

MF or UF Pressure membranes

Compared to submerged membranes, pressure UF membranes can operate with TMPs as high as 500 kpa (75 psi). As result flux rates will be higher at 50 to 100 l/m2/hr. To accomplish these higher flux rates, feed water to the membranes has to have water clarity < than 3 NTU (Swiezbin 2017)

Energy (Electricity) consumption for pressure UF membranes can range from 3 to 5 kwh/m3 (Hakami, 2020) (Shenana,2010).

Replaceable Skin Layer (RSL) Membranes ™

RSL Membranes™ are a hybrid submerged membrane using a low TMP (10 to 70 kpa, 1-10 psi) in combination with a very high flux rate 10 to 15 times higher than conventional submerged membranes. Operating at very high flux rates with an energy consumption less than submerged membranes results in high value energy savings per m^3 of water treated. Table 1 and 2 below provide a reference to the significant energy benefit of **RSL Membranes™**

Table 1 Energy Consumption Calculation for 5 MGD (865 m3/hr) Produced Water Treatment Facility Using **RSL Membranes™**

Electricity Demand for treatment of Produced water					volume=	855		m3/hr	
		Quantity	flow rate		press (m)	% used	efficiency	Ps (Kw)	Kw/M3/hr
P201	Raw water pump	1	780	m3/hr	10	98%	0.8	26.037	0.03
P204	RSL Slurry Pump	4	45	m3/hr	12	42%	0.8	3.066	0.00
P206	Backwash pump	2	30	m3/hr	50	23%	0.8	2.350	0.00
P207	B/W waste tank	10	10	m3/hr	12	50%	0.8	2.044	0.00
COMP1	Air Compressor	1				44%		38.000	0.02
Subtotal									0.06
Miscellaneous		10%							0.01
Total	kwh/m3	for RSL membranes							0.07
Total	per day								1458.09

Table 2 Unit Electricity consumption for surface water treatment plants using conventional UF Membranes

Plant size			
MGD	*m^3 day^{-1}*	*kWh MGD^{-1}*	*kWh m^3*
1	3 780	1483	0.39
5	18 900	1418	0.38
10	37 800	1406	0.37
20	75 600	1409	0.37
50	189 000	1408	0.37
100	378 000	1407	0.37

Source: Reproduced from California Energy Commission (CEC) Report (2005).

Operating Configuration of RSL Membranes™

Figure 1 provides a graphic on how **RSL Membranes™** operate as a hybrid between conventional submerged and conventional pressure UF or MF Membranes. Conventional UF submerged membranes operate with a flow pattern similar to the dead-end flow. Typically, the submerged membrane is in a tank (bioreactor- MBR). The flow is from the outside of the membrane tube to the inside of the membrane tube. The permeate then flows up the inside of the tube to a manifold where the permeate is collected for discharge to a treated water storage tank. The conventional UF pressure membrane operates in a contained housing where the flow is from the inside to the outside of the membrane tube and the housing is the collector of the permeate (treated water) which is conveyed to a storage tank. There are two components that are required to have the pressure membranes operate at a high flux rate. First the operating pressure (transmembrane pressure-TMP) is much higher than the submerged membrane (500 kpa vs 70 kpa). Secondly, there is a very high recirculation flow (cross flow) through the inside of the membranes to ensure solids do not cake on the inside surface of the membrane tube. Both the high pressure and the high recirculation flow use a significant amount of energy.

As a hybrid, **RSL membranes™** operate in a contained housing like the pressure membranes at flux rates 10 to 15 times higher than conventional submerged membranes but at pressures similar to submerged membranes. (i.e. 70 kpa).

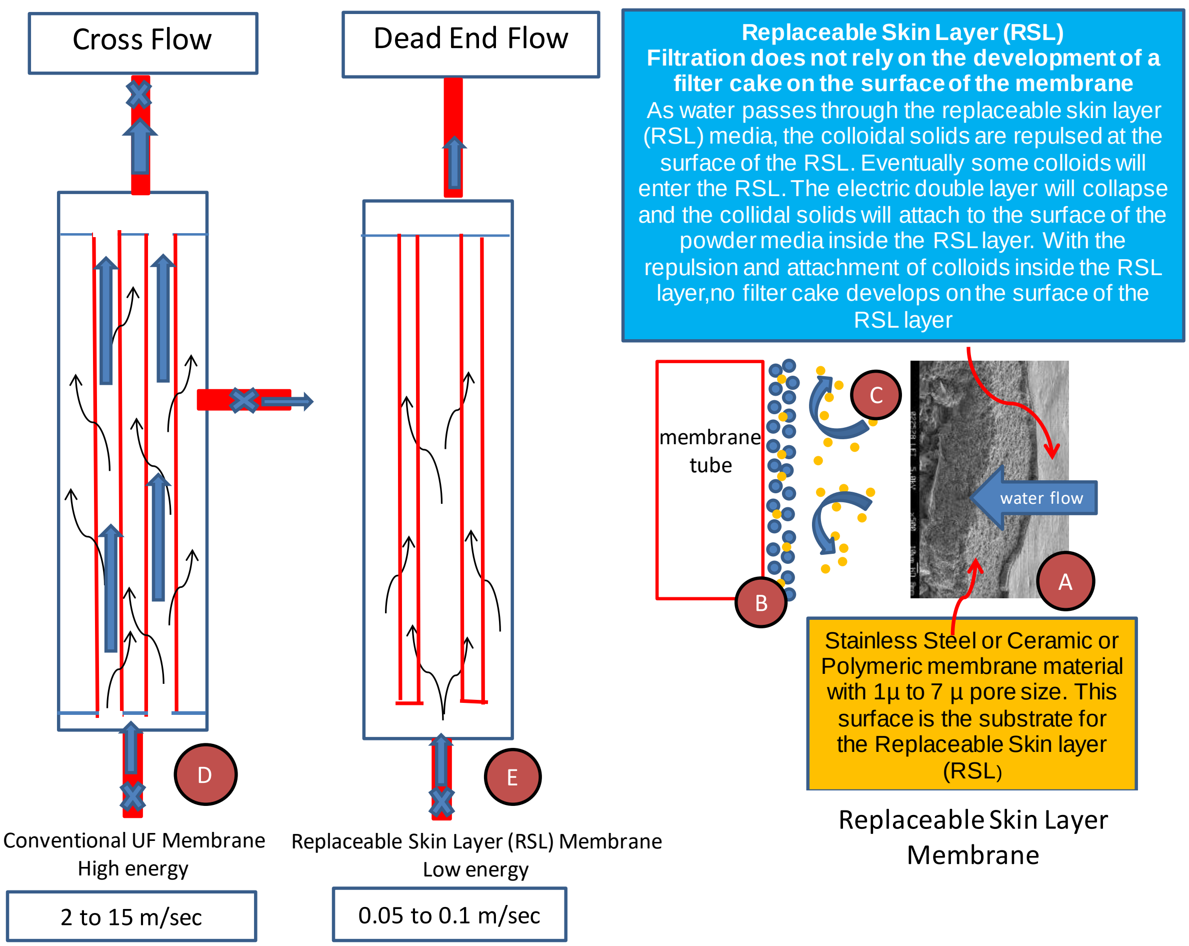

FIGURE 1: Membrane Flow Configuration and Repulsion with RSL powder

The flux rate for RSL membranes is so high that it is 5 to 7 times higher than conventional high flux, high pressure UF membranes. This ability to operate at very high flux rates, low pressure and no recirculation is due to a phenomenon explained by the DLVO theory (named after Boris Derjaguin and Lev Landau, Evert Verwey and Theodoor Overbeek). **Video "The DLVO theory" (link).**

A good example of the DLVO Theory is a river with fresh water carrying a high amount of suspended solids. In the river, the water is from the snow melt and the ionic environment is low so *the solids stay suspended. The electric double layer around the solids is strong causing the solids to repulse from each other. However once the river water reaches the ocean, the high ionic environment with the salt water and the Na^+ and the Cl^-, the suspended solids aggregate and settle thereby separating from the water. The water becomes clear.*

To further understand the DLVO theory lets take a 5 -minute lecture on this theory **Video 2 https://youtu.be/mtYblE0cfyg**

The DLVO theory teaches us why solids will stay in suspension and why they will repel from the surface of a membrane. **RSL Membranes™** use an ionic powder on the surface of a membrane tube to simulate the DLVO theory. This intense ionic environment on the membrane surface keeps the solids in the wastewater repelled from the powder surface there by allowing high flux (flow rates) through the membrane. The solids continuously are rejected away from the membrane surface and concentrate in the housing. Eventually some of the solids penetrate the powder layer and the electric double layer around the solid collapses causing the solids to aggregate with each other and the powder. The membrane powder layer rapidly clogs and the pressure rises to 70 kpa. This latter phenomenon is like the solids entering the ocean where the sodium and chloride cause the solids to aggregate and then settle. At the pressure differential of 70 kpa, the membrane and housing are backwashed

Video 3 The three operating steps of RSL membranes™ (link) *This video shows the three steps of operation which are as follows*

1. *Fill the housing with treated water and add the ionic powder to the surface of the membrane. **RSL Membranes™** rely on an ionic powder to simulate a highly ionic localized environment on the surface of the membrane in a contained housing full of water. The ionic powder is applied at the beginning of each filtration cycle.*
2. *Undertake the filtration of the water: A filtration cycle will last 2 to 30 hours, depending on the raw water quality. The ionic powder creates a 100 µm powder skin layer on the outside surface of a membrane tube. The membrane tube has pore sizes of 3 to 5 µm. As the filtration of the water continues the TMP increases.*
3. *Undertake a backwash: Once the pressure across the membrane (TMP) reaches 70 kpa (10 psi), the ionic powder skin layer is backwashed from the membrane tube. The contents of the membrane housing are also removed to a sludge tank. Step 1 is then repeated. The housing is filled with water and a new ionic powder is placed on the membrane tubes. **The replaceable skin layer (RSL) was the premise behind the naming of RSL Membranes™.***

During the filtration cycle, water carrying colloids, which have their own electric double layer (EDL) approach the surface of the membrane tube with the ionic powder skin layer. These colloids are confronted with a significant EDL on the surface of the membrane from the powder. The intense competing EDL environment causes the water to pass through the membrane and the colloids to repel away from the membrane surface. The ionic environment from the powder significantly enhances the hydrophilicity of RSL Membranes™. The hydrophilicity is so intense that **RSL membranes™** use a membrane pore size that is **2.5 x 10^5 larger** than the conventional UF membranes. This vast pore area difference facilitates the high flux rates at low pressure. In fact, **RSL membranes™** do not rely on the conventional barrier of a pore size to filter the water. RSL Membranes™ rely on the manipulation of the EDL around a colloid to cause repulsion away from the membrane surface.

Video 4 Solids repulsing from the Membrane surface (link). *In this video you can see the solids in the housing in suspension. As much as the flow rate towards the membranes is almost 100 ml/sec/m^2 of membrane area (350 litres /m2/hr), the solids are being repulsed from the surface and from each other and are remaining is suspension away from the surface of the membrane"*

RSL Membranes™ sometimes are compared to the dynamic membrane concept. Dynamic membranes are well recognized in the market where a filter cake is constructed on the surface of the membrane. In fact, there is research that shows that the development of a small particle filter cake on UF membrane surface, aids the filtration process but shortens the time periods between membrane back pulsing (See *Untangling Water treatment* (**Link**). Typically, for dynamic membranes, the turbidity of the water improves over the length of the filtration time as the filter cake builds on the surface of the membrane. This is not the case for **RSL Membranes™**. Turbidity levels are consistently low from the beginning of the filtration run to the end of the filtration cycle. In fact, since **RSL Membranes™** operate in a dead-end mode, the solids and or oil being separated from the water, will concentrate in the housing upstream from the membrane surface. Even with these high concentrations of solids (10,000 to 20,000 ppm) or emulsified oil (10,000 to 280,000 ppm) in the housing, the solid and oil concentration in the permeate remains very low.

Figure 2 is a typical turbidity and pressure curve. The pressure curve is asymptotic, and the turbidity is flat even though the **RSL Membrane™** powder skin layer is exposed with ever increasing solids and or oil concentrating in the housing.

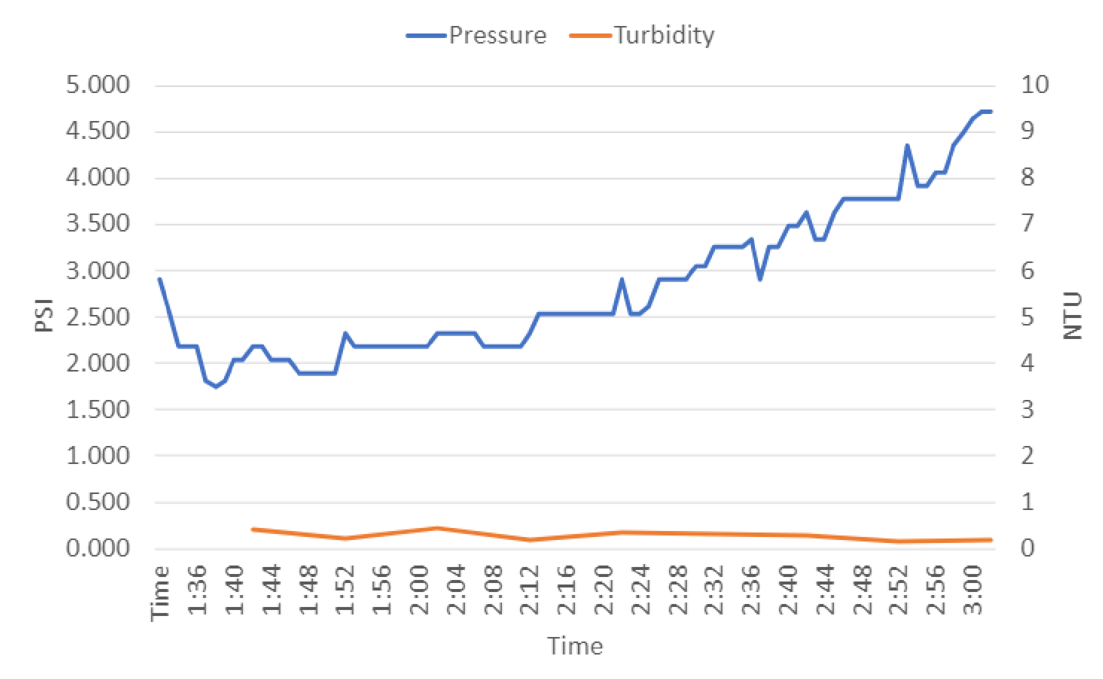

FIGURE 2: Filtering Kaolinite Clay Raw Water NTU= 41 with RSL Membrane™
Cosmetic clay allowed to settle for 20 hrs and supernatant filtered. 350 litres /m^2 /hr

Operations -Ultra Filtration (UF) Membranes versus RSL Membranes™

RSL Membranes™, use EDL manipulation to separate solids and oil, versus conventional UF membranes, which use barrier separation. A comparison of operating parameters between the two membrane configurations will accentuate the significant differences.

UF Membranes (pressure or submerged) rely on a multi step operating procedure including

1. Pre-treatment of the water so that the water flowing through the UF Membrane will optimize the barrier filtration system of the UF Membrane
2. Filtration of the water through the UF Membrane resulting in 5% to 20% of the water being rejected and either returned to the feed water to be filtered or disposed of into a local sewer or onsite disposal facility
3. Backwash pulsing as frequently as every 15 seconds using the treated UF Membrane water (permeate.)
4. Chemical enhanced backwash (see *Untangling water treatment*-**Link**) as frequently as once every hour
5. Clean in Place where the UF membrane is shut down for a major chemical cleaning as frequently as every 2 months but typically one to two times per year (see *Untangling water treatment*-**Link**)

Compare the UF Membrane operational procedure to the **RSL Membranes™** simple three steps discussed previously (1. Apply RSL Powder, 2. Filter the water, 3 Backwash the **RSL powder** from the membrane).

A further detail assessment of the operating procedures, will highlight the simplicity of **RSL Membranes™**

Pre-treatment Requirements :

a. For ultrafiltration (UF) membranes (Wikipedia Ultrafiltration Membranes), treatment of feed prior to the UF membrane is essential to prevent damage to the membrane and minimize the effects of fouling. Fouling of the membrane is a serious problem which greatly reduces the efficacy of the solid and oil separation as well as the life cycle of the membrane. 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 pre-treatment to manage organics and pH. For example, pre-treatment 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 3, the feed to a UF membrane cannot exceed 15 NTU. If the feed water has a higher than 15 NTU, typically the pre-treatment will 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 pre-treatment processes creates a complex operational procedure. These pre-treatment 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. For **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 up to 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.

Impact of Total Dissolved Solids (TDS): Low pressure membranes such as UF membranes are impacted by organics, microbial colloids, inorganics, and mineral colloids. The most significant issue is a buildup of a cake layer on the membrane surfaces with one or all of these parameters, (Dashtban et al,2016). Dashtban -Barbeau show in their research, the importance of an ionic environment to reduce fouling. Figure 3 provides three scenarios where the ionic parameters of the feed water are varied and the impact on the flux rate / lower fouling is observed. The first chart varies pH and shows that at a neutral pH, the flux rate is lower than when the ionic environment increases with a higher or lower pH. The second chart assesses the impact of ionic strength and displays that the higher the ionic strength, the higher the flux rate with lower membrane fouling. The third chart observes the impact of ionic strength from increased hardness.

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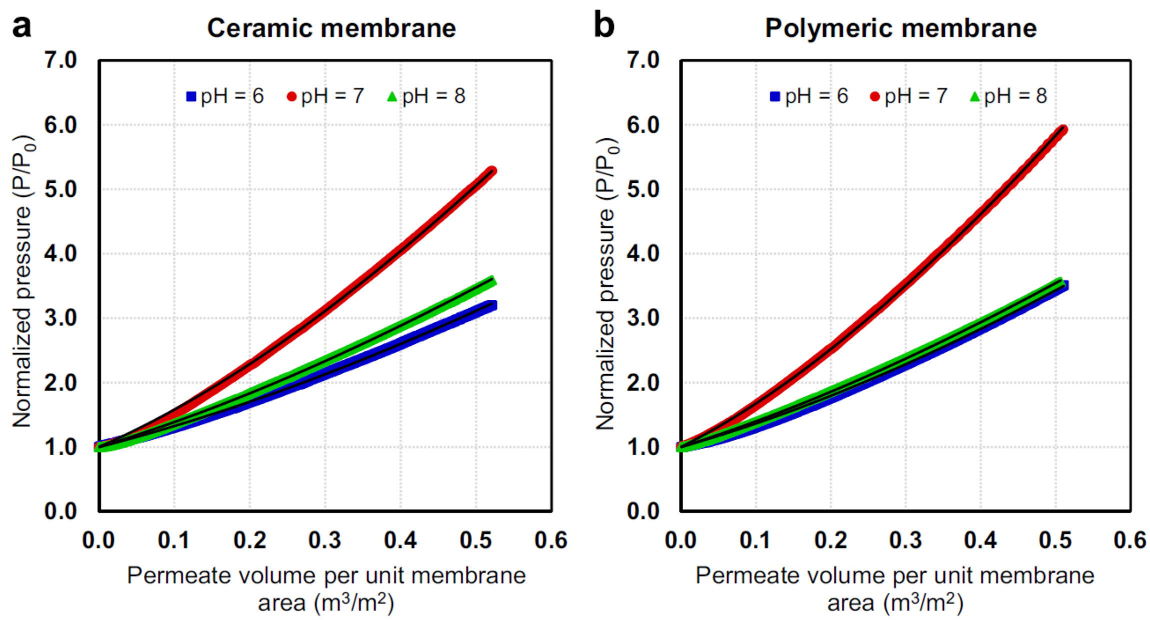

Figure 3A Change in Ionic Environment with pH adjustment

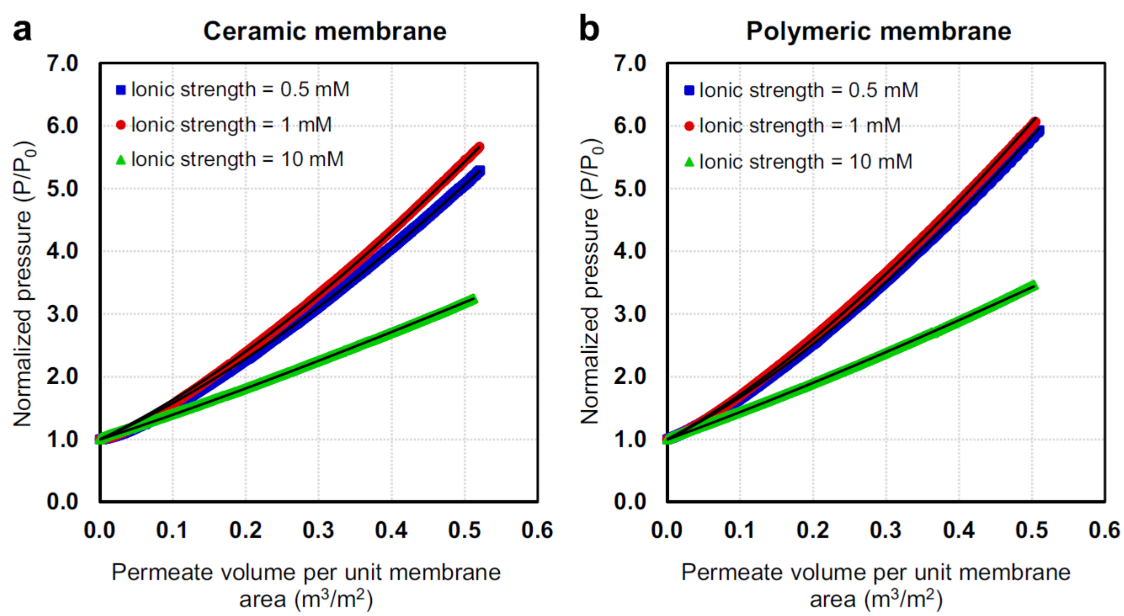

Figure 3B Change in Ionic Environment due to TDS

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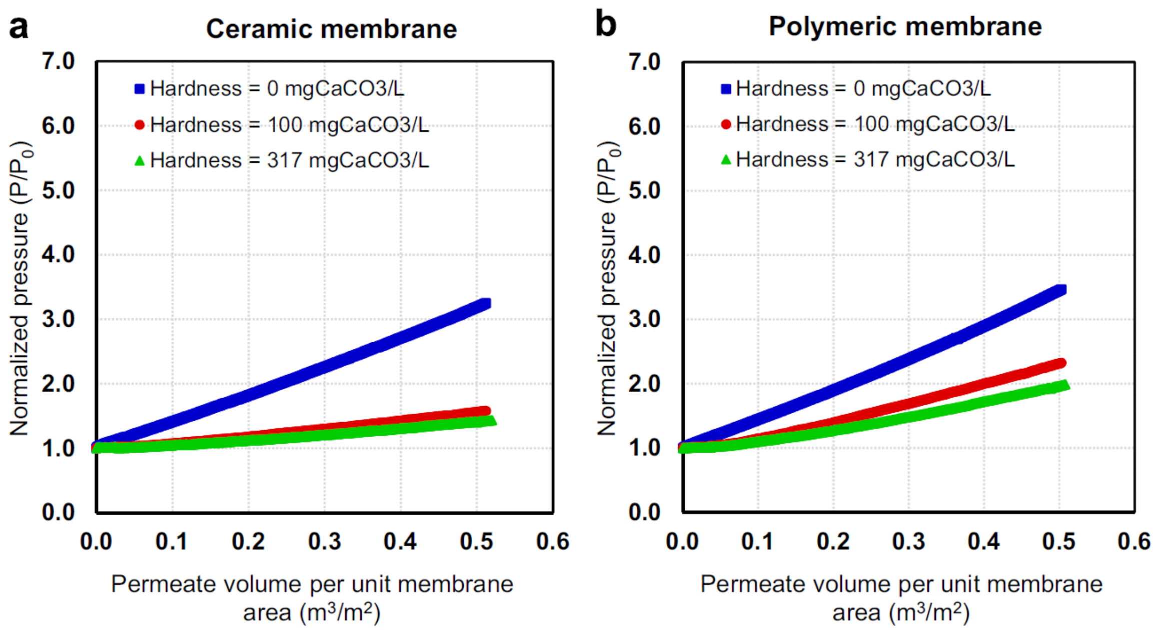

Figure 3C Change in Ionic Environment due to TDS

The above plotted data shows the significant impact in the improvement of flux and lower fouling due to the high ionic levels of the water being treated. **RSL Membranes™** with the addition of the highly ionic powder, as a replaceable skin layer, provides the localized strong ionic environment at the surface of the membrane. However, over the filtration cycle, the colloidal solids concentrate near the surface of the membrane powder. Eventually the ionic environment becomes so intense that the colloidal solids attach to the powder because the EDL around the colloidal solid collapses as it does in the ocean example presented earlier. The EDL around the colloid has lost its repulsion strength. The result is an asymptotic increase in the TMP across the membrane. **RSL Membranes™** can backwash off the powder skin layer and start again with a new skin layer. Conventional UF membranes do not have this luxury. The same EDL collapse of on the colloids occurs on the surface of the UF membrane skin layer. Those solids attach to the skin layer and the skin layer becomes fouled. The build-up of the colloidal solids creates a difficult to remove scale and ongoing deterioration of the membrane. There have been past attempts to pretreat wastewater by adding salt (NaCl) to the water and thereby simulating the same effect as the ocean example discussed earlier. The obvious problem, however, is the removal of the salt after the water is treated. **RSL Membranes™** have eliminated this problem with the use of the replaceable ionic powder skin layer. Furthermore, as shown in

Table 4, the **RSL Powder** has a propensity to adsorb ions and thereby reduce ionic levels in the treated water. (www.aquavarra.ie)

Removal of Dissolved Solids: Both Conventional UF membranes and **RSL Membranes™** are defined as membranes that will remove colloidal solids but not dissolved solids. However, based on the definition of total suspended solids (TSS), total solids (TS) and total dissolved solids (TDS), both membranes types will remove some dissolved solids. TS is calculated by taking a sample of the water, placing it in a crucible, and evaporating the water. The crucible is weighed before and after. TSS is measure by passing a sample of water through a filter. The filter is dried and weighed before and after. TS minus TSS = TDS. In North America there are three different standards to measure TSS;

a. EPA Method 160.2,
b. Standard Method 2540-D, and
c. ASTM Method D5907.

The three standards use different pore size filters to separate the TSS from a sample. The filter pore size can range from 0.7 micron to 1.5 micron. In Europe and Asia, 0.45-micron pore size is used for the filter which is the standard we have adopted for RSL membranes™.

However, **RSL Membranes™**, like UF membranes separate colloids as small as 0.01 micron. Therefore, both membranes can remove dissolved solids. Our research has shown that RSL membranes remove as much 50% of dissolved solids (TDS) based on the testing of raw water versus permeate using a 0.45-micron filter.

One significant benefit of the **RSL Membranes™** is their ability to absorb certain metals during the filtration process. Testing and ICP analysis has provided a data base which confirms that **RSL Powder**, used as the membrane skin layer, has consistently adsorbed

1. Aluminum >85%
2. Barium > 70%
3. Boron >40%
4. Fe >85%
5. Si >65%

Other metals, to a lesser extent are also being adsorbed. Table 4 summarizes a study that evaluated the adsorption capability of **RSL Powders** compared to conventional media (Activated Alumina and Diatomaceous Earth- DE) used for filter cake/dynamic membrane filtration processes. With this level of adsorption capability, specifically for Barium and Silica, **RSL Membranes™** are an excellent choice for pretreatment of water prior to RO membranes in pure water applications. Barium and silica create scaling issues for RO Membranes.

Table 4 Adsorption of Metals -RSL Powders 1 and 2 vs Activated Alumina and Diamataceous Earth								
metals	RSL Powder 1		RSL Powder 2		Activated Alumina		Diamataceous Earth	
	Reduction (%)	Data Set	Reduction (%)	Data Set	Reduction (%)	Data Set	Reduction (%)	Data Set
Al	85.06%	6	88.60%	4	50%	1	25%	1
B	41.67%	6					-11%	1
Ba	75.25%	4	31.28%	4	39%	2	-100%	1
Ca	16.71%	7			61%	2	-16%	1
Co								
Cr								
Cu					-1%	1		
Fe	91.37%	5	76.92%	1	-2%	1	100%	1
K	22.80%	5	42.00%	2			-13%	1
Li	19.80%	5			2%	1	-13%	1
Mg	18.14%	7			3%	1	-9%	1
Mn			5.56%	3	-3%	2	100%	1
Na	12.83%	6			27%	1	-11%	1
Ni					3%	1		
P					6%	1		
S	6.14%	7					-12%	1
Si	68.71%	7	72.25%	4	2%	1	26%	1
Sr	29.20%	5			16%	1	-6%	1
Ti			79.12%	3	100%	1		
V			28.13%	1				
Zn	13.00%	4			11%	1		

With the ability to remove solids less than 0.45 micron and to adsorb numerous dissolved metals, **RSL Membranes™** not only provide almost total elimination of TSS in the permeate, they also provide useful reductions in TDS levels.

Post-treatment (also see Untangling Water treatment)

One of the problems with all water treatment technologies is the need to manage the fouling of the media used to filter solids whether in a colloidal or dissolved state. Multi-media (sand) filters, cloth filters, disc filters, self-cleaning screen filters and low-pressure membranes (UF and MF membranes) all require an extensive backwash protocol to ensure the filtration system can be sustained. Backwash waters create another waste stream that must be managed. Other methods of solid separation such as clarifiers (settling tanks) or flotation technologies (DAF or IGF) and oil water separators must carefully manage the sludge produced by these processes.

RSL Membranes™ have overcome these issues of post treatment management. Six key operational procedures, identified below, have made **RSL Membranes™** the highest recovery (volume of treated water / volume of treated raw water) technology in the market.

1. Backwash is by air or gas at a pressure of 5 to 6 bar (75 to 90 psi) and takes 28 seconds

2. Backwash occurs only at the end of a filtration cycle. Filtration cycles last 2 to 30 hours depending on the raw water quality. Backwash occurs when the TMP reaches 70 kpa (10 psi)
3. Backwash pulses occur as much as every 15 seconds for conventional Ultrafiltration membranes. These pulses DONOT occur with **RSL Membranes™**.
4. All **RSL Membrane™** housings can be rated, if necessary, as pressure vessels to ASME standards
5. Once the housing and the membranes are backwashed, a new **RSL Powder** layer is applied to the surface of the membrane tube. Application of the **RSL Powder** layer takes about 5 minutes. Not only does the **RSL Powder** layer create a localized intense ionic environment on the surface of the membrane tube, simulating the DLVO theory, the **RSL Powde**r layer also protects the membrane tube. This protection normally eliminates fouling of the membrane tube resulting in 100% recovery of the membrane flux rate and TMP after backwash.
6. The dead-end filtration concept (see Figure 1) produces a concentrated sludge. When backwash occurs with air or gas, the concentrate in the housing is not diluted as it is with a water backwash. The concentrated and undiluted backwash provides the much higher recovery rate (>99%) compared to conventional UF membranes. (80 to 95%).

With regards to membrane cleaning to remove fouling

a. For UF Membranes, cleaning of the membrane is required regularly to prevent the accumulation of foulants and reverse the degrading effects of fouling on permeability and selectivity. Membrane cleaning is the most complex step in a UF Membrane operation. Cleaning involves the frequent use of acids, caustics and oxidizers. These chemicals are hazardous. In addition, these chemicals produce a waste stream that needs to be carefully managed. With a high degree of fouling, it may be necessary to employ aggressive cleaning solutions to remove fouling material. However, in some applications this may not be suitable if the membrane material is sensitive, leading to enhanced membrane ageing
b. **RSL Membranes™**, typically do not need chemical cleaning as explained previously in the *Post Treatment* section. The RSL powder provides a protection to the membrane tube. In addition, the large pore size of the membrane tube makes fouling more difficult and certainly much slower. The frequency of cleaning RSL Membranes is significantly less than UF Membranes. However, if on occasion. there is a need to clean the membrane the **RSL Membranes**™ have a built-in cleaning apparatus that typically is used to place the **RSL Powder** on the surface of the membrane tube. This built-in system allows for recirculation of cleaning fluid through the membrane tube. It simplifies and contains any hazardous chemicals used in the cleaning process. Furthermore, **RSL Membrane™** research team is developing a non-corrosive , nonhazardous acid for membrane cleaning that will be available soon.

Table 5 provides a further list of chemicals required for various types of membrane fouling.

Table 5 Summary of common types of fouling and their respective chemical treatments

(Wikipedia- Ultrafiltration)

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

1% SDS (sodium dodecyl sulfate) is an anionic detergent**,** commonly used to solubilize proteins and lipids and lyse bacterial and animal cells**.** It is used in denaturing protein gel electrophoresis.

Membrane specifications

Material

a. UF membranes use polymer materials (polysulfone, polypropylene, cellulose acetate, polylactic acid). Temperature limitation is typically 45^0 C due to the limitation with the potting material used in the membrane housing. For higher than 45^0 C, UF ceramic membranes are used.
b. **RSL Membranes™** also use polymer materials, as well as silica carbide. The polymeric membranes can be used up to temperatures of 90^0 C. For high temperature applications and high chloride application, titanium membranes are used. For high temperature and low chlorides, lower cost stainless steel membranes are available.

Pore size

a. For UF membranes, a general rule for choice of pore size in a UF system is to use a membrane with a pore size one tenth that of the particle size to be separated. This limits the number of smaller particles entering the pores and adsorbing to the pore surface. Instead they block the entrance to the pores allowing simple adjustments of cross-flow velocity to dislodge them. Figure 1 shows the use of cross flow in UF Membranes. A high recirculation flow through the inside of the membrane flushes the inside surface of the membrane tube removing blockage of the pores. Not only is this a high energy consumption due to the size of the recirculation pump, the potential for fouling increases significantly from the small pore size.
b. **RSL Membranes™** operate with a very large pore size 3-5 micron in comparison to UF membranes (0.01 to 0.05 micron). Based on the 10 to 1 principle noted above, UF membranes are designed to remove 0.1 to 0.5 micron absolute. **RSL Membranes™** have data from the treatment of produced water from the oil and gas industry that shows absolute micron removal of 0.65 micron. The ability of **RSL Membranes™** to use a large pore size and achieve similar quality water to UF membranes, facilitates the very high RSL membrane™ flux rates. (50 to 100 lmh vs 350 to 700 lmh respectively). This high flux rate ensures **RSL Membranes™** are the lowest cost UF quality membrane in the world. The high flux rates are achieved without the need for an energy intensive recirculation pump and at a very low transmembrane pressure (TMP). Electricity consumption (kwh/m3) is one of the lowest for any water treatment process used to separate solids or oil from water.

In summary, Table 6 provides an excellent overall comparison between conventional UF membranes and **RSL Membranes™**. The table accentuates the robustness and benefits of the **RSL Membranes™**. It also provides the basis for the claim that **RSL Membranes™** replace all other methods of solid and oil separation from water.

Table 6 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

(Wikipedia Ultrafiltration)

In 2020 **RSL Membranes™** have become a viable commercial product **Video 5 link**

This is a 25 m3/hr ***RSL Membrane****™ system treating produced water from an oil and gas operation. It is separating TSS and oil all within one process unit, The* ***RSL Membrane****™. It operates 7 days a week 24 hours per day treating a water with 50 to 100 ppm of oil and 150 ppm of TSS. The raw water also contains high amounts of poly acrylamide polymer (PAM) which is used for enhanced oil recovery. PAM is a serious membrane fouling agent yet the* ***RSL Membranes™*** *continue to operate on a 3 hour filtration cycle. After each backwash the membranes recover to 100% of their original TMP of a new membrane.*

One simple process unit is now available to handle a wide range of suspended solids, colloidal solids, dissolved solids and oil. The elimination of multiple processes in series simplifies water treatment to the point that autonomous water treatment systems are achievable. With one main process unit that can accept a broad range of water or wastewater quality, data analytics and smart technology can now be applied with confidence.

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