Technical Article

VSEP Treatment of RO Reject from Brackish Well Water

A Comparison of Conventional Treatment Methods and VSEP, a Vibrating Membrane Filtration System.

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Abstract

Conventional spiral wound membrane systems using reverse osmosis or nano-filtration membranes are increasingly being used to treat well water from underground sources to supplement local drinking water supplies. Many of the remaining underground water sources are "Brackish" water sources where the dissolved solids can be 5,000 mg/L or even higher. One of the difficult engineering aspects of conventional spiral membrane technology is the treatment of the residual concentrated brine left over from the process. New Logic Research, Emeryville California, has developed and manufactures a new proprietary vibrating membrane filtration system that is not limited by solubility of sparingly soluble salts and is capable of extremely high recoveries of treated water from brine. The use of a vibrating membrane mechanism to avoid membrane colloidal fouling is new and is just the kind of improvement needed to increase the yield of filtered water from brackish well water.

The Vibratory Shear Enhanced Process, (VSEP), technology has been installed in other areas for treatment of surface water to make ultrapure water for manufacturing and has also been used in manufacturing plants to treat the wastewater reject from other membrane systems to assist in Zero-Discharge. Recent pilot trials have been conducted using the VSEP technology to examine its use in brackish well water filtration and to volume reduce reject from other spiral membrane systems. This approach would extend the use of the VSEP technology to the municipal drinking water market in addition to the chemical processing and manufacturing markets where the technology has been used for many years. This article will discuss the recent VSEP pilot trial results and then make comparisons between using VSEP and other methods of brine reject disposal currently being employed or considered.

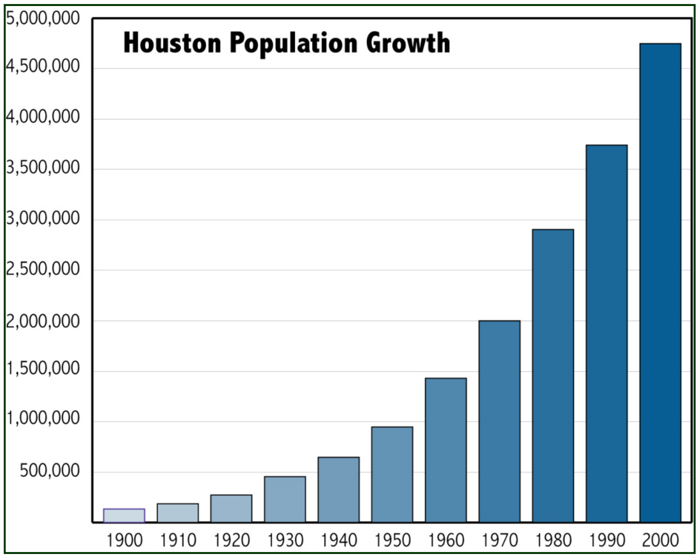
Water Supply Background

With populations rising and water sources becoming stretched, increasing attention is being paid on how water is used and reused. Industry, agriculture, and domestic water users are all competing for this most precious natural resource. Many in the Southwestern United States are seeing dramatic population growth rates, while population levels in the North and Northeast are remaining fairly stable. The problem is that populations are increasing in areas of the country with the most limited water supplies. For example, the U.S. Census Bureau [7] estimates that the population of Arizona will double within the next 25 years.

Clearly, the case for retrofits and additional capacity has been made. The EPA's Office of Water recently estimated the capital required over the next 20 years for both water and wastewater upgrades is nearly $500 Billion USD (EPA, The Clean Water and Drinking Water Gap Analysis, 2002). These estimates are not adjusted for inflation and use current value terms. The EPA attributes these costs to retrofitting treatment plants and infrastructure that are obsolete, more stringent drinking water and wastewater standards, and increasing expense and controversy associated with capital improvement projects.

During the 1970s and 1980s, the EPA provided more than 60 Billion Dollars for construction of public wastewater treatment projects through its Construction Grants Program. [1] The Clean Water Act (CWA) of 1987 changed the Construction Grants Program and through an amendment to the CWA, the grant program was terminated in 1990. Under the new procedure, the EPA initiated the State Revolving Fund (SRF). Through the SRF, the EPA provides capitalization seed money to the states, which in turn offer low interest loans to local communities for municipal projects. The net effect is that although local municipal districts receive low cost loans, they now must pay for 100% of capital improvement projects. Under the Construction Grants Program, the EPA paid about one-half of these costs directly.

Now that local water utility companies are responsible for 100% of the cost of capital projects, the construction of large mega projects such as Dams and large aqueducts will be greatly curtailed. Faced with aging infrastructure and limited current capacity, Municipal water districts are working on ways to optimize existing systems and supplement conventional sources of drinking water using relatively small capital projects. [3] Increasingly, well water is being used as a source of raw water for distribution to the Municipal water market. These relatively small capital projects can be implemented quickly to supplement water supplies and the cost of these projects is more in line with what local water districts are able to manage.



Texas Desalination Plants

There are currently approximately 100 brackish water desalination plants in Texas. Most use brackish well water, but about one in six uses brackish surface water. There are no seawater desalination plants currently in Texas. The current output of treated water of these plants totals about 39.6 MGD. From this effort, a waste stream of 10.5 MGD is produced that must be disposed of. Even though it is a large amount, this is much smaller than the total amount of Produced Water from Oil drilling already disposed of each day in Texas. [10]

Well Water Treatment

Most well water and surface waters contain varying amounts of suspended solids, including silt, clay, bacteria, and viruses. In addition, they may contain many harmful dissolved solids such as Arsenic. It is necessary to remove these prior to distribution to the domestic or industrial consumer. Suspended solids not only affect the aesthetic acceptability of the water; they also interfere with the conventional disinfecting process using chlorine. The principal treatment processes used to remove suspended solids are sedimentation and filtration. In the case of brackish waters containing large amounts of dissolved solids, membrane filtration must be used. In many plants that treat surface or well waters, there is a pre-sedimentation reservoir ahead of the treatment units. The reservoir allows the larger particles to settle as well as to provides a volume buffer against changes in water quality.

Rapid sand filters or mixed media filters are used next as pre-treatment to conventional spiral membrane systems. These can remove the larger suspended solids but cannot remove appreciable quantities of colloidal or sub-micron sized particles without chemical pre-treatment. While these can act as an initial filter, the effluent from media filters can be as colored or turbid as the incoming water. After media filtration, some chemical pretreatment is generally done to optimize the spiral membrane system. Finally, a reverse osmosis membrane system is used to filter the water and provide clean water suitable for drinking water supplies. Often, this water is blended with other fresh water sources to achieve an acceptable taste.

Water Standards

Drinking water is monitored to conform to acceptable levels of many harmful chemicals and organisms. Setting of standards is a continual process as more is learned about the potential harmful effects of various constituents. In addition to monitoring for health risks, water quality is controlled for aesthetic and operational purposes. For example water high in sulfate levels while not toxic can have a laxative effect. Water high in iron can lead to hardness and staining in laundering. Water high in organics can have a foul taste. Recent fatalities involving toxic microorganisms have renewed a review of the standards when it comes to monitoring and treatment to prevent harmful bacteria from entering the distribution network. The following list summarizes some of the targeted undesirable ingredients to drinking water.

EPA Standards for Health	
Total Organic Carbon	5.0 mg/L
Arsenic	0.010 mg/L
Barium	2.0 mg/L
Cadmium	0.005 mg/L
Chromium	0.1 mg/L
Cyanide	0.2 mg/L
Fluoride	2.0 mg/L
Lead	0.015 mg/L
Mercury	0.001 mg/L
Selenium	0.05 mg/L
Uranium	0.1 mg/L
Vinyl Chloride	0.002 mg/L

Arsenic - Arsenic is present at very low levels in all surface waters. It is a naturally occurring chemical found in mineral deposits and will go through a natural dissolution process bleeding it into waterways. Arsenic is a carcinogen and must be controlled in drinking water sources.

Chromium - Trivalent Chromium is the naturally occurring state of Chromium and is not considered toxic. However, naturally occurring Chromium can be oxidized in raw water to form the more toxic Hexavalent Chromium. Other sources of Hexavalent Chromium are from paint and plating wastewater that can contaminate waterways.

Cyanide - The human body detoxifies small amounts of Cyanide. Lethal toxic effects can occur if the levels are above certain limits and the detoxification mechanism is overwhelmed. Chlorination is normally sufficient to oxidize Cyanide and reduce it to appropriately low levels.

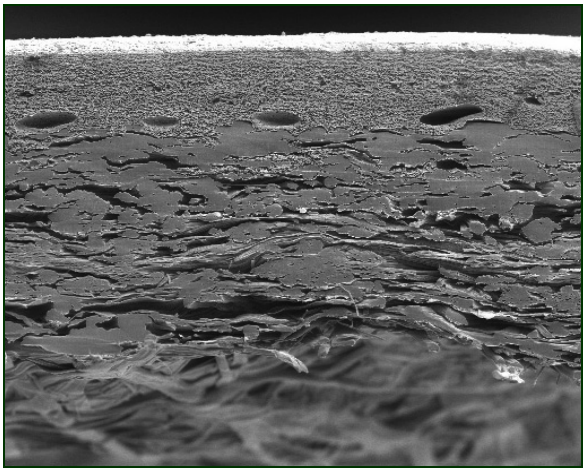
Selenium - Selenium is an essential trace element for human consumption. The exact toxic effects of it are not known and its interaction in the human body is very complex. In order to provide safety factor, levels of Selenium are controlled in drinking water so that over-exposure to Selenium does not occur.

Uranium - The naturally occurring form of Uranium is as the Uranyl Ion UO_2^{++}. Uranium, while it may be radioactive, is actually more serious as a toxin to the kidney. At high enough levels, it can cause permanent kidney damage.

Membrane Filtration of Drinking Water

The first sand filter used for clarifying drinking water was installed in Paisley Scotland in 1804. Since then some advances have been made in sand filter design and in the use of coagulation prior to filtration. However, the basic concept has remained the same for nearly 200 years. There has been a trend in recent years towards the use of polymer membranes for treatment of potable water for domestic and industrial use. Significant advances in polymer chemistry within the last 20 years and the use of membranes is becoming more widely accepted. In addition to the membrane itself, significant advances have occurred with respect to the delivery system. New technologies are appearing all the time and membrane systems now offer an effective competitive treatment method option.

There are four basic types of membranes based on pore size or rejection characteristics. Microfiltration (MF) is the most open media with pore sizes from 0.1 micron and larger. Ultrafiltration (UF) membranes have pores ranging in size from 0.005 micron to 0.1 micron. These are typically rated according the minimum nominal molecular weight size that the membrane will reject. This range for UF membranes is from 2,000 MWCO (molecular weight cut off) to 250,000 MWCO. Nanofiltration (NF) and Reverse Osmosis (RO) membranes don't have pores as such and work by diffusion. Ionic charge and size play a role in the permeation through the membrane. Monovalent ions will pass more freely than multivalent or divalent ions. NF membranes are designed to target multi-valents ions where as RO will remove monovalent ions.


0.1 µm Teflon MF Membrane

For the purpose of non-brackish water filtration, Microfiltration is generally good enough. There is a correlation between pore size and throughput. Generally, the larger the pore, the higher the flow rate through a given area of membrane. Since filtration of brackish water requires removal of silt, suspended particles, bacteria, and other microorganisms, a Microfilter is normally used. This type of filter will provide the highest throughput and best economics for a given flow rate. If the water source is especially colored or turbid or if taste complaints are a problem, Ultrafiltration can be used which is tighter than Microfiltration. UF membranes can remove very small organic matter, humic substances, and even viruses. UF membranes can improve color, taste, and odor of the drinking water. [6]

In the case of commercial bottled water or brackish water filtration, tighter membranes including Nano-filtration and Reverse Osmosis are used. In the case of brackish water, MF or UF would not reduce the high levels of dissolved solids and could not provide filtrate meeting the primary drinking water standards. Brackish water is a term that covers a very broad range of water quality. Brackish water can have anywhere from 1000 ppm to 10,000 ppm of TDS. Above 10,000 ppm is considered Saline Water. The most appropriate membrane for brackish water still depends on the concentration of TDS. For slightly brackish waters, (1,000 to 3,000 ppm), nano-filtration would probably yield an acceptable water quality. For high level brackish water, (>3,000 ppm), reverse osmosis is probably needed as in the case of seawater desalination.

Membrane Technology

Advanced treatment utilizing membranes for drinking water is becoming more popular. Although their use in generating drinking water has a long history, improvements in membranes lead to increasing acceptance and better overall economics. Membranes are uniquely capable of precise control of contaminant levels. NF and RO can be used to remove varying degrees of dissolved solids meeting the strict drinking water guidelines.

Most membranes used today are made of polymeric materials including: polyamide, polysulfone, regenerated cellulose, kynar (PVDF) and Teflon® (PTFE). The pores on most polymer membranes are so small they cannot be seen even with a scanning electron microscope. The pore sizes are determined by how well the membrane rejects particles of a known size. The membrane itself allows water to pass through the physical pores or through the matrix of the polymer and does not allow larger molecules or suspended solids to pass. Selection of the proper membrane depends on the separation required. [5]

Limitations of Conventional Membranes

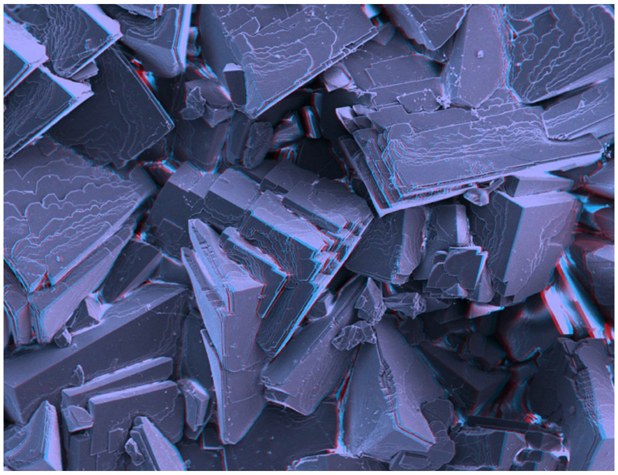
Membrane fouling and scaling can significantly increase the cost of a membrane system as well as reduce its reliability. As a result fouling, elaborate pre-treatment is used ahead of most membrane systems and the solubility limits of various constituents are monitored. The concentration of these constituents is controlled so that the solubility limit is not exceeded causing precipitation of colloidal materials and mineral scaling of the system. The net effect is that the % recovery of filtered water will be limited by the solubility of sparingly soluble salts and Silica. This limitation has been the cause of a great deal of recent development in membrane science. Several approaches have been used to try and minimize the effects of fouling. Polymer chemists are developing many new membranes that have "low fouling" characteristics. Several techniques are used like altering the Zeta Potential or amount of ionic charge of the membrane surface. Another method is modifying the thermodynamic potential of the membrane surface by using low surface energy materials. These materials reduce the chemical free energy change upon absorption of foulants.

Other developments have focused upon offering the potential foulants an alternate site for chemical attraction, or limiting their rate of precipitation. These methods ensure foulants are used up or diluted in their effect and thus will not pose a threat to the membrane itself. Examples of these are "anti-scalants" which can be organic compounds with sulfonate, phosphonate, or carboxylic acid functional groups. Chelating agents are also used which sequester and neutralize a particular foulant, especially metals. Carbon, Alum, and zeolites can be used as an additive. These offer huge surface areas loaded with nucleation sites suitable for absorption or crystallization to occur spontaneously at relatively low solubility levels.

Most often, the optimum membrane system will employ several of these techniques in order to combat or avoid fouling. For example, crossflow membrane systems will utilize pre-treatment of the feed water by using a 5.0µm bag filter followed by a 1.0µm Cartridge filter. Then the system will use a "Low Fouling" membrane with advantageous surface chemistry. An antiscalant will be dosed into the feed to sequester any potential foulants. And finally, aggressive crossflow is used to keep the membrane clear. This is a suitable treatment process as long as the feedwater is within specific criteria including: LSI (Langolier Saturation Index), SDI (Silt Density Index), and concentrations of sparingly soluble salts and other suspended colloids. [6]

Sparingly Soluble Salts

Even with all of these tools, the recovery of these systems can be limited to low levels. This results in a large volume of rejected brine that must be further treated or disposed. Minerals that will precipitate and foul conventional membrane systems as they come out of solution are predominantly composed of divalent metal ions. Monovalent metals such as Sodium and Potassium are nearly completely soluble, whereas, in the presence of Sulfate, Phosphate, or Carbonate, divalent ions such as Calcium, Iron, Magnesium, Barium, Strontium, Radium, Beryllium, Lead, and Silicon are nearly insoluble. [8]



Calcium Carbonate Crystals

When pressure is applied and reverse osmosis filtration occurs, nearly pure water is forced through the membrane thus changing the equilibrium and consequently the concentration of solutes to solvent. If this process continues until the solute reaches its limit of solubility, precipitation is likely to occur. Once precipitation has begun at appropriate nucleation sites then as more water is removed more precipitated materials are created. This will continue, as the system will attempt to keep the concentration of solutes at or below the solubility limit. If water is removed by filtration, but not in enough quantity to reach the solubility limit of the solutes, no scaling or precipitation will occur. One primary method used during conventional membrane filtration is recover water from the system to the point where solubility limits are not reached. The second method is to use anti-scalants that either inhibit the growth of crystals or sequester the reagents and thus reduce the available concentration. Software programs have been created to calculate the solubility limits based on known feed values. Once you enter the feed values, the program will calculate solubility and then instruct the user on the highest acceptable recovery value for sustainable system operation.

Common Forms of Mineral Scales	
Calcium Carbonate	Calcium Sulfate
Calcium Phosphate	Barium Sulfate
Strontium Sulfate	Iron Hydroxide
Silicon Dioxide (Silica)	

Calculating % Recovery & Solubility Limits

Conventional membrane systems have strict guidelines for incoming feed water composition. The reason for this is to minimize the potential problem of scaling or precipitating of slightly soluble ions. Precipitated insoluble materials like mineral scale can foul or blind off crossflow membranes quickly. These must be controlled in order to operate the system properly. Levels of reagents are measured to insure that they will remain soluble during the filtration process. These limits can be exceeded to some degree if antiscalants are used to consume reagents or to inhibit and block growth of scale.

For example:

Well Water is to be treated using membranes for purification. The water contains 30 ppm of dissolved silica (SiO_2). The solubility limit of Silica can be 120 ppm depending on pH and temperature. To figure how much pure water can be extracted through filtration before the solubility limit of silica is reached the following equations can be used:

120 ppm (Ksp) ÷ 30 ppm = 4

The Silica can be volume reduced by a factor of 4 before the solubility limit will be reached.

100% ÷ 4 = 25%

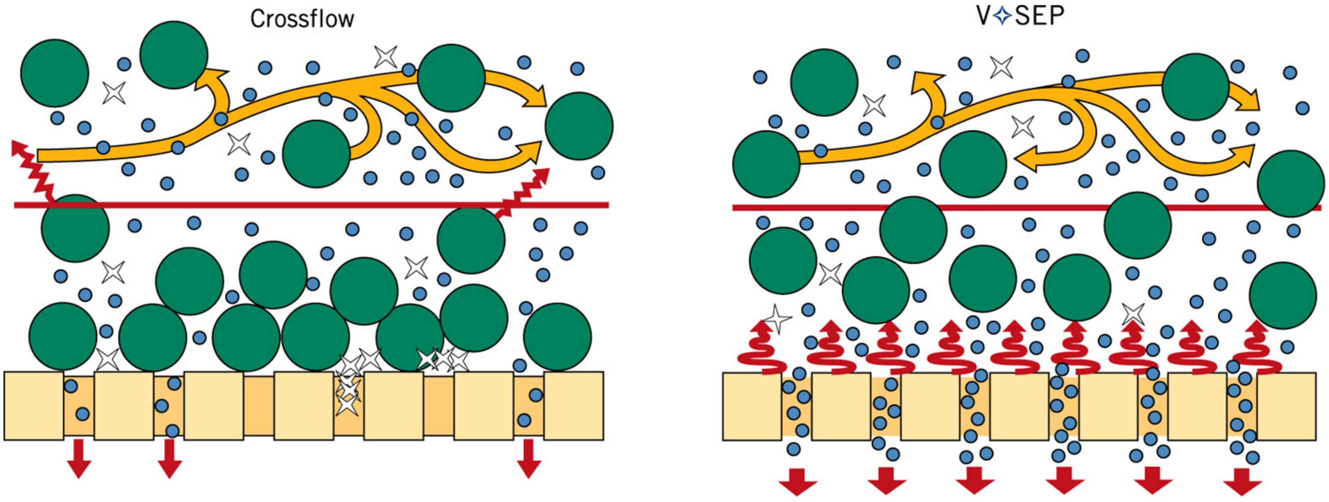
The liquid volume can be reduced by 75% so that a concentrate volume of 25% is left at which point the solubility limit has been reached. This is also known as a 75% recovery. Since near the solubility limit, there is a metastable region where precipitation can occur prior to the solubility limit if favorable conditions exist some safety factor must be used. Slight variations in temperature, pressure, and pH can shift the point of solubility and cause unexpected scaling. For this reason, conventional membrane systems are not run at the solubility limit, rather they are run at significantly less than that or anti-scalants are used to insure adequate safety factor.

In the example above, with 30 ppm of Silica, safe operation for conventional membrane systems would be at 50% recovery without pretreatment or 75% recovery with antiscalant addition. If the silica content of the raw water was 100 ppm, the water is almost not treatable using conventional membranes alone. Water softening must be used to reduce the hardness and mineral content to sufficiently low levels prior to entry into the membrane system.

When scaling occurs in a membrane system, colloids of insoluble mineral salts are formed. While some scaling can occur on the membrane itself, most of it will occur at other more efficient locations and then will become suspended colloids, which will act as any other suspended solid during the filtration process. Conventional membranes are subject to colloidal fouling as suspended matter can become polarized at the membrane surface and obstruct filtration. Crossflow is used to reduce the effects of concentration polarization. The main problem with scaling for membrane systems is that the process introduces a large amount of potential foulants into the system, which can reduce flux. Just as conventional membranes have limits on TDS due to the solubility limits of the various constituents, they also have limits on TSS, as colloidal fouling will occur if these levels are too high.

V✧SEP Advantages

V✧SEP employs torsional vibration of the membrane surface, which creates high shear energy at the surface of the membrane. The result is that colloidal fouling and polarization of the membrane due to concentration of rejected materials are greatly reduced. Since colloidal fouling is avoided due to the vibration, the use of pretreatment to prevent scale formation is not required. In addition, the throughput rates of V✧SEP are 5-15 times higher in terms of GFD (gallons per square foot per day) when compared to other types of membrane systems. The sinusoidal shear waves propagating from the membrane surface act to hold suspended particles above the membrane surface allowing free transport of the liquid media through the membrane. [9]

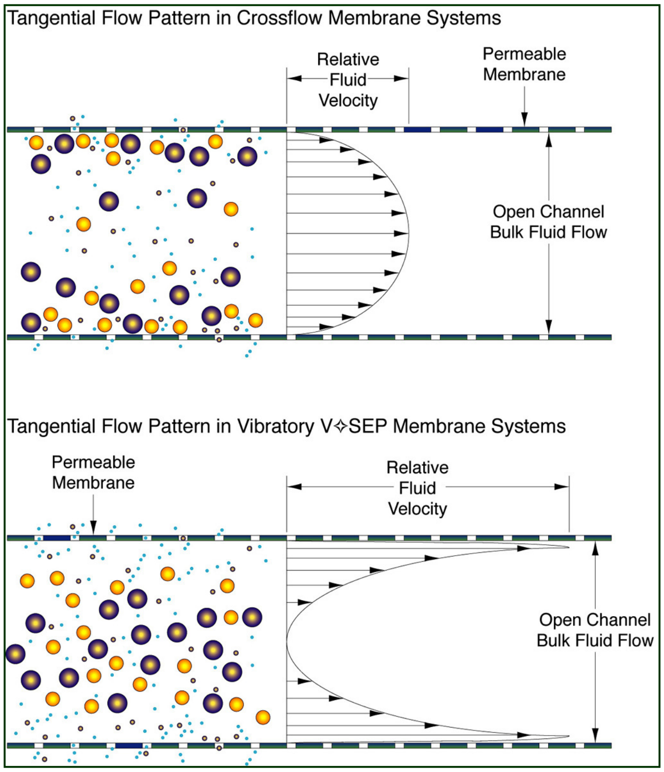


Fluid Dynamics Comparison between VSEP and Conventional Crossflow Filtration

The V✧SEP membrane system is a vertical plate and frame type of construction where membrane leafs are stacked by the hundreds on top of each other. The result of this is that the horizontal footprint of the unit is very small. As much as 2000 square feet (185 m2) of membrane is contained in one V✧SEP module with a footprint of only 4' x 4'.

VSEP employs torsional oscillation at a rate of 50 Hz at the membrane surface to inhibit diffusion polarization of suspended colloids. This is a very effective method of colloid repulsion as sinusoidal shear waves from the membrane surface help to repel oncoming particles. The result is that suspended solids are held in suspension hovering above the membrane as a parallel layer where they can be washed away by gentle tangential crossflow.

This washing away process occurs at equilibrium. Pressure and filtration rate will determine the thickness and mass of the suspended layer. Particles of suspended colloids will be washed away by crossflow and at the same time new particles will arrive. The removal and arrival rate will be different at first until parity is reached and the system is at a state of equilibrium with respect to the diffusion layer. (Also known as a boundary layer) This layer is permeable and is not attached to the membrane but is actually suspended above it. In VSEP, this layer acts as a nucleation site for mineral scaling. Beneath the hovering suspended solids, water has clear access to the membrane surface.



Mineral scale that precipitates will act in just the same way as any other arriving colloid. If too many of the scale colloids are formed, more will be removed to maintain the equilibrium of the diffusion layer. As documented by other studies, VSEP is not limited when it comes to TSS concentrations as conventional membrane systems are. Conventional membrane systems could develop cakes of colloids that would grow large enough to completely blind the conventional membrane. In VSEP, no matter how many colloids arrive at the membrane surface there are an equal number removed as the diffusion layer is limited in size and cannot grow large enough to blind the system. In fact VSEP is capable of filtration of any liquid solution as long as it remains a liquid. At a certain point, as water or solvent is removed, the solution will reach a gel point. This is the concentration limitation of VSEP.

In the VSEP membrane system, scaling will occur in the bulk liquid and become just another suspended colloid. One other significant advantage is that the vibration and oscillation of the membrane surface itself inhibits crystal formation. The lateral displacement of the membrane helps to lower the available surface energy for nucleation. Free energy is available at perturbations and non-uniform features of liquid/solid interfaces. With the movement of the membrane back and forth at a speed of 50 times per second, any valleys, peaks, ridges, or other micro imperfections become more uniform and less prominent. The smoother and more uniform a surface, the less free energy is available for crystallization. In the absence of any other nucleation sites, this would lead to a super-saturated solution. In actual fact, what happens is that nucleation occurs first and primarily at other nucleation sites not being on the membrane, which present much more favorable conditions for nucleation.

Crystals and scale also take time to form. The moving target of the membrane surface does not allow sufficient time for proper germination and development. The solids in the bulk fluid present a much more favorable nucleation site. Whereas, with conventional static membranes, scale formation on the membrane is possible and has plenty of time to develop and grow. Another feature of VSEP is that filtration occurs at a dramatically higher rate per m^2 than with conventional membranes due to the suspension of colloids above the membrane. Studies have shown as much as a 15 times improvement in flux per area. The result of this is that as much as 1/15th of the membrane area is required to do the same job as a conventional crossflow membrane. This is beneficial for many reasons one of which is hold-up volume of feed waters.

The result is that filtration occurs quickly and the length of travel of feed waters over membrane surfaces is reduced by as much as 15 times. This means that there is much less time for scaling and crystal formation within the membrane system. Crystal formation is a function of time, especially with respect to Silica, which is very slow to grow. If scaling is to occur within the system, it will more likely occur at high-energy nucleation points and not on the membrane. In addition to that, the high filtration rate is capable of making a super saturated solution, which may not even have residence time sufficient to react within the membrane system itself and may wait until it has been discharge to complete the equilibrium process.

Since VSEP is not limited by solubility of minerals or by the presence of suspended colloids, it can actually be used as a crystallizer or brine concentrator and is capable of very high recoveries of filtrate. The only limitation faced by VSEP is the osmotic pressure once dissolved ions reach very high levels. Osmotic pressure is what will determine the recovery possible with a VSEP system.

Validation Testing

New Logic has pilot tested several projects where the objective was to volume reduce reject from a spiral RO membrane system. This section will illustrate the performance of pilot tests conducted recently all pertaining to high TDS brine concentration.

The first example is not a case of spiral reject, rather it is a case of VSEP treating saline water from an oil production well known as produced water. This test case illustrates the capabilities of the VSEP system. New Logic conducted onsite pilot trials for several months at an oil production site in Central California. The objective was to treat the water from the oil production wells using reverse osmosis so that the treated water could be re-injected into the drinking water aquifer for pressure stabilization.

The results with respect to the primary objective of generating permeate of a quality that reaches the goals for re-injections to the aquifer were met. The water treated was very high in Chlorides and because of the very low limits for discharge, two stages of RO filtration were required. In this case, VSEP RO was used as a primary stage with the RO filtrate being polished in a 2nd stage using a conventional Spiral RO system. The following table shows the analytical results from this test work.

Component:	**Chloride**	**Sulfate**	**Nitrate**	**TDS**	**Boron**	**Sodium**
Initial Feed	3285 mg/L	304 mg/L	4 mg/L	7314 mg/L	23.4 mg/L	2900 mg/L
VSEP Permeate	628 mg/L	25 mg/L	0 mg/L	1617 mg/L	5.4 mg/L	614 mg/L
Spiral Permeate	11 mg/L	0 mg/L	0 mg/L	51 mg/L	0.39 mg/L	25 mg/L
Discharge Limit	127 mg/L	127 mg/L	4.3 mg/L	510 mg/L	0.64 mg/L	85 mg/L

This test illustrates the ability of VSEP to treat water that is very high is TDS and in other scale forming components. In fact, in this case, Silica, Carbonates, and Sulfates were at saturation with respect to solubility.

VSEP for Brackish Water Reject from an Existing Spiral System

New Logic conducted recent pilot trials on reject from an existing membrane system installed in Southern California. The primary objective was to treat the reject water to minimize reject from the water plant. The result is that disposal costs would be reduced and the yield of clean water could be increased. The primary objectives were to meet limits for Color, TOC, and other taste related organics. The customer had previously tested other Ultrafiltration membrane systems for treating this reject and the results were poor regarding flux rate and recovery. The purpose of this test was to see how well VSEP could perform as compared to conventional UF membrane systems.

VSEP Onsite Pilot Trials in California

Since VSEP is not limited by solubility and since meeting Primary Drinking water standards would be a benefit, a tight Nano-filtration membrane was used. The filtrate from the existing plant and the VSEP 2nd stage concentrator system would be blended, so the better the quality from the VSEP, the more flexibility there would be when it comes to blending.

After scanning several NF membranes, a 90% NaCl reject NF membrane was chosen for further study. Concentration and Flux vs. Time studies were completed and the results were excellent. During a concentration study, the system was started up first in "Re-circulation" mode and also set to the Optimum Pressure and expected process temperature. The system was run for a few hours to verify that the flux was stable and the system had reached equilibrium. Then, the permeate line was diverted to a separate container so the system is in "Batch" mode. The permeate flow rate was measured at timed intervals to determine flow rate produced by the system at various levels of concentration. The following Table shows the performance during the “Concentration Study”:

Ave Flux	Initial Flux	Ending Flux	Pressure	Initial Solids	Ending Solids	% Recovery
65.2 gfd	144.5 gfd	11.47 gfd	450 psi	0.3 %	11.8 %	98.8 %

Based on the Data, the NF Membrane was found to be suitable because it provided a high, stable permeate flux with no solids or color in the permeate. It also met the process objectives for % recovery and demonstrated good performance over time. In this case, the maximum % recovery achieved was 98.8 %, which yielded an average flux of 65.2 gfd. (gallons/sq ft/day)

The following table shows the final results of testing:

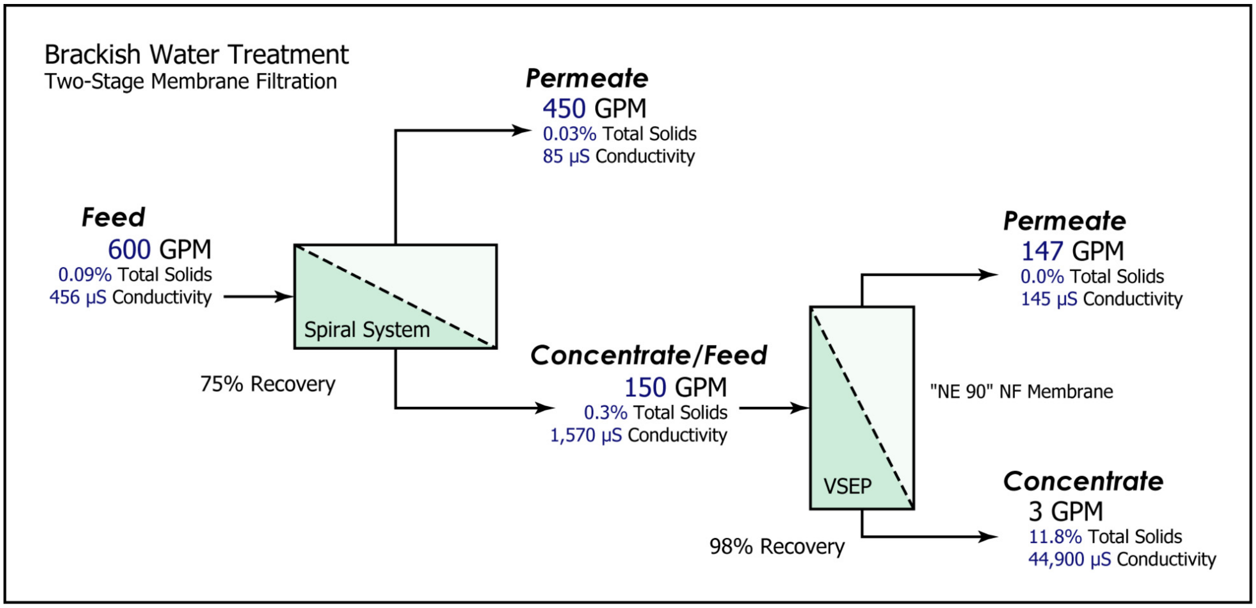
Membrane	% Total Solids	Conductivity	pH	Volume
Initial Feed	0.3 %	1,570 µS	8.68	100 %
Final Permeate	0.0 %	145.4 µS	8.98	98.8 %
Final Concentrate	11.8 %	44,900 µS	9.35	1.2 %

The results exceeded expectations as the VSEP was able to produce greater than 98% recovery of treated water. In addition, the customer had previously tested other UF membrane systems that had flux rates of about 20 gfd. VSEP, using a much tighter NF membrane, was able to achieve a very high flux rate of 65 gfd (gal/sq ft/day).

The following table shows the complete analytical results from grab samples collected during the pilot trails. The purpose of testing was to confirm compliance with Primary and Secondary EPA drinking water standards related to health issues and aesthetic considerations.

RO Reject VSEP Analytical Results			**VSEP**	**VSEP**	**VSEP**	**Reporting**
Analyte		**EPA Limit**	**Feed**	**Permeate**	**Reject**	**Limit**
Aluminum	Al	0.050 mg/L	0.600	ND	27.550	0.100
Arsenic	As	0.010 mg/L	0.008	ND	0.253	0.005
Barium	Ba	2.000 mg/L	0.120	ND	5.706	0.010
Cadmium	Cd	0.005 mg/L	ND	ND	-	0.005
Calcium	Ca	none	45.00	ND	2,235.0	0.500
Chromium	Cr	0.100 mg/L	0.038	ND	1.557	0.010
Copper	Cu	1.000 mg/L	0.029	ND	1.107	0.010
Iron	Fe	0.300 mg/L	2.300	ND	112.55	0.100
Lead	Pb	0.015 mg/L	ND	ND	-	0.003
Magnesium	Mg	none	3.200	ND	147.75	0.500
Selenium	Se	0.050 mg/L	0.008	ND	0.302	0.005
Silver	Ag	0.100 mg/L	ND	ND	-	0.005
Zinc	Zn	5.000 mg/L	0.180	ND	8.510	0.020
Cyanide	CN	0.200 mg/L	ND	ND	-	0.010
Silica	SiO_2	none	23.00	5.300	890.3	1.000
Chloride	Cl	250 mg/L	50.00	8.300	2,093.3	0.200
Fluoride	F	2.000 mg/L	1.500	0.200	65.20	0.100
Sulfate	SO_4	250 mg/L	120.0	1.800	5,911.8	0.500
Total Dissolved Solids	TDS	500 mg/L	2,340	82.0	112,982	10.0
Color		15 color units	13,000	ND	-	5.0

By using VSEP to treat the current reject from the installed NF system, this client will be able to achieve 99% recovery of treated water, leaving only 1% of the volume to be disposed of as reject. The following is a process schematic of the final system design.



Other VSEP Water Installations

V✧SEP Treats River Water

New Logic installed its Vibratory Shear Enhanced Processing (V✧SEP) in July, 1997 at a major international electronic disk manufacturing facility at Hokkaido Island in Northern Japan. The V✧SEP system is used for treatment of river water for ultra-pure water production at this facility. The V✧SEP system uses an ultrafiltration membrane module and is able to treat river water in order to remove or reduce humic substances, color, turbidity, permanganate consumption and total iron to below the required limits. The application of V✧SEP membrane technology to treat river water for ultra-pure water production at electronic disk fabrication facility was found to be an attractive economic alternative to the conventional sand filter water treatment technology. Concentration of the raw river water ranges from 5 to 10 mg/L of TSS. Permeate from the V✧SEP has less than 1 mg/L TSS. VSEP also reduced color from 67 color units to <1 color unit, from 2 NTU turbidity to <0.1 NTU, and from 0.1 mg/L Iron to <0.05 mg/L of total Iron.

Commercial Drinking Water Case Study

New Logic has installed a nearly 1 Million Gallon per day water filtration system for a major bottling company. The filtrate from this system is purified and disinfected using an Ultrafiltration membrane and then sent on to the bottling process where it becomes a consumer product for consumption. In this case, aesthetic improvement was the goal due to a large number of taste complaints. Reduction of TOC causing poor taste has been effectively reduced by the use of a 30,000 mwco UF membrane. One other benefit of the filtration is the near complete removal of all bacteria and other organisms. Normally, Microfiltration could be used with higher throughput per SF of membrane, but in this case TOC reduction required the use of a UF membrane. The previous system design consisted of a Multi-Media filter feeding a Carbon filter. Normal operation involved frequent recharging or disposal of the Carbon media. In addition, the water quality led to numerous taste complaints. The addition of V✧SEP to the process improves taste, reduces TOC, and allows the Carbon filters to run trouble free. New Logic has completed several surface water facility installations using this vibrating membrane system for treatment to produce ultra-pure water. The results have demonstrated many advantages of this new membrane technology when compared to the conventional treatment methods.

Brine Treatment Method Comparisons

There are many methods of treatment currently being used for Brackish Water RO Reject Disposal. Some of these methods include:

- Evaporation Pond
- Deep Well Injection
- Disposal at Sea
- Reclaimed use for Industry or Irrigation
- Blending with POTW Discharge
- Advanced Thermal Evaporation Methods

The treatment method selected will vary depending on the site conditions. For example, if a willing party can take the reject water and benefit from it, this would be the easiest solution. However, willing recipients may be hard to find. Disposal at Sea would only be possible if in close proximity to the coastline. This option is not available to places like El Paso. Even if disposal at sea were considered, some discharge limits would apply and may not be met without further treatment. No one treatment method fits all scenarios, however, the more that the reject volume can be reduced, the better the choices for final disposal. The primary options for brine reject disposal are shown below.

Evaporation Ponds - Evaporation Pond or Solar Pond use is limited to regions where the evaporation rate exceeds the annual precipitation. Desalination plants located in arid areas such as the Southwestern United States could consider such treatment methods. The design of the evaporation pond should include liners, leakage monitoring, and accurate sizing calculations. The sizing calculation can be complicated as several competing factors must be evaluated including inflow rate, annual precipitation, and evaporation rates. Sufficient excess capacity must be provided. The cost of construction will vary quite a bit depending on the terrain and site conditions. Once installed, the actual operating costs are relatively small, however, one cost often overlooked is the closure of the pond at the end of the life.

Deep Well Injection - Deep well injection is used for many difficult to deal with waste streams. However, the option of Deep Well Injection is limited by the underlying geology. Any deep well discharge must be protected against mixing with drinking water aquifer supplies. The permitting process can also be long and arduous. Usually deep well injection is a last resort since it is more difficult and time consuming than other methods of disposal.

Costs for disposal wells like the one shown on the right are mostly related to permitting, drilling, and logistics. Very often, disposal well locations are not in the same area as well water supply for drinking water. This means that brine reject would need to be piped and pumped dozens of miles to a suitable location with porous rock formations. [13] One other factor is that in many areas of the United States, oil wells are becoming depleted. Such spent wells are candidates for disposal wells. There are some costs involved in converting the well to a disposal well, but overall there are cost savings if existing wells can be used for this purpose. [10]

Advanced Thermal Evaporation Methods - Thermal Evaporation methods include Brine Concentrators and Crystallizers. Brine Concentrators are used extensively for wastewater applications and employ a falling film evaporator with vapor recompression. Once started, operating costs are manageable. The vapor recompression provides much of the needed thermal energy. The system must be protected against scaling and fouling of the heat exchange surfaces. These systems are capable of reaching up to 15% total solids in the final brine slurry. Crystallizers rely on thermal evaporation of dissolved solids. As the water is flashed off, the solids will begin to crystallize in the unit and are then purged for disposal.

Vibrating Membranes as an Option for Brine Treatment

With new regulations as part of the Clean Water Act and with the advent of new technologies to address this problem, many municipal facilities are re-evaluating their existing methods. One of the new developments includes the new open channel plate and frame type polymeric membrane filtration systems. There are several types including the VSEP (Vibratory Shear Enhanced Process) made by New Logic Research of Emeryville, California. Competition and scientific advances have greatly reduced the cost of membrane systems making them more attractive for treating a variety of wastewaters.

Reverse Osmosis was previously not appropriate due to solubility limits. Now with this limitation removed as in the wide channel flow membrane modules like VSEP, RO membranes offer an excellent alternative to increase overall yield of drinking water and reduce the reject volume to be handled. RO V✧SEP membranes can be used in parallel and in series to handle any flow and produce nearly any water quality needed.

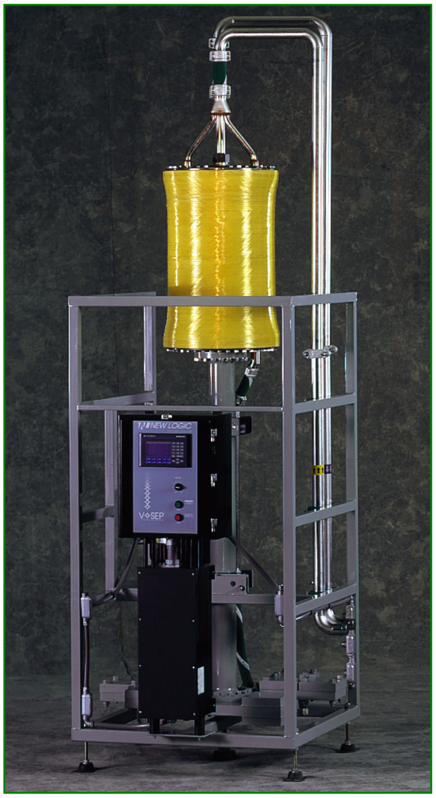
The V✧SEP filtration system incorporates a modular design, which makes it compact. Because the basic design is vertical rather than horizontal, the needed floor space per unit is inherently less than other types of dewatering systems. The V✧SEP does require up to 17’ in ceiling clearance. In most industrial applications ceiling clearance is ample, it is floor space that is limited.

Benefits of the V✧SEP Compact Design:

1] Easily added into an existing system to enhance performance
2] Can be installed in areas where space is at a premium
3] Is easily portable and can be moved from plant to plant
4] Can be installed as multiple stage system or as single stage
5] Can be “chain linked” to any number for any process flow demand.

Very often floor space is so limited, or the system being designed is so large that a separate structure is built to accommodate the treatment system. In such cases, the fact that the V✧SEP units are vertical and compact, it may be able to fit into an existing area of the building or it will reduce new building costs by requiring less space. Construction costs of $80 to $120 /square foot for new industrial buildings can add up and are a consideration when figuring the overall cost burden of a completed system. In addition to the limited space required for the mechanical components, the actual filter area has been designed in such a way as to be extremely compact and energy efficient. In the largest model, the “Filter Pack” contains 2000 Square Feet of membrane surface area, about the size of a medium size house. This 2000 SF of membrane has been installed into a container with a volume of about 15 Cubic Feet.

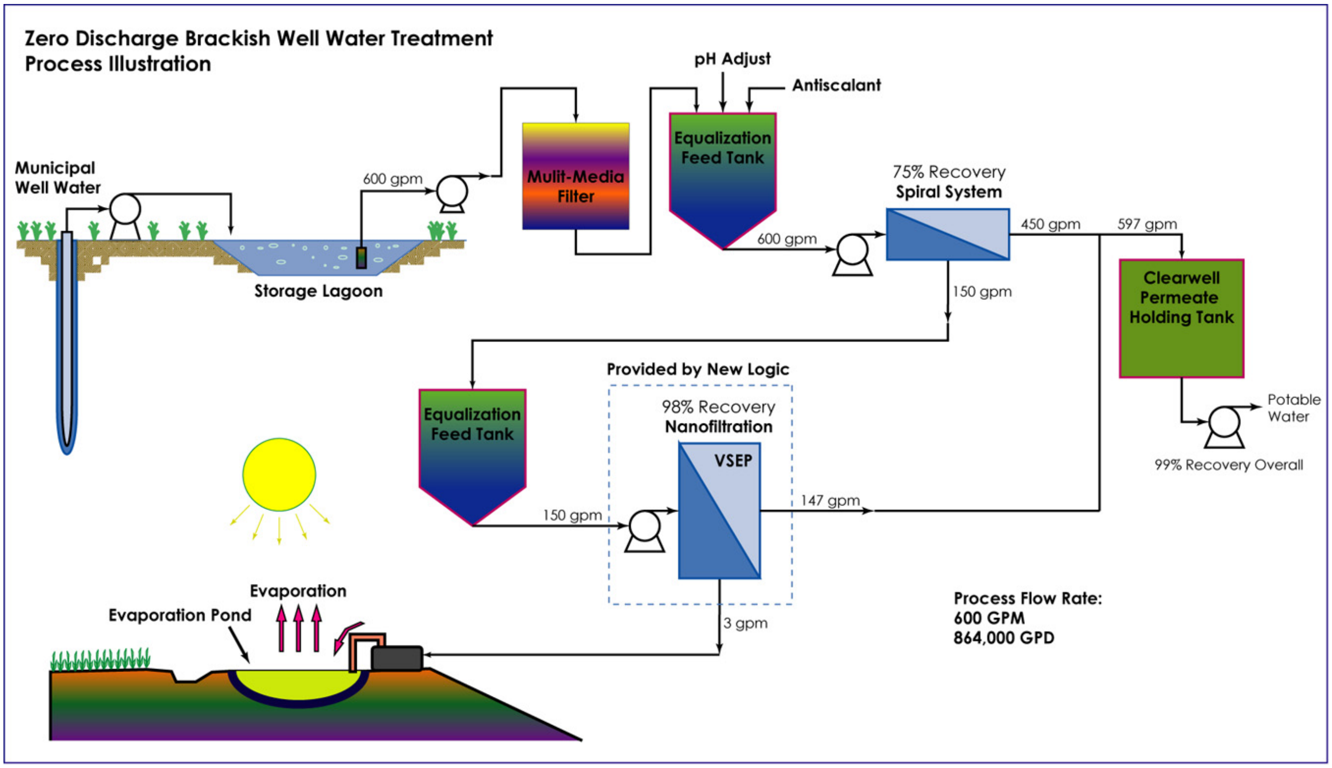
In the case of Brackish RO Reject treatment, the primary benefits are the increased treated water yield and the volume reduction of reject for disposal. In the test case shown earlier, only 3 gpm of reject would be left out of an initial 600 gpm of feed flow to the treatment plant. The reject volume would be 150 gpm, without the VSEP. Since the cost of Zero Discharge will hinge on the final disposal of brine, reduction of the reject volume is critical.



VSEP Module

VSEP Process Conditions

A process schematic for the proposed project related to the test case described above is shown on the following page. When a VSEP system is added on as a second stage, the well water is fed through the multi-media filter and then the water is pH adjusted and anti-scalant is added. The water is then fed to a spiral membrane system at the rate of 600 gpm. The spiral system produces 450 gpm of treated water and 150 gpm of brine reject. This brine reject would be then sent to the V✧SEP treatment system at a rate of 150 gpm and a pressure of 450 psig. Industrial scale V✧SEP units, using Nano-filtration membranes are installed to treat the spiral reject flow. The final reject stream after VSEP of 3 gpm would be discharged to an evaporation pond or other disposal method. V✧SEP generates a permeate stream of about 147 gpm which is blended with the stage one filtrate from the RO. The permeate contains approximately 1 mg/L of total suspended solids (TSS), and a low level of total dissolved solids (TDS), all well below the standards for drinking water. Membrane selection is based on material compatibility, flux rates (capacity) and permeate quality requirements. In this example, the TSS reduction is over 99%. The permeate quality from the V✧SEP can be controlled though laboratory selection from more than 200 membrane materials available to fit the application parameters.



VSEP Process Schematic for Recently Pilot Tested RO Reject Application

Economic Value

New Logic's V✧SEP system provides an alternative approach for Brackish RO Reject treatment applications. In a single operation step, V✧SEP will provide ultra-pure water and reduce TOC, TSS, TDS and color to provide a high quality filtrate free of harmful microorganisms. The justification for the use of V✧SEP treatment system in your process is determined through analysis of the system cost and benefits including:

Large land area for evaporation ponds not required as would be without VSEP
Simple automated treatment system requiring little operator involvement
Small system footprint
No chemical pre-treatment addition required
Non-Thermal process with low operating costs

Operating Cost Comparisons	VSEP Membrane Concentrator	Thermal Brine Concentrator	Injection Well Disposal	Evaporation Pond Disposal
Capital Cost Ratio	1.00	7.43	11.25	3.93 [13]
Power Consumption	$0.21/1000 gal	$4.44/1000 gal	---	---
Chemical Consumption	$0.02/1000 gal	$0.18/1000 gal	---	---
Membrane Replacement	$0.21/1000 gal	---	---	---
Operation & Maintenance	$0.18/1000 gal	$1.59/1000 gal	---	---
Total Operating Costs	$0.45/1000 gal	$6.21/1000 gal [12]	$1.13/1000 gal [11]	$0.91/1000 gal [13]

The VSEP Capital and Operating costs shown above correspond to the case that was recently pilot tested and described above. Actual VSEP results can vary depending on the make up of the brackish water feed source. Pilot testing should be done to verify system throughput and the resulting capital and operating costs.

Due to the lack of need for pre-treatment, the VSEP technology has been shown to be competitive with conventional spiral membrane systems and could even replace the spiral system completely yielding up to 98% recovery of treated water. A desalination plant composed entirely of VSEP would be a very cost effective alternative to existing conventional membrane plants. However, in such cases where an existing spiral membrane system is operating and where additional yield of treated water is desired, VSEP can be used as a complimentary technology. Compared to all other brine disposal methods, VSEP is much less expensive to own and operate.

Conclusion

Arid regions of the United States such as the southwest states of California, Arizona, New Mexico, and Texas are rapidly growing in population. Local Water Utilities are scrambling to come up with economical sources of drinking water. There has been a lot of research on this subject and this prospect poses a challenge for creative engineers working on the project. Due to competition and scientific advances, membranes are becoming a much more economical method of delivering drinking water from any source.

New Logic has been contacted by many engineers in the Southwest and is currently working on various research projects to measure the suitability of using VSEP technology to treat brine reject from brackish water desalination plants. The initial results are very promising and warrant further consideration. The VSEP technology has been used for more than a decade in the chemical processing industry. This unique opportunity for treatment of RO Reject from desalination plants comes at a time when the VSEP technology is mature, proven, and very cost effective compared to other competing methods.

Addition of a VSEP membrane concentrator system would significantly reduce the volume of brine reject that needs disposal. The reduction of the volume to be treated greatly simplifies the choices for final disposal. In the test case described above, an evaporation pond would only need to be 2% of the size it would be without the VSEP brine concentrator. Reducing the size of the evaporation ponds not only reduces the costs, but has aesthetic and political benefits as well. In addition to helping to solve the brine disposal problem, addition of the VSEP system to an existing desalination plant will increase the yield of treated water to as high as 98% as shown in the case described above.

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Publications:

Chemical Processing Magazine, March 2003, Industrial Strength Membrane Filtration - VSEP® Vibrating Membrane System Proves Membranes Aren't Just for Water Anymore

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0 Membrane Filtration of Waste Oil - An Economical and Environmentally Sound Solution,
1 Case Study - Membrane Filtration of Hog Manure
2 Technical Summary - Membrane Filtration of Phosphoric Fertilizers
3 Case Study - Membrane Filtration of Colloidal Silica, 2001
4 Case Study - Membrane Filtration of Acid Mine Drainage
5 Using VSEP for Polymer Diafiltration and Desalting
6 VSEP Filtration of Desalter Effluent
7 Membrane Filtration of Metal Plating Wastewater
8 VSEP Filtration for Glycol Recovery
9 Membrane Filtration and Precious Metals Recovery
10 Using VSEP to Treat Produced Water
11 Membrane filtration of Commercial Drinking Water

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Publications:

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Various Technical Articles Posted at: http://www.vsep.com/downloads

- Membrane Filtration of Landfill Leachate
- Using VSEP for Filtration of Oily Wastewater from a Waste Hauler
- Concentrating Carbon Black using Membrane Filtration
- An Examination of the use of VSEP Technology to Replace Cold, Warm, and Hot Lime Softening

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Website: www.vsep.com

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Glossary:

Batch Concentration: The machine configuration where a fixed amount of feed slurry is progressively concentrated by removal of permeate from the system. The concentrate from the system is returned to the feed tank.

Concentrate: The part of the fluid solution, which does not permeate through the membrane. Also called Reject or Retentate.

Feed: Also called feed slurry. It is the raw solution, which is offered for filtration. It typically has suspended solids, bacteria, or molecules, which are to be segregated from a clear filtrate, and reduced in size making a concentrate solution of feed slurry.

Filter Pack: The filtering module, which contains the membrane, layers and is housed by a fiberglass enclosure

Fouling: The accumulation of materials on the membrane surface or structure, which results in a decrease in flux

Flux: Not the same as flow rate. Flux is a measurement of the volume of fluid, which passes through he membrane during a certain time interval for a set area of membrane, ie GFD, LMH

Microfiltration: Filtration of particles suspended in solution, which are ≥ 0.1 µm or 500,000 daltons in size or weight.

Micron: A unit of measurement. 1 Micron is equal to one-millionth of a meter (10^{-6}). 1 Micron also equals 12,000 mesh or .0000394". The limit of human visibility is 40 Microns.

Molecular Weight: The number that expresses the average mass of the molecules of a compound to the mass of an atom of Carbon 12 at a value of exactly 12

Nanofiltration: Filtration of particles suspended in solution which are ≥ 0.01 µm or 1000 daltons in size or weight.

Percent Recovery: The ratio of permeate flow rate to the feed flow rate

Permeate: Also called filtrate. It is the part of the solution, which is able to or allowed to filter through the membrane. The particle size of solids still suspended is determined by the pore size of the discriminating membrane.

Reverse Osmosis: Filtration of particles suspended in solution, which are ≥ 0.001 µm or 100 daltons in size or weight.

Ultrafiltration: Filtration of particles suspended in solution which are 0.01 to 0.1 µm or 1000 to 500,000 daltons in size or weight.