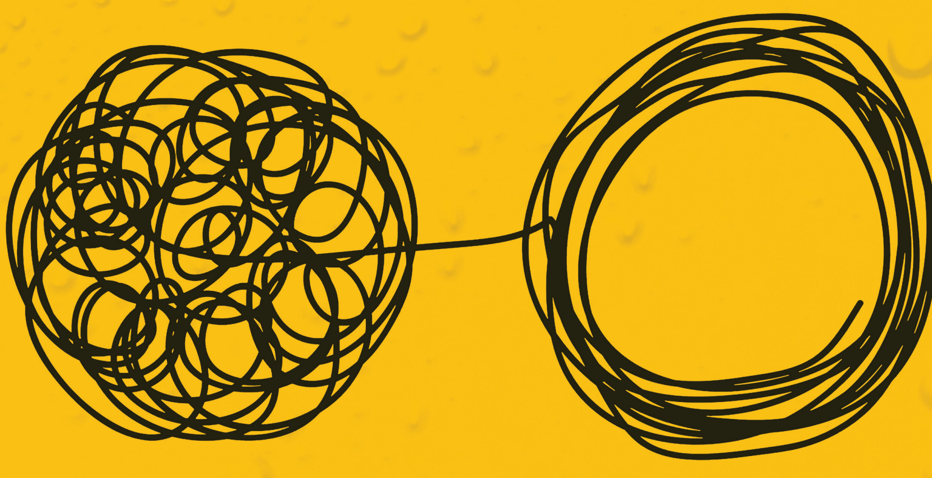
RSL Membranes™

Replaceable Skin Layer Membranes™

Finalist as the most Disruptive Technology in the World

Untangling Water Treatment *with* Transilience



The World's lowest cost membrane

www.dbe-rsl.com patent protected

About Us

The David Bromley Engineering Ltd. (DBE) is a 44-year-old water treatment technology-based company. The firm has been involved in the development, evaluation, and/or commercialization of over 50 clean water and energy technologies. DBE Hytec Ltd is a fully owned subsidiary of DBE.

In the last 12 years, DBE has focused on the water energy "Nexus" and developed a highly disruptive, globally recognized, water treatment technology. The technology, known as RSL Membranes™, provides as much as a 50% reduction in capital and operating costs, a 90% reduction in energy consumption, a 90 to 95% reduction in waste reject volumes and as much as 35% reduction in process equipment area requirements.

The RSL Membrane™ technology was a finalist as the most disruptive sustainable technologies in the world and was also awarded the designation of being one of the "top 100 environmental technologies in the world".

In 2019, DBE was also recognized as one of the top 51 water leaders in the world because of its development of the RSL Membrane™ technology.

Visit our website at [Home - DAVID BROMLEY ENGINEERING LTD (dbe-rsl.com)](dbe-rsl.com) which illustrates the research and science behind the technology as well as it's commercial applications. The webinars and videos facilitate an easy understanding of RSL Membranes™.

Founder

Mr. David Bromley M.Eng., P. E. is an internationally recognized expert in industrial and pure water treatment technology with over 40 years' experience working throughout North America, Asia and the Caribbean. Mr. Bromley was selected by the US EPA for his expertise in the energy-water nexus to coauthor a book on water treatment and infrastructure. He then coauthored a second book, with the leading scientific publisher, Elsevier Publishing, on the food-water-energy nexus. Mr. Bromley is the inventor and developer of the patent protected RSL Membrane™ technology.

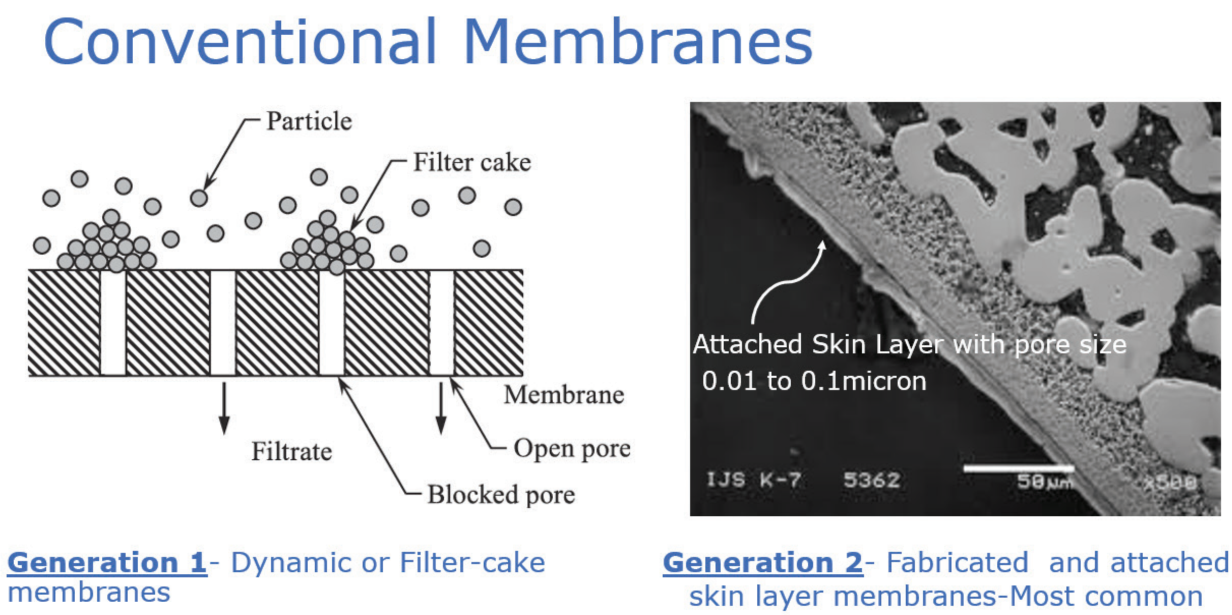
"RSL Membranes™ have a pore size 25000 times larger than conventional UF membranes yet produce similar quality water."

Replaceable skin layer (RSL) membranes™ rely on the use of an ionic charged powder placed on the surface of a membrane substrate where the powder simulates a well-known scientific theory called the DLVO theory (named after Boris Derjaguin, Lev Landau, Evert Verwey and Theodoor Overbeek). The DLVO theory teaches the impact of an ionic environment on the strength of the electric double layer (EDL) around colloidal solids. Colloids in suspension (suspended solids) remain in suspension because of a strong EDL around the colloidal solid. Replaceable skin layer membranes use a strong ionic powder layer that causes a strong EDL on the surface of the membrane. This strong membrane EDL prevents the caking of solids on the surface of the membrane. However, there is a buildup of solids within microns of the powder surface. This gap between the solid mat layer, shown in Figure 1, and the actual powder layer on the membrane substrate is called the "Colloidal Gap" where the water is essentially free of discrete particles and solids. The purity of water, in the colloidal gap, facilitates a low resistance through the powder and the wall of the membrane substrate. As this solid layer builds, the pressure drop across the membrane (TMP) is close to zero. In addition, this low TMP occurs at a flux rate of 300 to 800 litres per m^2 per hour (i.e.,10 times conventional membranes). RSL Membranes™ act as a dead-end membrane. As the separated solids continue to accumulate on the solid mat layer, there is a point where the solids in the mat layer leak into the ionic powder. When the solids leak into the ionic powder, their EDL collapses and the solids attach to the powder causing the TMP to increases asymptotically. When the pressure reaches 0.7 bar (70 kpa or 10 psi), the membranes are backwashed. Figure 5 below shows the typical TMP and Turbidity vs time for the RSL Membranes™. The two stages of TMP development with first stage being a low and constant TMP and then followed by a rapid increase in TMP defines RSL Membranes™ as a Generation 3 membrane.

Figure 1 Solids Mat build up and development of colloidal gap to facilitate low and constant TMP

A comparison between Generation 1 and Generation 2 Membranes with RSL Membranes™ is helpful. Generation 1 Membranes are commonly referred to as dynamic membranes (see Figure 2). They rely on the placement of a powder precoat (filter cake) and/or the placement of solids inherent with the liquid being filtered, on a porous substrate. This placement of solids on the porous substrate causes a bridging to create a small pore size for filtration. The more the bridging of solids, the smaller the pore size. As a result, the permeate (filtered liquid) from dynamic membranes improves in quality over the length of the filtration run. A typical dynamic membrane will use a precoat material such as diatomaceous earth (DE).

Figure 2: Conventional Generation 1 and 2 Membranes



After the development of Generation 1-dynamic membranes, Generation 2 -conventional low-pressure membranes were developed to provide a consistent high-quality water throughout the filtration cycle. These membranes are commonly referred to as Microfiltration (MF) Membranes and Ultrafiltration (UF). Generation 2 membranes dominate the market today and are entrenched as the key process in most water treatment systems. Conventional membranes consist of a fixed skin layer that has a pore size which provides the barrier for solids larger than the pore size to pass through. The skin layer is affixed to a porous substrate material in a tube or sheet format. There are also small tube formats (2 mm diameter) that are constructed only of the skin layer itself. (i.e. there is no substrate).

The common problem with conventional membranes is the fouling of the skin layer. To facilitate and reduce fouling, frequent backwash pulses are required. When the skin layer does become fouled, aggressive chemical cleaning is necessary. Unfortunately, the skin layer never recovers to its original condition and eventually deterioration requires the entire membrane to be replaced.

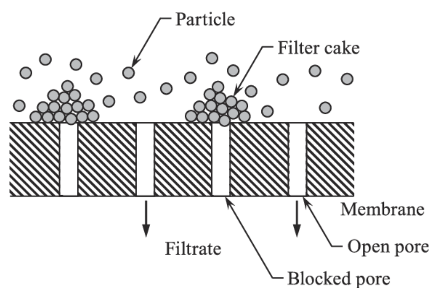
Both Generation 1 and 2 membranes rely on the separation of solids and colloids via a barrier. The smaller the pore size of the barrier, the smaller the solid or colloid that can be removed. Whereas RSL Membranes™ operate with pore sizes 500,000 times greater than conventional low-pressure membranes yet achieve similar solid /colloid separation. Replaceable skin layer membranes rely on the colloidal solid being repelled away from the surface of the membrane. If the colloidal solid does penetrate the surface powder layer, the EDL around the colloid collapses, the colloid becomes destabilized and attaches to the powder. The powder eventually becomes fouled and must be backwashed/removed. A new powder is applied, and the filtration cycle repeats itself. The operation of RSL membranes™ consists of three consistent and easy steps.

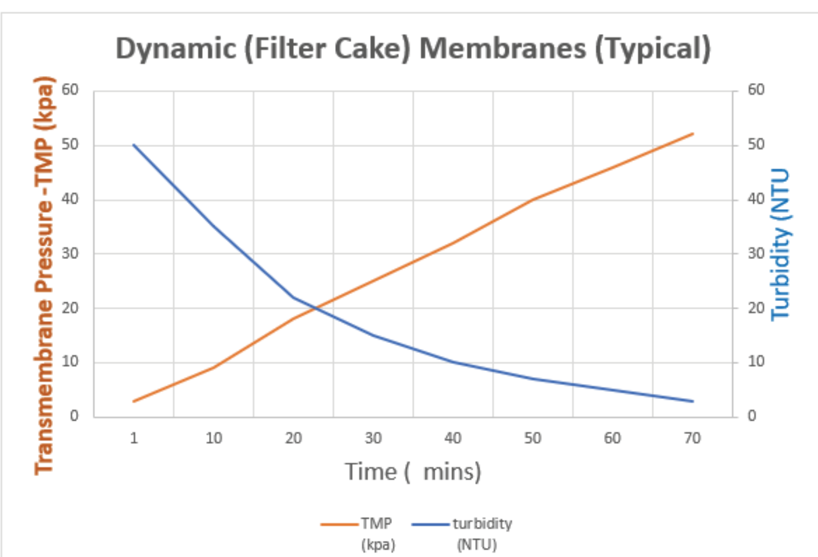
1. Apply the ionic powder to the surface of the membrane tube (15 minutes)
2. Filter the water at a flux rate between 300 to 800 lmh until the TMP reaches 70 kpa (10 psi) (3 to 20 hrs)
3. Backwash (air and water) and refill the housing with permeate, ready for Step 1 (5 minutes)

A comparison of the TMP and Turbidity (NTU) versus Time for each of the three generations of membranes is a helpful graphic for comparison of operating conditions and performance. Figure 3 ,4 and 5 show the typical TMP and Turbidity versus time for dynamic membranes (Generation 1), conventional MF and UF membranes (Generation 2) and RSL Membranes (Generation 3), respectively.

Figure 3 Generation 1- Dynamic (Filter Cake Membranes) TMP and Turbidity vs Time (Typical)

Note: The “X” plot where turbidity improves through the filtation cycle but as the filter cake builds on the surface of the membrane the TMP increases.





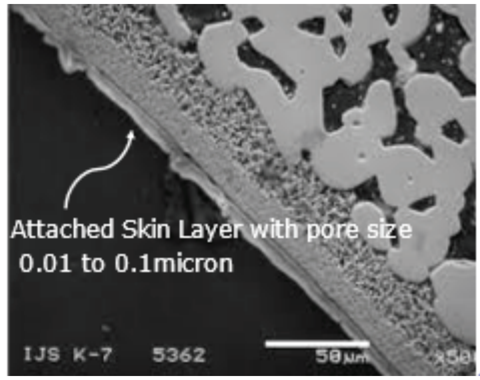


Figure 4 Generation 2- Conventional Microfiltration and Ultrafiltration (MF or UF Membranes) TMP and Turbidity vs Time (Typical)

Note: 1.TMP rises on a linear basis. In this case, after approximately 16 minutes, a backwash (BW) occurs. When the backwash occurs the TMP drops but never drops to the original new membrane TMP level. The linear increase in TMP is evidence of a thin filter cake building on the surface of the membrane skin layer.

2. Eventually a chemical enhanced backwash (CEB) is performed. The CEB provides a better recovery of the TMP than the BW pulse.

3. Once the TMP reaches 200 to 300 kpa, a clean in place (CIP) with acid and caustic washes occurs to cause the TMP to be significantly reduced but never to the level of a new membrane.

4. Turbidity remains consistent and of high quality throughout the filtration cycle

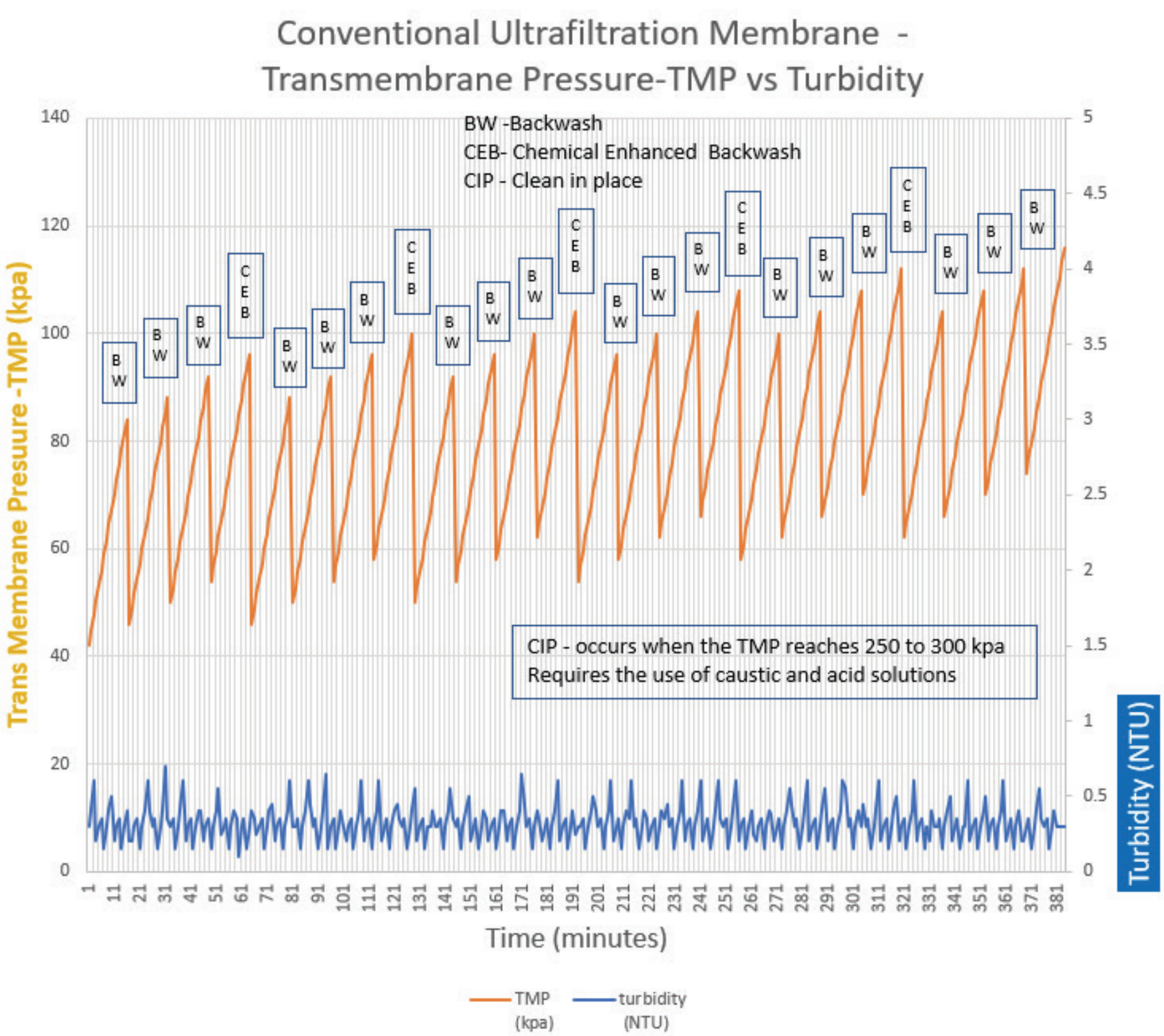


Figure 5 Generation 3-Replaceable Skin Layer Membranes- TMP and Turbidity vs Time (Typical)

Note1: Zone A where the TMP is very low and close to zero and Zone B where the TMP increases asymptotically.
2: B/W occurs after many hours and at a low TMP of 70 kpa. B/W typically restores membrane to original TMP

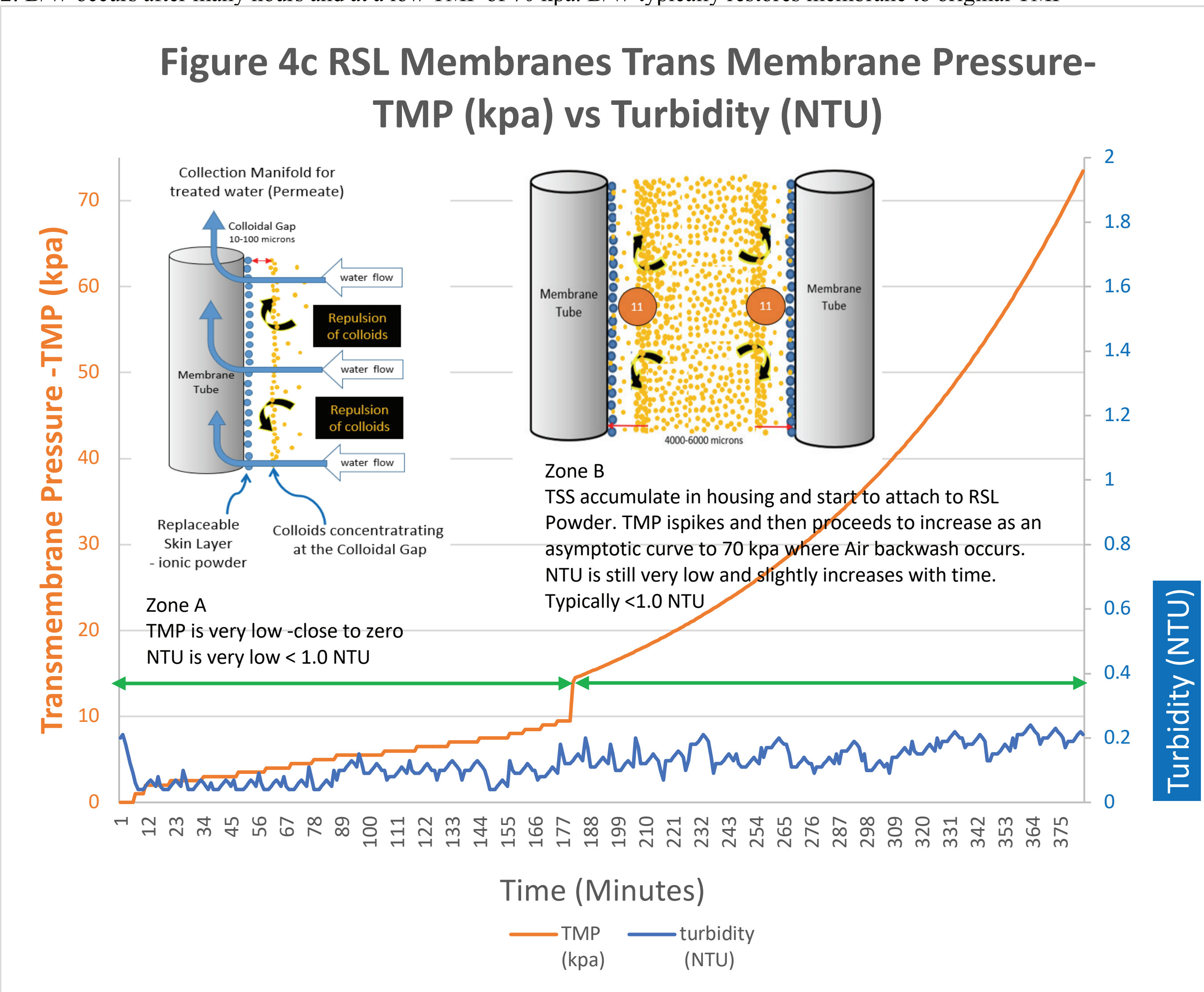


Figure 6 The New 100 m^3/ hour RSL Membrane™ treatment module

1. FT MCMURRAY, ALBERTA-HORIZON MINE - CANADIAN NATURAL RESOURCES LTD.(CNRL): The first long term assessment of RSL Membranes™ occurred at CNRL's Horizon mine site in Ft McMurray Alberta. The one-year assessment involved the comparison of RSL Membranes™ and ceramic membranes developed by Veolia. The operation and assessment of both technologies was controlled by a third party (Epcor Utilities) where the third party operated the technologies seven days a week and 24 hours per day. The technologies were being evaluated as a method of pretreatment for an RO membrane process. The source of the water was CNRL's process tailings pond. At that time in the development of RSL Membranes™, they were used as part of a hybrid process called "nanoflotation". Nanoflotation used a surfactant to cause the bubble in a flotation system. It was thought at the time, the RSL Membranes™ like Generation 2 conventional membranes needed a pretreatment system before the ceramic (conventional) membranes. In this test the UF ceramic membrane pretreatment system was a lamella clarifier. Because UF ceramic membranes had specific specifications as to the water they could treat, there was the need for pretreatment. The RSL Membranes™ not only performed consistently, but they also

outperformed the ceramic membrane with a 10-fold improvement in flux rates. In addition, the RSL Membranes™ displayed a high level of robustness. In fact, there was no need for pretreatment using the surfactant based flotation technology. On the other hand, the ceramic membranes were limited in operation up to TSS levels of <100 mg/l. Figure 7 shows the testing site. The white trailers were for ceramic membrane technology and the blue trailer (to the left of the white trailers) was the replaceable skin layer technology. The difference in footprint is significant. Table 1 provides a summary of the treatment results.

Figure 7 Testing Site at Canadian Natural Resources -Field Test of the RSL Membranes™ versus Veolia ceramic membranes with the silica carbide skin layer.

Table 1 Water Quality Data for RSL Membranes™ treating Tailings Pond Water (EPCOR Study)

Average RCW and Treated Water Quality with % Reductions (Maxxam)

Parameter	Units	Average RCW	Average Membrane Tank	% Reduction by Flotation	Average NF Effluent	% Reduction by Filtration	Overall % Reduction
pH (on-site lab)	SU	8.27	8.08	2.4%	8.07	0.1%	2.5%
Turbidity	NTU	115	12	89.2%	0.2	98.3%	99.82%
Electrical Conductivity	µS/cm	2983	2817	5.6%	2850	NA	4.5%
Total Dissolved Solids	mg/L	1750	1600	8.6%	1650	NA	5.7%
Hardness (as CaCO3)	mg/L	48	52	NA	53	NA	NA
Bicarbonate	mg/L	853	780	8.6%	790	NA	7.4%
Total Alkalinity (as CaCO3)	mg/L	700	638	8.8%	647	NA	7.6%
Silica	mg/L	4.94	4.32	12.6%	4.58	NA	7.3%
Ammonia	mg/L	1.38	1.33	3.6%	1.37	NA	1.2%
Chloride	mg/L	473	443	6.3%	452	NA	4.6%
Sulphide	mg/L	0.0057	0.0022	62.2%	0.0026	NA	55.2%
Total Organic Carbon (C)	mg/L	36	31	13.8%	30	5.9%	18.8%
Dissolved Organic Carbon (C)	mg/L	34	30	11.8%	28	6.7%	17.6%
Oil & Grease	mg/L	30	24	19.8%	24	NA	17.5%
Naphthenic Acids	mg/L	63	55	12.7%	56	NA	11.1%
F1 Hydrocarbons (C6-C10)	µg/L	50	50	NA	50	NA	NA
Dissolved Aluminum	mg/L	0.37	0.43	NA	0.12	71.4%	66.8%
Dissolved Barium	mg/L	0.26	0.18	33.5%	0.17	1.9%	34.8%
Dissolved Boron	mg/L	2.30	2.10	8.7%	2.22	NA	3.6%
Dissolved Calcium	mg/L	10.3	11.8	NA	11.8	NA	NA
Dissolved Iron	mg/L	0.30	0.26	15.0%	0.26	NA	15.0%
Dissolved Magnesium	mg/L	5.30	5.33	NA	5.67	NA	NA
Dissolved Manganese	mg/L	0.032	0.021	35.1%	0.020	4.0%	37.7%
Dissolved Mercury	µg/L	0.001	0.001	8.0%	0.001	25.0%	31.0%
Dissolved Phosphorus	mg/L	0.50	0.45	9.7%	0.43	5.9%	15.0%
Dissolved Potassium	mg/L	10.2	9.2	9.3%	9.9	NA	2.5%
Dissolved Silicon	mg/L	3.00	1.93	35.6%	2.07	NA	31.1%
Dissolved Sodium	mg/L	640	593	7.3%	637	NA	0.5%
Dissolved Strontium	mg/L	0.30	0.28	7.8%	0.29	NA	3.3%
Dissolved Sulfur	mg/L	30.5	28.8	5.5%	30.2	NA	1.1%

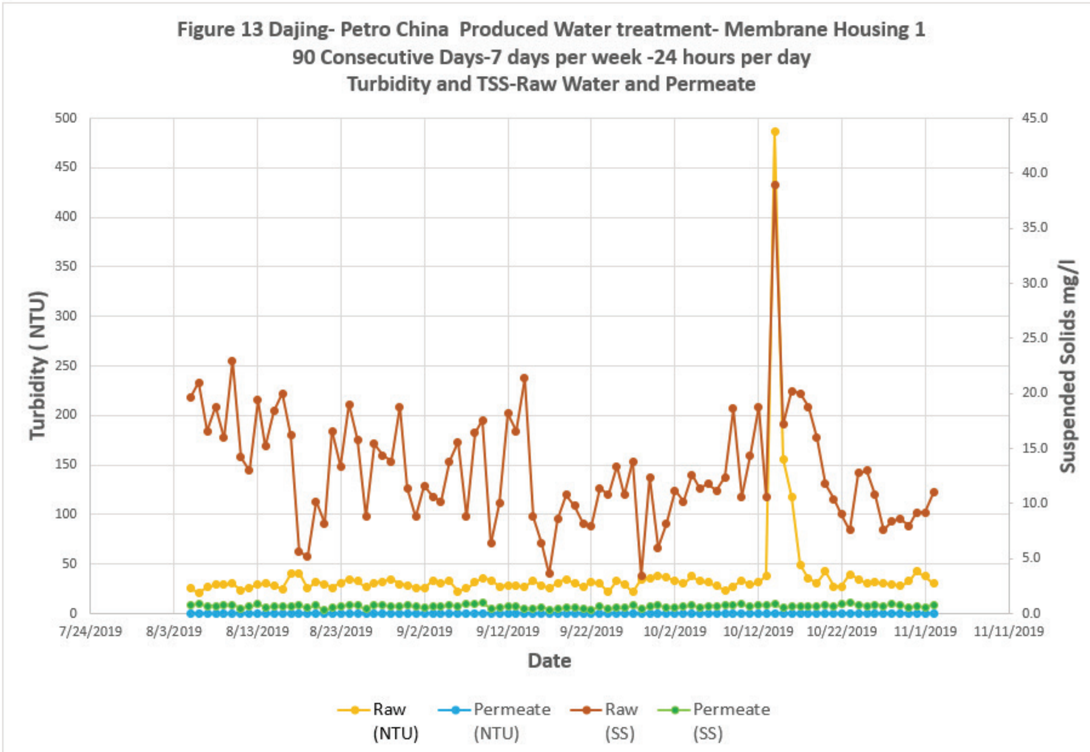
2. DAJING CHINA -PETRO CHINA. In 2019, after two years of laboratory tests and small field applications to evaluate the replaceable skin layer membrane technology, Petro China purchased a 25 m3/hr (4000 bbl/day) produced water treatment unit. The system operated for one year until operations were closed due to Covid. The treatment system has now been refurbished and will be placed back into operation in the fall of 2023.

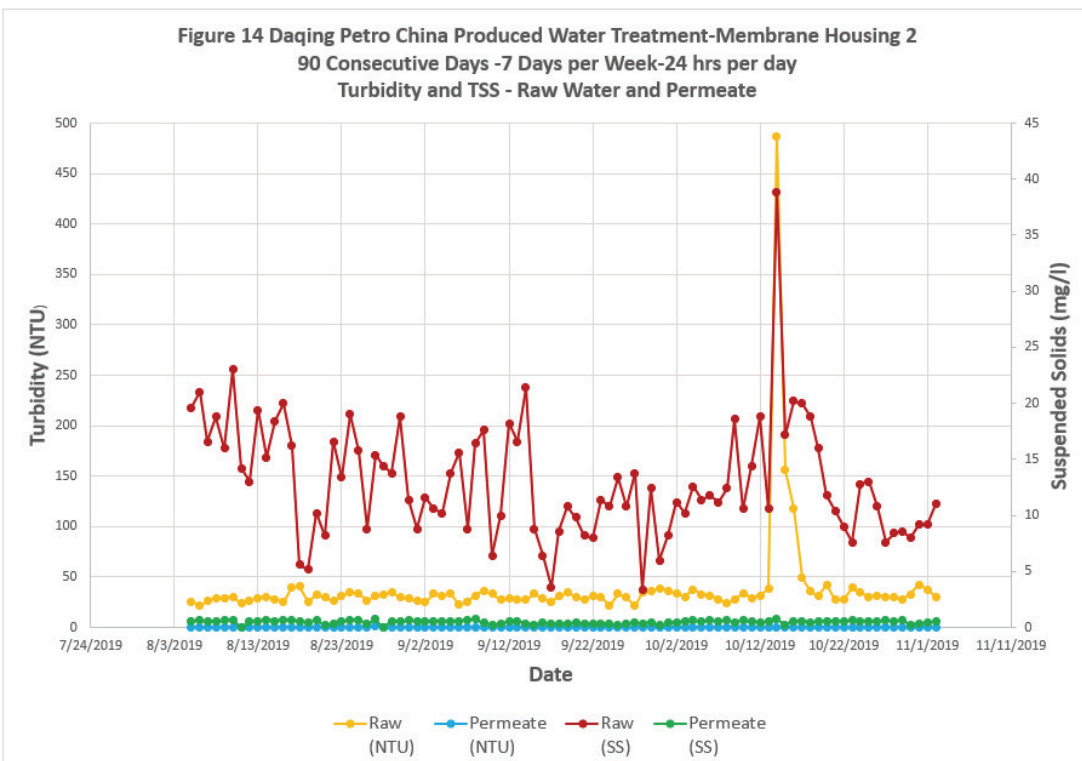
Isle Utilities, a third-party global water technology assessor, assessed the replaceable skin layer technology and the results of the Dajing Oil field operation. The Isle Utility assessment was undertaken as per a contract via a group of major offshore oil production E&P companies. Their interest in the replaceable skin layer technology was the small footprint. Isle Utilities was responsible for an assessment that compared many technologies that could be used to treat produced water from offshore oil and gas production platforms. The conclusion of their assessment identified RSL Membrane™ technology with its small footprint, as the lead technology to be considered for the treatment of produced water generated on offshore environments. The recommendation was based on the excellent performance data obtained from the operation of the replaceable skin layer technology in the Dajing oil field.

Figure 8: Dajing China: Operators taking samples on 25 m3/hr Replaceable Skin Layer Membrane.

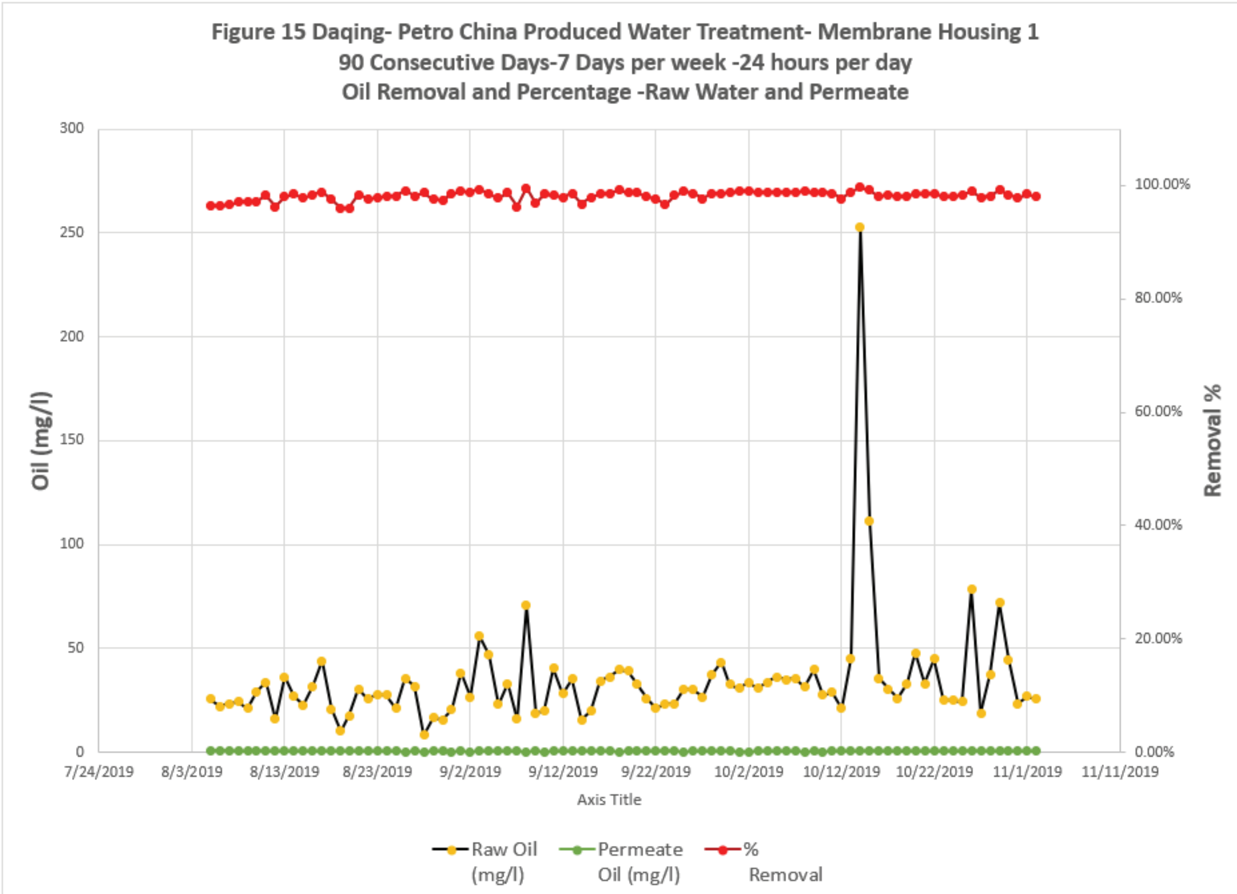
Figure 9: Feed water and permeate from 25 m3/hr replaceable skin layer membrane– Petro China-Dajing Production Zone

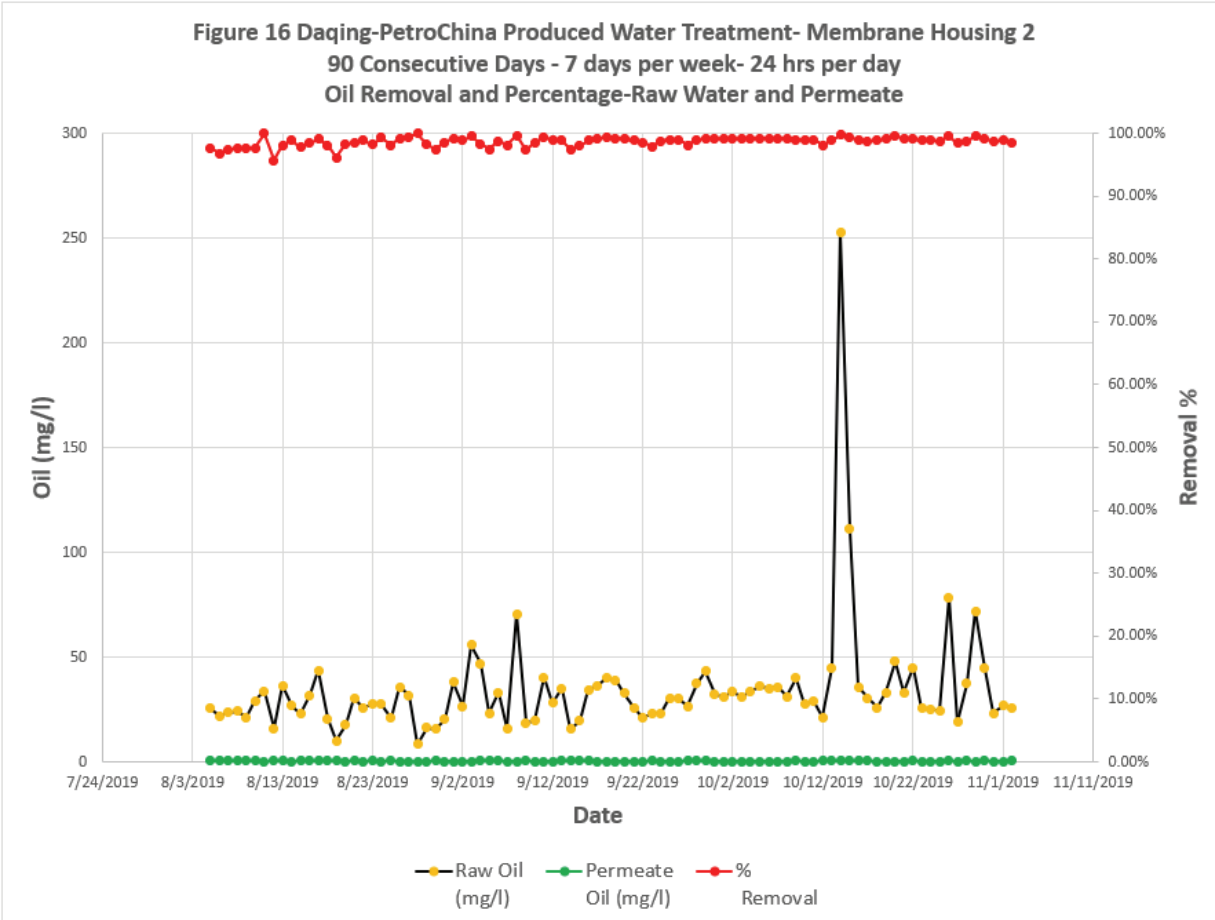
Petro China used their own laboratory and third-party testing facilities to develop a comprehensive data set for 90 consecutive days of operating 24 hours per day. There were two membrane housings. Data was obtained from each housing to create a duplicate set of turbidity, total suspended solids (TSS), oil and particle size. See Figures 13 to 18.





For both turbidity and suspended solids, the raw water had some wide variations and specifically a spike in the October 14th time frame. Nevertheless, the replaceable skin layer membranes produced a consistent and high quality permeate for both membrane housings throughout the 90 consecutive days of data. The average raw and treated produced water had 38.5 NTU and 0.22 NTU respectively, and 13 mg/l and 0.67 mg/l of TSS respectively. For comparison, the averages for Membrane Housing 2 were the same for the raw water but for the permeate, the turbidity was 0.21 NTU and 0.5 mg/l for the TSS respectively.





With regards to oil, the spike in oil concentration in the raw water appeared at the same time as the spike in turbidity and TSS. As with turbidity and TSS, the replaceable skin layer membranes provided a consistent and high-quality water throughout the spike time frame and throughout the 90 days of analysis. Almost 100 % of the residual oil in the raw water was removed by the replaceable skin layer membranes. The average oil contents in the raw water and permeate for Membrane 1 were 34.2 mg/l and 0.5 mg/l respectively. For Membrane 2, the average the oil concentration in the permeate was 0.22 mg/l.

Figures 17 and 18 provide a plot of the D_{50} particle size. The particle size in the raw water was very small at an average D_{50} of 2 microns. The membrane tubes had a pore size of 3 to 5 microns. The average D_{50} in the permeate for housing 1 and 2 was 0.68 and 0.58 microns respectively.

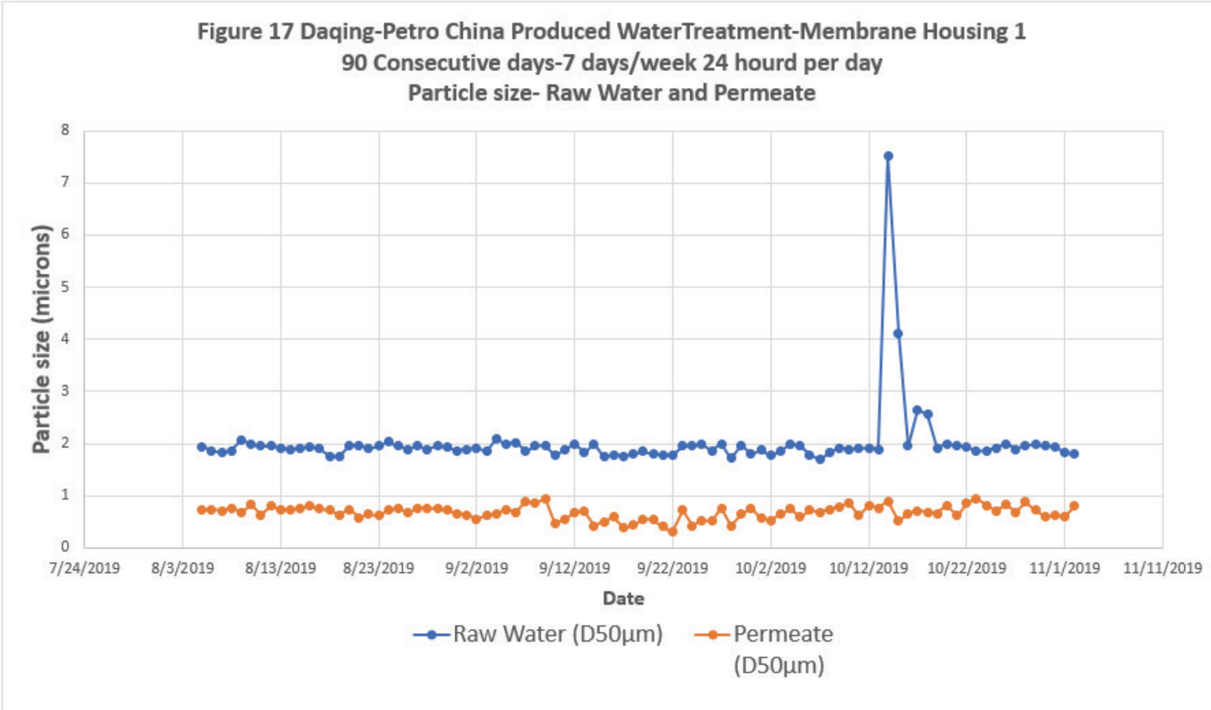


Figure 17 Daqing-Petro China Produced WaterTreatment-Membrane Housing 1
90 Consecutive days-7 days/week 24 hourd per day
Particle size- Raw Water and Permeate
Particle size (microns)
0
1
2
3
4
5
6
7
8
7/24/2019
8/3/2019
8/13/2019
8/23/2019
9/2/2019
9/12/2019
9/22/2019
10/2/2019
10/12/2019
10/22/2019
11/1/2019
11/11/2019
Date
Raw Water (D50µm)
Permeate (D50µm)

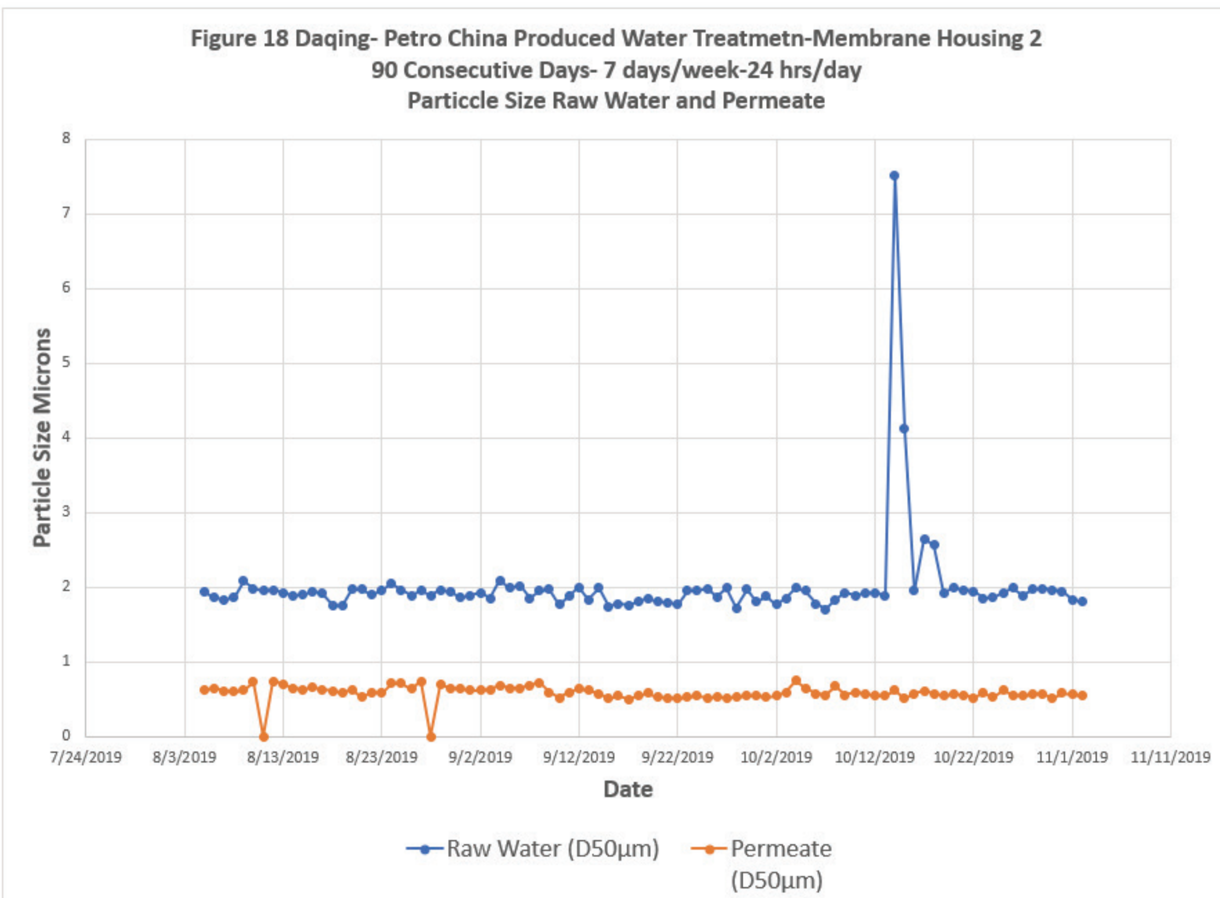


Figure 18 Daqing- Petro China Produced Water Treatmetn-Membrane Housing 2
90 Consecutive Days- 7 days/week-24 hrs/day
Particcle Size Raw Water and Permeate
Particle Size Microns
0
1
2
3
4
5
6
7
8
7/24/2019
8/3/2019
8/13/2019
8/23/2019
9/2/2019
9/12/2019
9/22/2019
10/2/2019
10/12/2019
10/22/2019
11/1/2019
11/11/2019
Date
Raw Water (D50µm)
Permeate (D50µm)

3. MIDLAND TEXAS NOVEMBER 2021-FEBRUARY 2022: This case study was the result of a 9-million-dollar financing where the financing consortium wanted to see physical real time proof that the RSL Membranes™ could perform as stated. A 10 m3/hr (800 bbl/day) replaceable skin layer membrane system was operated for a four-month period and was reviewed by the financing consortium. The operating data confirmed the following.
    - RSL Membranes™ provide the benefit of one process unit being capable of separating colloidal solids and oil simultaneously. In fact, the operator of the E&P facility, where the field test occurred, declared that there was no oil in the produced water that would be the feed water to the pilot. The reason he made this declaration is because prior to the pilot RSL Membrane™ unit, the produced water had already gone through three conventional oil water separation processes. A frack tank was used to collect the contents of the RSL Membrane™ housing during the back wash of the membranes. During backwash, air is used as the backwash agent. A mixture of water separated solids and oil are vacated from the RSL Membrane™ housing during the backwash cycle into a frac tank. As shown below, (see Figure 19), there is a distinct layer of oil on the surface of the frac tank. In fact, the frac tank has three distinct layers; the top oil layer, the bottom settled solids from the back wash and a relatively clean layer of water sandwiched in the middle. The middle layer of water is conveyed back to the raw water tank feeding the RSL Membranes™. The separated oil is skimmed and sent to the production tanks. The remaining small volume of solids/sludge waste on the bottom of the frack tank is sent to a solids handling facility and is the reject component of the RSL membrane™ technology.
    - The treated permeate water from the RSL Membranes™ was crystal clear with an NTU was <1
    - The cost to operate the RSL Membrane is significantly less than the closest competing technology, commonly known as DAF (dissolved air flotation technology). Because conventional membranes have typically failed due to fouling, DAF was considered the best available technology to treat produced water from the North American Petroleum industry. More detail is provided in the 5th Case study below

Figure 19: Frack tank containing Backwash (Water, Oil and Solids) resulting from Produced Water Treatment using RSL Membranes™

Figure 20: Frack tank storing Permeate from the treatment of Produced water by Replaceable skin layer membranes.

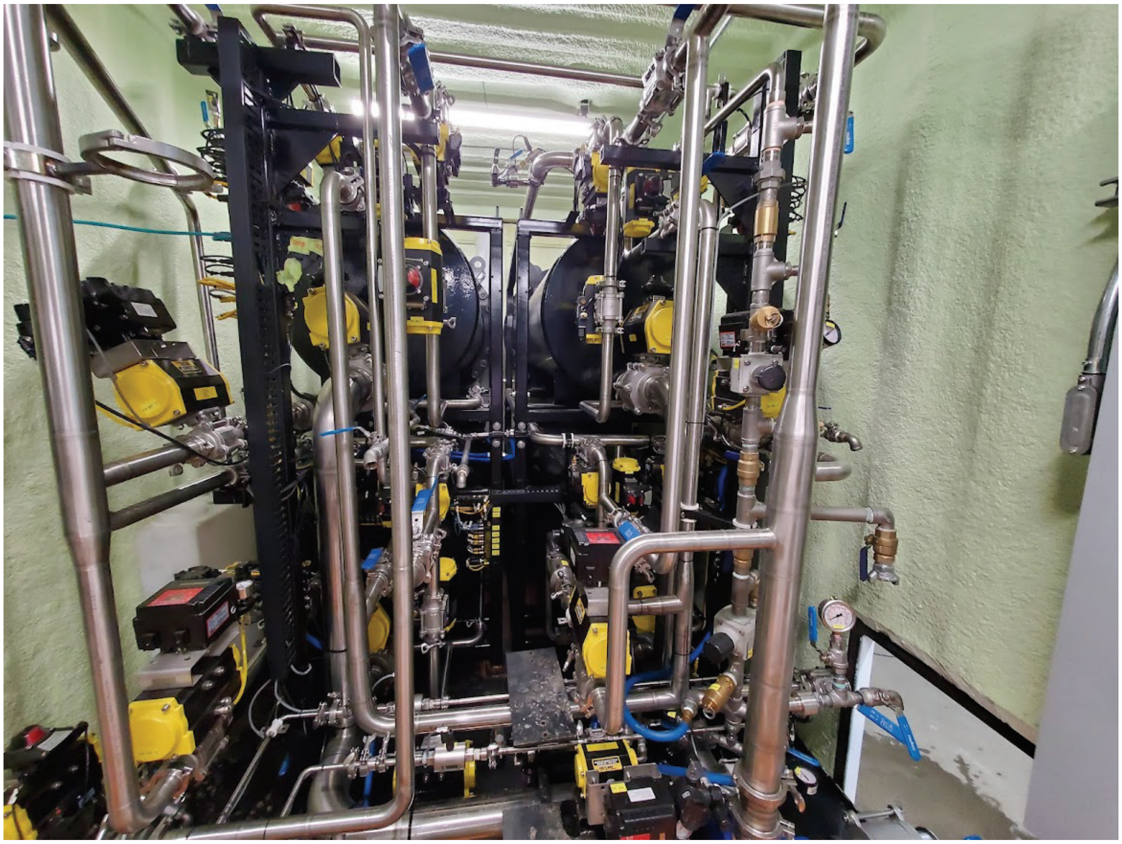
4. OPERATION AT A SALTWATER DISPOSAL (SWD) FACILITY- BARSTOW TEXAS- NEW 100 M3/HR (15000 BBL/DAY AUGUST -OCTOBER, 2022 This case study was generated as a result of the operator of an SWD wanting to apply the replaceable skin layer membranes to improve the capacity of their SWD by removing residual oil. The intent was to increase flow into the SWD but not increase the conventional oil water separation tankage known as a gun barrel. This field application was useful as DBE Hytec had just built its first 100 m3/hr (15000 bbl/day) produced water treatment system and needed a location to commission the process unit. The process unit treated water from two locations at the SWD facility.

- The bottom of the gun barrel which is considered as tank bottom waters. Tank bottoms are one of the worst waters to treat.
- The inlet to the gun barrel at the location where a layer (commonly referred to as a pad layer of emulsified oil) occurs and causes significant operational issues with the SWD.

The results of those two test locations are displayed in the table below. Unfortunately, the second location at the inlet of the gun barrel did not result in the treatment of a pad layer. Just prior to the RSL Membrane™ being connected to this location, the operator had cleaned the tanks and the pad layer did not develop during the time that the replaceable skin layer membranes were treating water from this location. Nevertheless, this location did allow for the treatment of water directly from the pipeline which transports the produced water to this SWD facility.

Figure 21 Setting up Replaceable skin layer membranes Sea Container unit at SWD Facility – Barstow TX

Figure 22 Inside Container there are two operating Skids with 4 housings.



By opening the double wide doors at the ends of the trailer unit, the membranes within the housings are accessible. The flange cover on the membrane housing can be removed exposing the membrane tube bundle which slides out of the housing via a slide out tray.

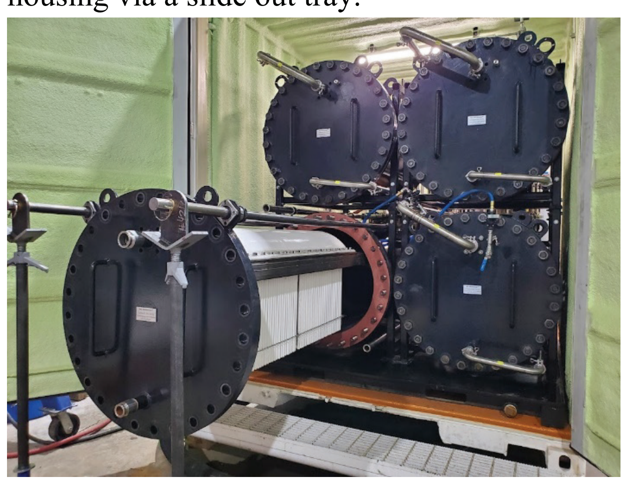
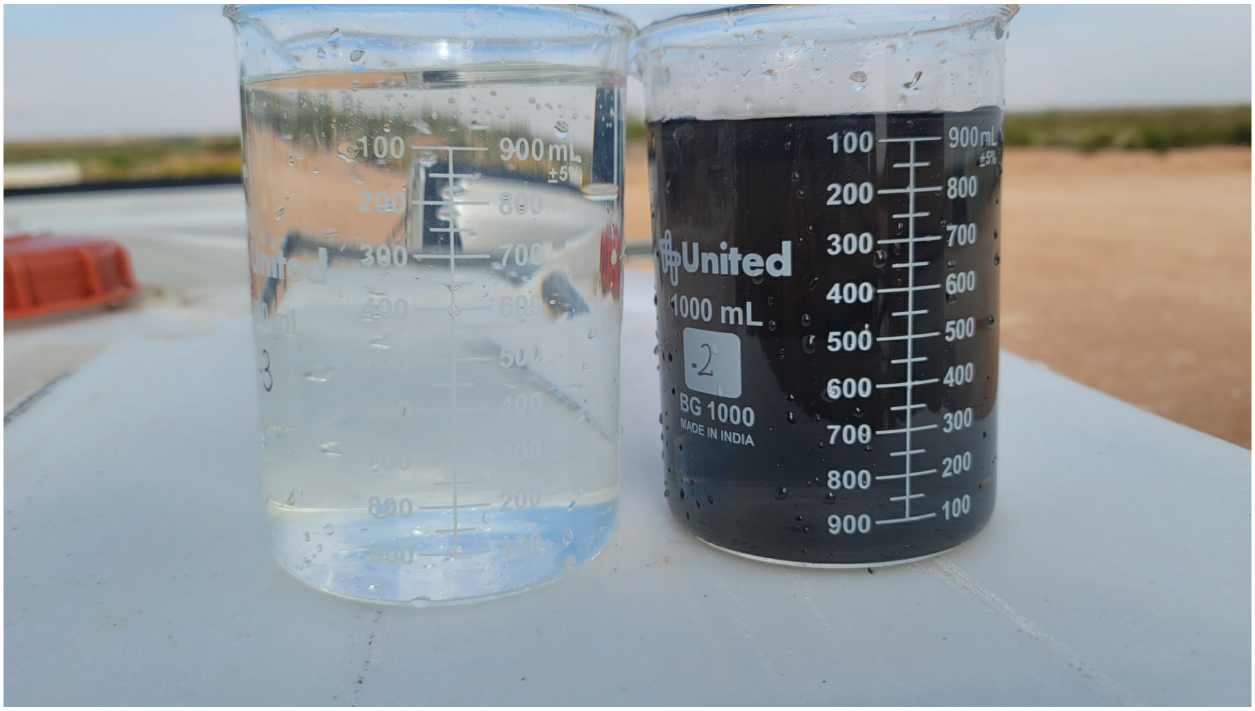


Figure 23 Treated Permeate water resulting from the treatment of the water from the bottom of the Gun Barrel



The following table provides a more detailed analysis of the treatment capability of the RSL Membranes™.

The data confirms the ability of the technology to provide a high level of

- colloidal solid removal resulting in low turbidity water.
- residual oil removal
- Iron removal

In addition, the operation of the replaceable skin layer membrane at the inlet location of the gun barrel confirmed the replaceable skin layer membrane can treat water directly from a produced water pipeline thereby avoiding the use of a SWD for recycling purposes. This is a significant benefit in that a replaceable skin layer membrane module can be set up easily at any riser location along a produced water pipeline to provide water for fracking or EOR applications in proximity to the pipeline.

Table 2 Water Quality Data for RSL Membranes treating Produced Water in West Texas at a Saltwater Disposal Facility

Water Quality Analysis of Waters from a Salt Water Disposal Facility- Barstow, Texas								
Date	October 14-22					October 27-22		
	Raw water pipeline	% Reduction based on treated water	Bottom of Gun Barrel	% Reduction based on treated water	Treated water	Raw water from Pad layer region of Gun Barrel	Treated water	% Reduction based on treated water
Turbidity	73	100.00%	120	100.00%	<0.2	27	<0.2	100.00%
TSS (ppm)	94	100.00%	162	100.00%	<1	26	<1	100.00%
Oil (ppm)	10	100.00%	7	100.00%	<2.5	10	<2.5	100.00%
pH	6.51		6.47		6.78	6.54	6.52	
ORP	-95		-130		132	-42	95	
H2S	0		0		0	0	0	
CO2	246	-22.36%	285	-5.61%	301	198.00	282	-42.42%
Al (ppm)	0.15	0.00%	0.15	0.00%	0.15	0.15	0.15	0.00%
Arsenic (ppm)	0.15	0.00%	0.15	0.00%	0.15	0.15	0.15	0.00%
Barium (ppm)	33.669	-16.26%	30.663	-27.65%	39.142	37.00	36.2	2.16%
Boron (ppm)	46.443	9.26%	46.952	10.25%	42.141	45.00	39.3	12.67%
Calcium (ppm)	12204	-14.20%	16308	14.54%	13937	10422	8853	15.05%
Chloride (ppm)	127091	21.20%	128992	22.36%	100143	110790	101003	8.83%
Iron (ppm)	12.42	99.88%	2.168	99.31%	0.015	9.80	0.015	99.85%
Lithium (ppm)	23	8.70%	23	8.70%	21	17.40	17	2.30%
Manganese (ppm)	5	-20.00%	7.9	24.05%	6	5.50	5.8	-5.45%
Magnesium (ppm)	3102	15.22%	3415	22.99%	2630	1948.00	1879	3.54%
Potassium (ppm)	1295	12.28%	1365	16.78%	1136	894.00	732	18.12%
Sodium (ppm)	60630	30.20%	56740	25.42%	42317	50314.00	40657	19.19%
Strontium (ppm)	1657	4.59%	2017	21.62%	1581	1072.00	1581	-47.48%
Sulfate(ppm)	315	-23.81%	332	-17.47%	390	224.00	245	-9.38%

5. OPERATION IN SOUTH TEXAS TO TREAT PRODUCED WATER AT A MURPHY OIL FRACK OPERATIION SITE: DECEMBER -2022 TO DECEMBER-2023: The RSL Membranes™ were moved to a commercial "pay per volume" treated E & P operating site where there was a need to operate on a 24 hour-7 day a week basis and treat water as generated at varying flow rates and quality. The project lasted almost 12 months. Adjacent to this site was another site where the E & P operator was using flotation (DAF) technology which is the technology competition to the RSL Membranes™.

Figure 24: Easy Mobility for the replaceable skin layer membrane Treatment Unit 100 m^3 / hr being moved from Barstow, Texas to a southern Texas E & P Operator Site.

Figure 25 The Replaceable skin layer membranes after two months of operation with the slide out tray for easy maintenance.

The E & P operator was concerned with iron in the treated water. As a result, hydrogen peroxide H_2O_2 was used to oxidize the iron to a precipitated solid before the water was treated by the replaceable skin layer membranes.

Below are the results of

- the water as a raw water,
- the water pretreated with H_2O_2 and
- the final permeate (treated water) after the RSL Membranes™.

The results confirmed the production of high-quality water, the removal of residual oil as well as iron. All these parameters were superior to the DAF technology output at the adjacent site. However, in this case study, a very significant new benefit of the replaceable skin layer membranes was demonstrated. When compared to the DAF technology, RSL Membranes™ have a 90- 95%% reduction in sludge production volumes. Managing sludge is very expensive. Furthermore, the DAF process required pretreatment with three weir tanks. Not only did the weir tanks increase the equipment footprint, but they also exasperated the sludge volumes. The RSL Membrane's™ ability to significantly reduce sludge volumes provides a further and significant cost advantage. In addition, DAFs rely on chemistry for the treatment process and as a result, temperature has a significant impact on the treatment performance. Temperature has little impact on the replaceable skin layer membrane performance.

Figure 26: Duplicate samples of Raw water without H_2O_2, Raw water with H_2O_2, and RSL Membrane treated water(permeate).

Table 3 Water Quality Data for Replaceable skin layer membranes treating Produced Water in South Texas

Produced Water Analysis- Treated by RSL Membranes South Texas					
Date	February 13-23- average of two separate samples (Feb 11 and 12)				
	Raw Produced Water before Hydroxide addition	% Reduction based on treated water	Raw Produced Water after Hydroxide addition	% Reduction based on treated water	Permeate (treated) from RSL Membranes
Turbidity	135	98.52%	190-390	99.31%	<2
TSS (ppm)	94	94.68%	110-290	97.50%	<5
Oil (ppm)	56	95.54%	93	97.31%	<2.5
pH	6.9		7		6.78
ORP	-95		180-310		200-375
H2S					
CO2					
Al (ppm)	<5	0.00%	<5	0.00%	<5
Arsenic (ppm)	<1	0.00%	<1	0.00%	<1
Barium (ppm)	13.7	1.46%	14	6.25%	13.5
Boron (ppm)	113	1.77%	116	4.31%	111
Calcium (ppm)	6570	10.35%	6500	9.38%	5890
Chloride (ppm)					
Cobalt (ppm)	<1	0.00%	<1	0.00%	<1
Chromium (ppm)	<1	0.00%	<1	0.00%	<1
Copper (ppm)	<1	0.00%	<1	0.00%	<1
Iron (ppm)	7	71.43%	10.5	80.95%	<2
Lead (ppm)	<1	0.00%	<1	0.00%	<1
Lithium (ppm)	94.4	10.70%	92.3	8.67%	84.3
Magnesium (ppm)	565	2.65%	606	9.24%	550
Manganese (ppm)	4.09	19.32%	3.75	12.00%	3.3
Nickel	<1	0.00%	<1	0.00%	<1
Phosphorus	4.28	69.63%	3	54.70%	1.3
Potassium (ppm)	1160	12.07%	1160	12.07%	1020
Sodium (ppm)	26400	5.68%	27400	9.12%	24900
Strontium (ppm)	622	6.27%	617	5.51%	583
Sulfate (ppm)					
Zinc (ppm)	12.4	89.11%	11	87.73%	1.35

This case study provided the benefit of comparing the cost to treat the same produced water with dissolved air flotation technology and replaceable skin layer membranes. Both technologies are accepted technologies by the oil and gas industry. Table 4 differentiates the opex cost and the five-year depreciation cost.

dbehytec

Table 4 Cost Comparison between DAF and Replaceable skin layer membranes

OPEX and 5 Year Depreciation Cost Comparison for Produced Water Treatment DAF vs Replaceable skin layer membranes							
	Fixed Site - $ USD / m3				Mobile-$USD/ m3		
		DAF	RSL		DAF	RSL	
Labor		$0.322	$0.049		$0.322	$0.194	
Subsistance	site specific						
Maintenance		$0.014	$0.061		$0.014	$0.061	
Powder		$0.000	$0.232		$0.000	$0.232	
Coagulants		$0.166	$0.000		$0.166	$0.000	
Peroxide							
Pretreatment	typically $0.417/ m3						
Polymer		$0.358	$0.000		$0.358	$0.000	
Fuel	covered under "Electricity"			covered under "Electricity"			
Air Compressor	covered under "Electricity"			covered under "Electricity"			
Generator	covered under "Electricity"			covered under "Electricity"			
Electricity		$0.030	$0.011		$0.110	$0.039	
Sludge disposal		$3.150	$0.315		$3.150	$0.315	
Sub Total		$4.040	$0.667		$4.120	$0.840	
Contingency	10%	$0.404	$0.067		$0.412	$0.084	
Depreciation		$0.110	$0.205		$0.110	$0.205	
Total Cost/ m3		$4.554	$0.938		$4.642	$1.129	

There is no comparison between a DAF and replaceable skin layer membranes when considering permeate water quality. Typical water quality for DAF and replaceable skin layer membranes is shown in Table 5.

Table 5 Typical Permeate (treated water) Quality

Quality Parameters		DAF	RSL
Turbidity	(NTU)	10-25	<1.0 NTU
TSS	(mg/l)	15-25	<2 ppm
Oil	(mg/l)	25-50	< 3ppm

Nevertheless, the end user may find the water quality of a DAF acceptable. Therefore, cost is important. The key cost differences are circled in Table 4 and are as follows.

1. One of the significant cost savings observed in case studies 5 and 6 was the **reduced costs to manage sludge (the reject volume)** for replaceable skin layer membranes
2. Labor is significantly lower on replaceable skin layer membranes because of the simplicity of operation and maintenance.
3. Maintenance is a higher cost due to the higher capex of the replaceable skin layer membranes compared to DAF technology.
4. Replaceable skin layer membranes utilize approximately 1/3 the electricity compared to DAF technology. Replaceable skin layer membranes provide an excellent opportunity for an end user of the technology to achieve net zero standards.
5. One of the significant cost savings observed in case studies 5, 6 and 7 was the reduced costs to manage sludge (the reject volume) for replaceable skin layer membranes.
6. Depreciation is two times higher for replaceable skin layer membranes because the capital cost is approximately 2 times higher than DAF technology.

Below is the text from an email received from Murphy Oil regarding their experience with the application of the RSL Membranes™.

From: Adam McConnell <Adam_McConnell@murphyoilcorp.com>
Sent: Tuesday, October 17, 2023 1:51 PM
>
Subject: RSL

I was asked to provide an experience letter, from Daniel Young, for the recent adoption and implementation of a RSL Membrane filtration unit supplied by Remote Energy. Murphy Oil has trialed a variety of methods for filtering our frac and flow back water for reuse for completion operations in the Eagle Ford, Montney and Duvernay areas. We have trialed chemical treatments, DAF units and most recently the RSL membrane filtration system.

Having had the opportunity to evaluate and utilize the above-mentioned technologies, the RSL unit has been the most effective and low-cost solution for our flow back water treatment to date.

We continuously compare the treatment methods with water analysis pre and post treatment and have noticed increased water quality and clarity with the RSL membrane. TSS in the post treatment samples were significantly lower than the other treatment samples we have trialed.

We have noticed significant cost reductions in the disposal of the solids due to the low water content in the waste stream in comparison to chemical treatments and the DAF system we trailed before the use of the RSL membrane system. We had the RSL unit running for the last few pads we completed in the EFS and with lower manpower requirements, less fuel consumption, cheaper disposal of solids has been beneficial on the economics of the treatment.

The water quality we seen post frac after trialing the RSL unit on purchased water from a disposal company was rather impressive. The water we initially received was less than desirable with high TDS and entrained oil, and post treatment the water was a viable product for our completions.

Murphy oil will continue to use the RSL as our main water treatment in the Eagle Ford and we are looking into having a unit shipped to Canada for our Montney operations.

If you have any questions, please don't hesitate to reach out.

6. MINING TAILINGS POND WATER PILOT TESTING TO REMOVE CONTAMINANTS OF CONCERN (COC) TO PPB LEVELS TO SATISFY REGULATORY REQUIREMENTS.

Water Strider Ltd of Vancouver BC, at the request of a gold mine in northern British Columbia, developed a novel treatment process that crystallized metals and contaminants of concern (COC). Table 6 provides the discharge limits for the COC's.

Table 6 Water Quality and Permit Requirements at a Mine in BC: Dissolved Metal Concentrations

Parameter	Units	Maximum	Minimum	Standard Deviation	Mean	Permit Requirement	
						Maximum in Any Sample	Monthly Average
Total Suspended Solids	mg/L	57.0	1.0	9.2	8.9	30	15
Dissolved Metals (Water):							
Aluminum (Al)-Dissolved	mg/L	0.1250	0.0010	0.0299	0.0137	0.5	0.1
Antimony (Sb)-Dissolved	mg/L	0.0320	0.0183	0.0040	0.0033	0.16	0.02
Arsenic (As)-Dissolved	mg/L	0.0054	0.0031	0.0006	0.0005	0.03	0.01
Cadmium (Cd)-Dissolved	mg/L	0.00907	0.00188	0.00208	0.00159	0.00012	0.00002
Copper (Cu)-Dissolved	mg/L	0.0138	0.0021	0.0032	0.0021	0.04	0.01
Iron (Fe)-Dissolved	mg/L	0.0930	0.0100	0.0201	0.0092	0.30	-
Zinc (Zn)-Dissolved	mg/L	1.2000	0.2270	0.2702	0.2001	0.18	0.03

The required treatment process needed to remove COC's to satisfy stringent discharge parameters that had constituent limits in the parts per billion (ppb). Water Strider was able to take dissolved metals and crystallized the metals into colloids less the <1 micron. However, they were stymied on how to separate the sub-micron colloids. Water Strider pilot tested conventional clarifier, flotation and multimedia filters. All of these technologies failed. Membranes were the obvious technology that should separate the crystal colloids, but the team's concern was the high levels of silicates in the water which would cause membrane fouling. Numerous membrane types were tested in the laboratory using small disc membrane samples and all tests showed rapid fouling. However, one membrane seem promising. This technology had been developed by a team in Hamilton Ont. who were originally involved the development of Zeeweed (Zenon) membranes. Pilot testing was undertaken on this membrane. The results showed daily fouling. Water strider then approached RSL Membranes™. Piloting was undertaken and the results were excellent. Water Strider then undertook robust testing using extreme conditions on the RSL Membranes™. The results showed that the RSL Membranes™ could perform under extreme conditions. In some cases, fouling did occur but conventional Clean-in- place procedures brought the membrane back to original TMP levels. RSL Membranes™ were selected as the separation technology used to pilot 90,000 litres. Table 7 provides the treatment results in parts per billion.

Table 7 Overall Treatment Results on Metal removal

Constituent	Permit Limit [μg/L]	Feed [μg/L]	Treat [μg/L]	Removal [%]
Aluminum	62	779,719	25	>99.9
Antimony	20	19.8	7	64.7
Arsenic	50	4,010	17.8	99.6
Barium	50	70	32.1	54.3
Cadmium	0.02	122	<0.1	>99.9
Chromium	720	757	2.5	99.7
Cobalt	4.4	4,489	1.82	>99.9
Copper	18	19,148	<2	>99.9
Iron	350	661,944	<50	>99.9
Lead	12	969	<1	>99.9
Lithium	-	33,900	29.6	99.9
Manganese	1,217	12,073	542	95.5
Molybdenum	7,600	9,590	313	96.7
Nickel	60	4,799	8.3	99.8
Nitrate	10,000	5,930	1,260	78.8
Selenium	5	658	3.32	99.5
Sulphate	1,600,000	1,486,000	364,000	75.5
Uranium	5,300	5,529	207	96.3
Zinc	30	549,000	<20	>99.9
Selenium has to be less than 1 ppb dissolved; Pilot Project achieved <0.5 ppb				

Below is a reference letter from Water Strider.

waterStrider TREATMENT

January 25, 2024

dbehytec
David Bromley, CEO
davidbromley@dbe-rsl.com 778 8820137
www.dbe-rsl.com

Endorsement of dbe's RSL Membrane

David,

waterStrider strongly recommends dbe's RSL Membrane.

We have been searching for a solids separation technology for some time that complements waterStrider's electrochemical, chemical, and physical processes to remove a wide range of dissolved constituents from water at mines and from oil and gas produced water. In particular, our needs are as follows:

- Excellent removal of particulate solids
- Non-fouling
- Mechanically simple solids separation
- Minimum (no?) chemical requirements
- Reasonable cost

waterStrider testing of the RSL Membrane has certainly met our requirements. In sharp contrast with our experience with other commercially available membranes, dbe's RSL Membrane treated water quality meets our rigorous standards, the membrane does not appear to irreversibly foul, and operation is relatively simple. Chemical requirements for membrane cleaning promise to be extremely modest.

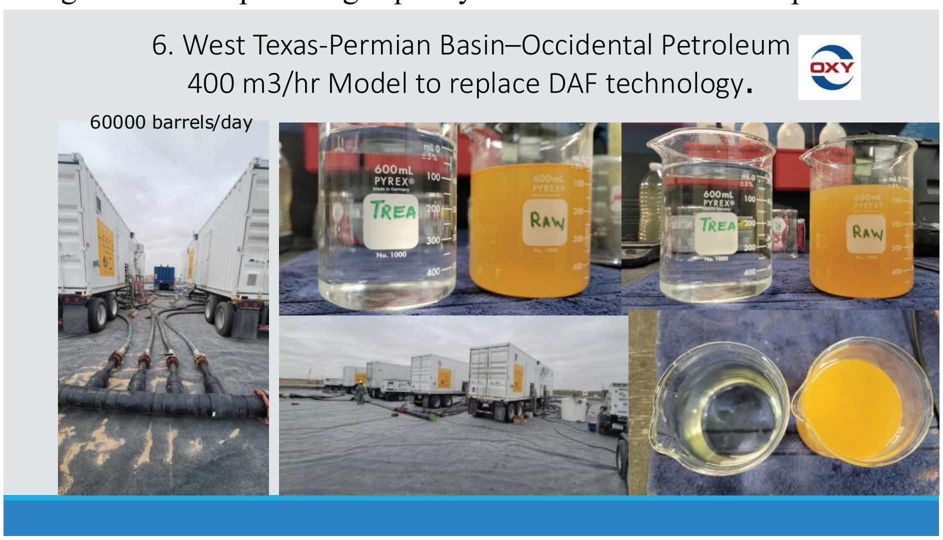
Overall, dbe's RSL Membrane offers excellent value that we can recommend to our clients. waterStrider plans on implementing the RSL Membrane on our future projects.

Rob Stephenson, PhD PEng
Chief Technical Officer, Co-Founder and Director
waterStrider Treatment Inc.
rsephenson@aterstridertmt.com

7. <u>OPERATION IN WEST TEXAS TO TREAT PRODUCED WATER AT A OCCIDENTAL PETROLEUM SITE: MARCH -2024 TO PRESENT:</u>

Continental Water Recycling LLC was selected to undertake a project for Occidental Petroleum in west Texas to treat produced water with the RSL Membranes™. The project required the treatment of 60000 bbl per day of produced water where the water would be reused for fracking operations. This project had some treatment volume limitations but did provide very high-quality water. The project team was concerned with the inability to treat the volumes per day as originally designed. The project team indicated to the client that some treatment processes could be modified to increase volumes to the 60000 bbl /day objective but treated water quality would be sacrificed. The client, however, stressed the importance of the high-quality water production as The RSL Membrane™ treated water quality had significantly improved downstream operations. The application of RSL Membranes™ to treat produced water to a very high quality continues for this client.

Figure 27: Set up and high-quality treated water for frack operations



In the second project for Occidental, capacity goals were exceeded and high-quality water (<2 ntu) was achieved. This treatment level avoided a common and costly problem in treated water retention ponds with high sludge content as shown in Figure 28.

Figure 28 Typical treated water storage pond with iron based sludge

The photo in Figure 28 shows iron-based sludge from a Dissolved Air Flotation (DAF) treated water. The solids in the treated water settle onto a liner in the treated water pond. As the water is used, the liner becomes exposed and the sludge bakes onto the liner making the cleanup of the pond very expensive. RSL Membranes™ eliminate this issue.

8. GLOBAL AGREEMENT WITH ONE OF THE WORLD'S LARGEST ENERGY SERVICE COMPANIES

After 1.5 years of stress testing RLS Membranes™ for a specific application in the energy sector, a global exclusive agreement was signed for the use of RSL Membrane™ into that specific sector. The testing was undertaken by a professional technology evaluation firm that built an automated pilot plant to test the RSL Membranes™. The testing included a comparison to conventional low pressure membrane technology regarding standard parameters related to permeate quality, recovery and operations including energy consumption and net zero objectives. RSL Membranes™ were considered the superior technology.

Summary

The RSL Membranes™ are a third-generation membrane technology distinct from dynamic (filter cake) type membranes (Generation1) and conventional low-pressure microfiltration (MF) or ultrafiltration (UF) membranes (Generation 2). The oil and gas industry and their need to treat and reuse water that is produced from oil and gas operations, has provided a valuable opportunity to display the significant benefits of replaceable skin layer membranes. These benefits include.

1. High flux rates that are 10 times conventional MF and UF membranes
2. Very low energy requirements
3. Simplicity in operation and maintenance
4. High recovery rates and low rejection volumes
5. Simultaneous removal of oil, suspended solids and colloidal solids less than 1 micron
6. Small footprint, and
7. Low opex cost

Table 8 provides specification comparison between RSL Membranes™ and conventional generation 2 membranes

Table 8 (https://en.wikipedia.org/wiki/Ultrafiltration) provides a summary of the specifications for RSL Membranes™ based on the experience of the five case studies presented.

RSL Membranes ™

Product Comparison with Conventional UF Polymeric or Ceramic Membranes

Table 6: Process Characteristics - Manufacturers Recommendations

Operating Parameters	UF Hollow Fibre	UF Spiral-wound	UF Ceramic Tubular	RSL Membranes™
Energy Requirements Kwh/M3	0.8 + pretreatment energy (0.3-0.4)	0.8 + pretreatment energy (0.3-0.4)	1 to 5 + pretreatment energy (0.3-0.4)	0.1
pH	2–13	2–11	3–7	2-13
Flux (Litres/m2/hr)	25-50	25-50	35-100	275-800
Feed Pressure (psi)	9–15	<30–120	60–100	0-10
Backwash Pressure (psi)	9–15	20–40	10–30	air 14 to 65
Temperature (°C)	5–30	5–45	5–400	2-400
Total Dissolved Solids (mg/L)	<1000	<600	<500	<250000
Total Suspended Solids (mg/L)	<50 max 100	<50 max 100	<300	<1000 max 5000
Turbidity (NTU)	<50 max 100	<1	<10	<1000
Iron (mg/L)	<5	<5	<5	<150 but no limit has been defined
TOC (mg/l)	<10	<10	<10	unknown- not identified as a problem parameter
Surfactants (mg/l)	NA	NA	NA	<2000
Oils and Greases (mg/L)	<0.1	<0.1	<0.1	<1000 max 3000
Solvents, phenols (mg/L)	<0.1	<0.1	<0.1	unknown- not identified as a problem parameter

Reference: https://en.wikipedia.org/wiki/Ultrafiltration

Notes

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