RSL Membranes™

Replaceable Skin Layer Membranes™

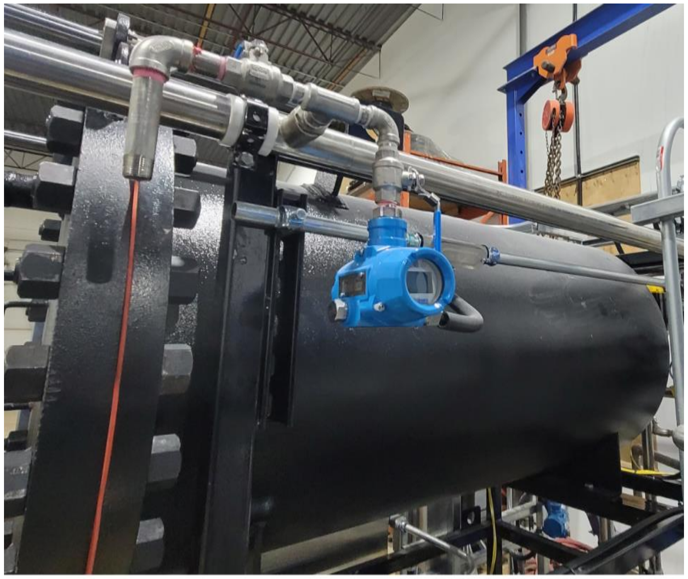
Finalist as the most Disruptive Technology in the World

Untangling **Water Treatment**

with **Transilience**

The World's lowest cost membrane

The Application of ionic surface chemistry to manipulate the electric double layer around colloids



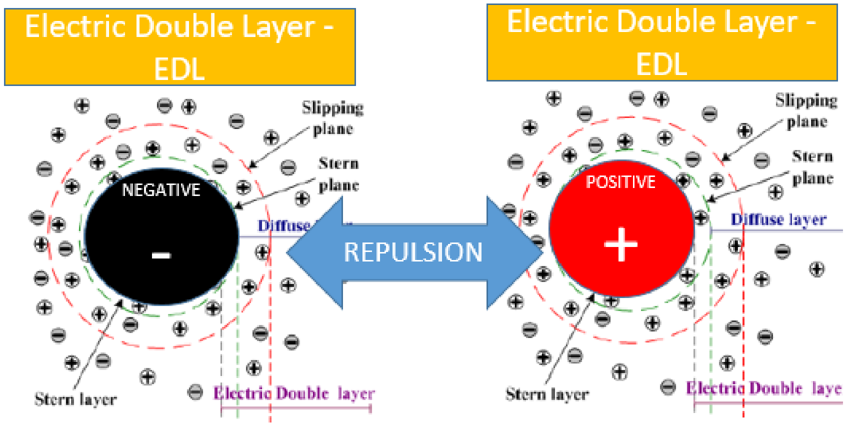
A new and disruptive water treatment technology has been developed to replace existing filtration and oil separation technology resulting in a 10-fold improvement in capacity, 90% reduction in energy and 25 to 40% reductions in capex and opex. The technology, known as RSL Membranes™, was a finalist in the California based Katerva awards as the most disruptive sustainable technology in the world. After third party peer review, the Chinese Ministry of Environmental Protection selected RSL Membranes™ as the one of the top 100 environmental technologies in the world.

The rapid separation of solids and oil from water is a result of the ability to manipulate the nano-environment and the electric double layer (EDL) around colloids. The well-known DLVO theory explains the ability to simultaneously repulse and attract colloidal particles.

DLVO Theory

This photograph shows a river that has natural rainfed water with low ionic concentration and solids in suspension. The river enters the ocean where there is a high ionic environmnent due to the NaCl. As a result the solids separate from the water. When the solids are in suspension the Electrical Double Layer (EDL) around the colloid solid is strong and repulsion forces are strong. When the ionic strength of the local environment increases, the EDL collapses and attraction forces (van der Waal) become dominant

The charge on a colloidal solid does not cause a solid to repulse or attract. It is the EDL that causes repulsion or attraction. Once the ionic environment around the colloidal solids increases, the EDL collapses, and the colloidal solids attach to each other or to other surfaces via Van der waal forces.



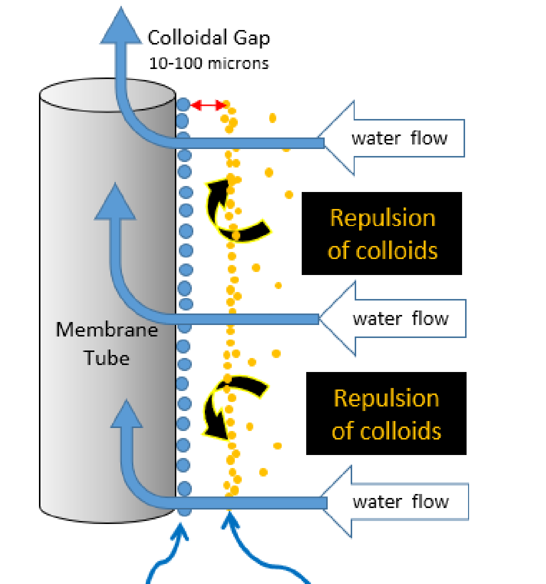
The EDL is causing **+** and **-** particles to repulse. An increased ionic environment around the colloids causes the collapse of the EDL and colloids attract.

To simulate the DLVO theory a highly ionic powder is added as a replaceable skin layer to the surface of a membrane tube or sheet as the first operational step (powder application takes ~5 minutes).

Replaceable Skin Layer
RSL Membranes™
Surface of Membrane tubes with pores >than 1 micron are covered with a highly ionic powder inside the housing while submerged in water. The RSL powder layer is 50 to 100 micron thick.Time required for placement of RSL layer is <5 minutes

The fluid to be treated is then processed through the powder layer and the membrane (Filtration cycle and be 2 to 30 hours). The powder has its own EDL and repels the colloids from the surface. Once the trans membrane pressure (TMP) increases to 70 kpa, air used to backwash the skin layer off the membrane surface and vacate the contents of the membrane housing (1 -2 minutes). The housing is refilled with treated water and the powder is added again to repeat the filtration and backwash cycles.

Note: RSL Membranes™ are not a filter cake or dynamic membrane technology. The technology does not rely on a filter cake forming for filtration. To the contrary, solid separation from the fluid being treated relies on no filter cake forming on the surface of the membrane.



The technology is well proven. Waters containing very high suspended/colloidal solid content and emulsified oil are easily treated. The first one year evaluation of the technology was undertaken through a third party independent review process. Twelve technologies were originally selected and were then narrowed to two technologies for field testing. The two technologies were RSL Membranes™ and a Ceramic membrane marketed by Veolia, the world's largest water treatment utility operator. It was through this testing that the Replaceable Skin Layer (RSL) Membranes™ were rated has having a 10-fold improvement in capacity compared to the conventional ceramic membranes.

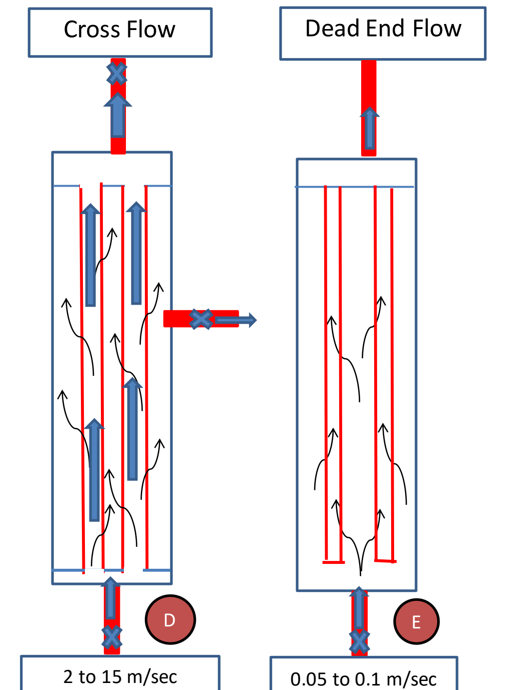
For example, where conventional membranes require 1000 m^2 of membrane area to treat a specific water, the area required for RSL Membranes™ is 100 m^2. The significant reduction in membrane area has allowed for the economic application of exotic membrane materials. This is important as it has allowed RSL Membranes™ to be used in high temperature applications (up to 600 C), such as steam and hot oil operations.

In 2017, the technology was applied in a $16 million contract to commercially treat water at high temperatures and pressure for oil sands operations. Specifically, RSL Membranes™ were used to separate silica from produced water at temperatures of 130 C and 3 Bar pressure.

The contract was awarded after three independent evaluations of the technology.

To create water suitable for human consumption or high quality process water, the priority treatment is the removal of suspended solids. Total Suspended Solid (TSS) concentrations as high as 2000 ppm can be managed by the RSL Membranes™. Typical effluents/permeate will have non-detect TSS. For parameters that are dissolved (Si, Ca Mg, Ba, Sr, Fe) but can be precipitated into a discrete solid, the RSL Membranes™ provide a simple one component method to reduce these parameters.

Another key design benefit of RSL Membranes™ is the use of the dead-end filtration mode thereby saving the energy typically used in cross flow membranes. This is the key reason, RSL Membranes™ provide a 90% reduction in energy consumption.



Conventional UF Membrane
High energy

Replaceable Skin Layer (RSL) Membrane
Low energy

The Power of Simultaneous Repulsion and Attachment- Electric Double Layer (EDL) and the DLVO Theory

SAGD Produced Water Example 1 - after 1 minute | SAGD Produced Water Example 1 - after 5 minutes | SAGD Produced Water Example 1 - after 10 minutes | SAGD Produced Water Example 2 - after 30 minutes | SAGD Produced Water Example 2 - after 45 minutes | SAGD Produced Water Example 2 - after 60 minutes | Rubber Waste Water - during Backwash after 9 hour filtration cycle

In Example 1 (far left) the produced water is introduced to the RSL™ Membrane. The highly charged white powder skin layer is visible on the surface of the stainless steel membrane tube. The velocity vectors of the flow of raw water and the white powder material are sufficient to hold the white powder on the surface of the membrane tube. The colloidal solids entering the tube, however, have a much slower vector velocity towards the tube because of the repulsion force from the white powder skin layer. As a result, the solids to be removed from the water, do not cake onto the surface of the powder skin layer. This is evident in Example "1" @ 5 minutes and 10 minutes as well as in Example "2". Observing the colloidal solids shows that they are being repulsed from the surface of the RSL™ membrane and actually create a sludge layer on the lower part of the column. Because the RSL™ Membrane operates as a dead end filtration with no crossflow, the solids build up in the concentrate (upstream of the RSL™ Membrane skin layer). Eventually, as shown in Example 2 at 60 minutes, the membrane housing does not have a distinctive sludge layer. The colloidal solids continue to concentrate in the housing. In some tests, these solids have concentrated as high 10% (100,000 mg/l) and emulsified oils as high as 280,000 mg/l. Eventually the solid levels become so high in the concentrate, the colloids penetrate the powder skin layer. The EDL on the colloids collapses and the solids attach to the white powder within the RSL™ Membrane skin layer. The skin layer grows in thickness as shown in the rubber waste water example (far right). This causes the trans membrane pressure (pressure across the membrane) to rise. Once the pressure reaches 1 bar after 6 to 15 hours of filtration, the skin layer is replaced and the filtration cycle starts over. In 4 minutes the expended skin layer is removed and a new skin layer is applied.

A commercial RSL Membranes™ is a bundle of Polymeric, stainless steel or Titanium tubes.

The tube surface area is designed for a typical flux rate of 350 litres/m2/hr (lmh) but depending on TSS loading (high =1000-2000 ppm and low=100-200 ppm), the design could be as low as 200 lmh to 800 lmh respectively. In addition, the type of solid impacts the flux rate. The design depends on the repulsion and attraction of the solid to the RSL powder.

Because the RSL Membranes™ operates in a dead-end filtration mode the solid concentration (TSS) on the upstream side of the membrane builds up to 14000 to 20000 ppm. This concentration level results in a transmembrane delta pressure of approximately 70 kpa (10 psi). Where the RSL Membranes™ is being used for the separation of emulsified oil, the concentration of oil on the upstream side of the membrane can be as high as approximately 28% (280,000 ppm).

Oil Removal from Refinery Coker Process

After RSL Membrane Water Sample

Right to Left: Raw Water /Oil : After Flotation- free oil removed -emulsified oil 2000 mg/l : After one pass of RSL Membranes™ Oil 29 mg/l, NTU 0.55.
Flux rate is 375 lmh

The dead-end mode of operation and the use of air for backwash facilitates a high recovery rate for the RSL Membranes™ >98%. The concentrate in the housing on the upstream side of the membrane is conveyed to a sludge tank to ensure efficiency in managing the sludge. Solids settle rapidly in the sludge tank due to the destabilizing effect of the wasted powder in the sludge. The supernatant from the sludge tank is returned to the front end of the treatment process resulting in a small volume of waste to be discharged from the sludge tank.

Finally, the use of the replaceable skin layer (ionic powder layer) eliminates the problem with conventional membranes (i.e., cleaning the skin layer attached to the membrane substrate). Conventional membranes have the skin layer affixed to a membrane substrate and once the skin layer is fouled and cannot be cleaned any further, all of the membrane tubes need to be replaced.

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