An EconoPure™ White Paper

EconoPure™
Water Systems

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Depth Exposed Membrane for Water Extraction (DEMWAX™) for seawater desalination

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Introduction

The Depth Exposed Membrane for Water Extraction (DEMWAX™) is a novel approach to both fresh surface water treatment and seawater desalination that deploys a system directly within the source water body. The DEMWAX^{TM} system is configured to take advantage of the natural (free) pressure of the source water body to drive a membrane process. This configuration has many advantages over the incumbent technologies. This paper provides detail on the DEMWAX™ system and its advantages.

Basic Theory

The idea behind the DEMWAX™ system is harnessing natural water pressure to drive a reverse osmosis process in lieu of artificially creating this pressure. The system deploys membranes where natural pressure already exists and it takes advantage of natural water movement, eliminating the need to mechanically handle the corrosive feedwater. The DEMWAX^{TM} system has many applications (see discussion below) but the two primary applications are the desalination of seawater and the treatment (potable) of fresh surface water.

For both primary applications, there are five basic premises or design traits behind the technology.

1. Natural water pressure in a water body: This pressure is free, constant, and abundant. The use of this free pressure means that with the DEMWAX™ system, only the treated water is pumped.
2. Atmospheric pressure communication: Communication of atmospheric pressure to the product water side of the membranes allows the natural creation of the pressure differential needed for the process.

3. Natural water movement: All membrane processes require the movement of feed water to the membrane surface and removal of the concentrate or brine. Membrane sheets in the DEMWAX™ system are designed so that gravity removes the concentrate and brings more water to the surface of the membranes. The space between the membrane elements is nearly 10 times that used in spiral wound configurations allowing for the natural flow of water between them and avoiding surface tension “locking” the source water in place.
4. Low recovery: The water bodies can be considered an endless supply of high pressure source water, similar to the concept of a ‘heat sink’. As such, there is no need for high recovery, which just raises the osmotic pressure requirement. This allows the design pressure to be just greater than osmotic pressure for the source water (osmotic + transmembrane or driving pressure).
5. Low flux: Membrane flux (produced water per unit of membrane area) is often associated with system efficiency in traditional systems. That is, higher flux means less pre-treatment costs, less membrane, fewer pressure vessels, etc. However, higher flux also means higher transmembrane pressure and higher velocities into the membrane face. Low flux, on the other hand, reduces the driving pressure requirement and lowers the velocity of the water into the system. Low flux also reduces stress on membranes increasing the effective life and reduces particulate fouling.

New Paradigm

Most research in seawater desalination has focused on reducing the energy requirements as that remains the largest cost component of desalination plants today. There are physical limits in energy required for separating dissolved ions from water and these limits bound the efficiency gains that are available. For any membrane desalination process the recovery rate (ratio of permeate to feedwater volumes) dictates the energy requirement as it defines the concentration of the water fed into the system and separation energy is proportional to concentration of a solution, in this case salt and water.

In the past, systems have found optimal operating points that balance the pressure and the volume of the feedwater. That is, low recovery means low salt concentration in the feed water and therefore low pressure because osmotic pressure is proportional to concentration. However, low recovery also means processing higher volumes of feedwater. This limitation is represented by parabolic cost curves when plotting energy requirements against the rate of recovery. Optimum operating points often reflect the recovery rates at the minimums of these cost curves.

The figure below shows a series of such cost curves. The uppermost cost curve shows the case for simple reverse osmosis (RO). In this case one can see that raising or lowering the recovery rate increases the energy cost of the process from the minimum at about 60% recovery. A process that can lower the recovery and therefore the pressure required, must, by definition, pump more volume at the lower pressure. Conversely, a process designed with higher recovery can pump less volume, but must pump that volume at higher pressure given the increase in concentration. The minimum energy for such simple RO processes tends to the 50 to 65% range.

With the advent of efficient energy recovery devices, the optimal operating point started shifting to lower recoveries as can be seen on the second, lower cost curve in the figure. As energy recovery devices allowed beneficial use of the residual brine pressure, there is less waste associated with the pressurized water not converted to potable. Thus, optimal recovery rates tended lower, 30 to 40%.

Still lower energy consumption is possible by using the natural hydrostatic pressure in the sea. Researchers have successfully attempted this by submerging a spiral wound membrane system to depth in the sea. The natural pressure did the work of the pump on a traditional shore based system. However, the produced water pumped to shore had to overcome the same head of pressure used in the treatment process, seemingly eliminating the benefit. However, only the produced water must be pumped rather than the far more voluminous feed water, thus generating savings.

Past natural pressure systems were designed with membrane configurations specifically designed for traditional shore based systems. These membrane elements required water be pushed through them since they were designed for systems where water is moved with pumps. In these cases the optimal recovery rate (and energy requirement) was lower than the shore based system but were limited on the low end by the fact that these systems still required pumping the flow of the feedwater. The pumping was not for static pressure, as that existed infinitely in the sea. Rather, it was only for the movement of the feed in the volumes associated with the recovery. This limitation can be seen on the third cost curve by the steeply increasing curve at very low recovery rates.

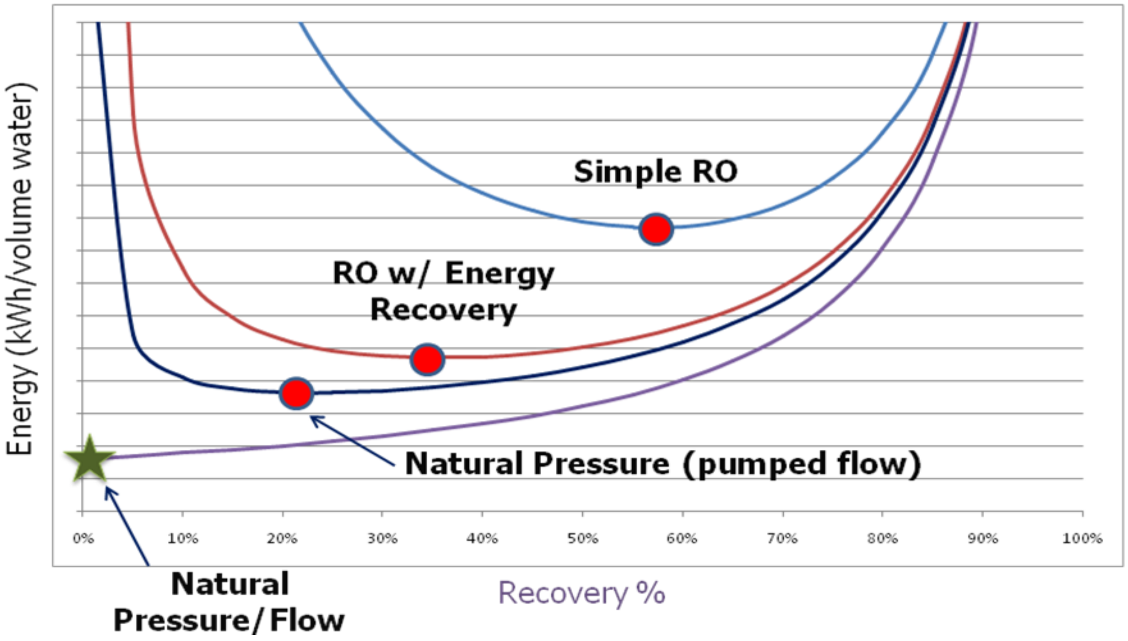

Figure 1 - Energy vs. Recovery

The final cost curve represents the case of the DEMWAX™ system, using natural static pressure in the sea, but also designed to capture natural movements of the feedwater. The DEMWAX™ system uses the natural forces of gravity and currents in the ocean to naturally move the feedwater. In this case, the energy requirement tends toward the physical limit at a zero recovery.

To do this, the DEMWAX™ membrane cartridge is configured to allow gravity to move the concentrate, necessarily more dense than surrounding seawater, down and away from the system. The membrane cartridge is comprised of a multitude of vertical, parallel, flat sheet membrane elements spaced to minimize head loss. The membranes are directly exposed to the seawater like radiator fins suspended in the water column. The voids between these membrane sheets are open on the top and bottom to allow water to naturally pass through. The lower recovery rate, and thus lower pressure requirement, corresponds to a lesser depth requirement for the system. The depth needed for the DEMWAX™ system in the ocean is approximately 260 meters[1].

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[1] Past natural pressure systems required much greater depth in order to achieve the osmotic pressure of the more concentrated feedwater due to the higher recovery rate. See, for example: Paolo Pacetti, et al, "Submarine seawater reverse osmosis desalination system," Desalination 126 (1999) 213 – 218.

Energy Efficiency

The result of the DEMWAX™ design is a low energy process that harnesses natural forces efficiently. For the seawater DEMWAX™ the power reduction is approximately 70% versus current state-of-the-art traditional SWRO systems. In general terms, this reduction can be summarized as half the flow at half the pressure. A typical large scale SWRO plant with energy recovery uses approximately 16 kilowatt-hours per thousand gallons of product water (or about 4.2 kWh/m^3). A SWRO plant that operates at 50% recovery must pre-treat and pressurize 2 gallons of feed water to yield 1 gallon of product water. The DEMWAX™ system only needs to pump the 1 gallon of product water or about half the flow as compared to a traditional SWRO plant.

To achieve the 50% recovery, a traditional SWRO system must reach a pressure of nearly 800 to 1,000 psi (55 to 69 bar). As osmotic pressure for typical Pacific Ocean seawater is approximately 320 to 350 psi (22 to 24 bar), the required pressure is more than twice osmotic. Since the DEMWAX™ is designed to operate at extremely low recovery; the required pressure is only slightly higher than osmotic at about 350 to 400 psi (24 to 28 bar) or about half the pressure of a traditional onshore SWRO plant. This required pressure is supplied free by the water column in the source water body. While the DEMWAX™ system must use energy to pump the product water to the point of use, it is not quite half the pressure of traditional systems. The resulting total energy is about 70% less than traditional SWRO.

Water Flow and Membrane Spacing

For all membrane processes, effective transfer of source water to the membrane surface, and the removal of concentrate from the membrane surface are critical. In the spiral wound configuration, a raw water spacer is used to create a channel between the membranes to convey the source water and brine. However, this space is very small, on the order of 0.03 inches (0.76 mm). In a static seawater environment, even at high pressure, the feedwater and brine would not flow efficiently to match the flux and avoid excessive concentration at the membrane surface without mechanical means to remove the brine. The close spacing of the traditional spiral wound membrane would inhibit flow if no mechanical means were used.

The DEMWAX™ system solves this problem. Instead of trying to force the water through a small channel, the membranes in the DEMWAX™ system have a much larger channel (increased spacing between membranes) reducing the associated friction loss. In addition, the membranes are oriented vertically to allow gravity to assist this flow. As the concentration of the seawater on the high-pressure side of the membrane increases, so does its density due to incremental increase in salinity as fresh water is extracted.

Since the more dense water is slightly heavier, gravity (g) will induce a flow of the dense water from top to bottom.

Figure 2 shows this occurring between four such membrane elements. Natural currents assist this process of new feed water coming in the top of the membranes and flowing through to the bottom, but the DEMWAX™ is designed to work even without currents.

It is important to understand what happens to the concentration of the dissolved solids. Some may assume a buildup of such concentrated solids will gather at the membrane face and block the flow of water through the membranes. This is not the case.

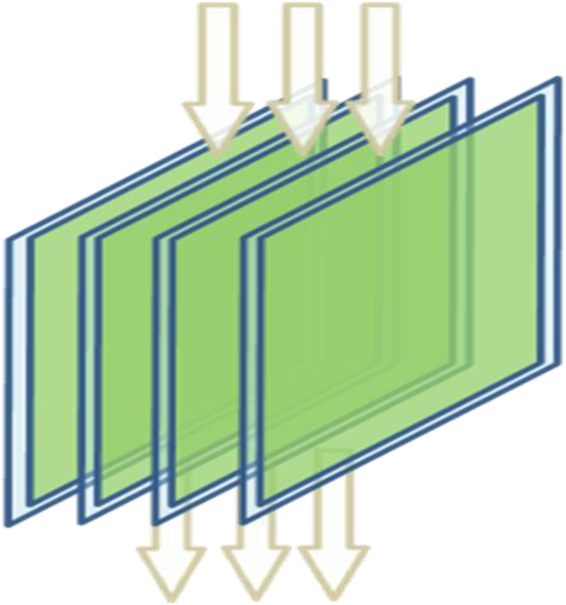

Figure 2 - Membrane Sheets

The natural mixing effect (*m*) will pull the extra concentration of dissolved solids away from the face as is shown in *Figure 3*. When some product water penetrates the membrane, the feed water right on the face of the membrane (*p*) is temporarily concentrated. As all solutions in nature seek equilibrium with regard to concentration (like a gas filling its container), the concentrated water right at the point of production (*p*) will 'jump' away from the membrane to mix (*m*) with the lower concentration water in the middle of the channel between the membranes.

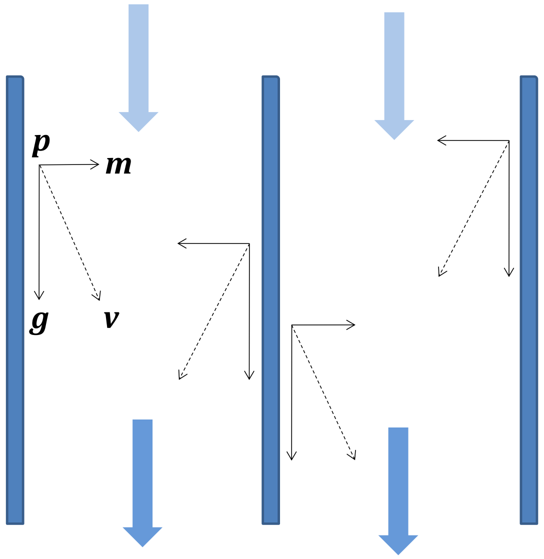

Figure 3 - Concentration Movement in Water

The combination of these two effects, the gravity pulling down the higher density water and the mixing effect pulling toward the middle of the channel, will pull the flow in a vector (*v*) away from the membrane and down toward the floor of the water body. As the water moves down and out of this space, more feed water will enter from the top.

In conjunction with the smaller flux (25% of typical SWRO), the draw of water molecules out of the source water is also small in relation to the available volume between the two sheets, so the water is only slightly concentrated (estimate 1 to 3%) toward the bottom of the channel between the membranes.

This effect can be seen in *Figure 3* showing an exaggerated cross-section of three membrane elements and the two channels they create. The DEMWAX™ Membrane Cartridges are designed for this flow to occur naturally in perfectly still water, though generally that is never the case as currents will assist the mixing (*m*) and gravity (*g*) to replenish new feedwater when concentration briefly occurs.

This concentration movement is not as pronounced for fresh water applications. However, the concentration buildup is not as large, nor is the osmotic pressure nearly as significant.

Spacing Algorithm

As discussed above, one of keys to the operation of the DEMWAX™ system is the increased spacing between the membrane faces. However, to maximize plant output per unit of plant 'footprint,' closer spacing is better. EconoPure™ has developed an algorithm that takes into consideration the several parameters that determine the optimal spacing of the membrane elements.

The exogenous variables used to determine the optimal spacing are as follows:

- Membrane element height – The distance between the top and the bottom of the membrane element will determine how far the brine will fall before meeting regular seawater. With no change in velocity, flux or recovery, a taller element must be spaced further from the neighboring element.
- Brine velocity – As potable water penetrates the membrane the remaining brine is heavier due to its higher salinity. Gravity will cause the heavier brine to fall, drawing more feedwater from the top. Natural currents will increase the velocity, but the membranes are spaced to allow just the gravity to impart enough velocity on the concentrate.
- Flux – The amount of fresh water that penetrates each unit of membrane surface area will vary depending on the flux of the system. The higher the flux the less membrane is required per unit of permeate. For a given raw water velocity and membrane height, the higher the flux, the more concentrated will be the water falling out the bottom of the channel. Too much flux without increased raw water velocity will increase the recovery and, therefore, the required pressure. Flux rates will vary by membrane materials and depth.
- Recovery – The percentage of water that is exposed to the membranes that actually penetrates is called the ‘recovery.’ The higher the recovery, the less water that must be exposed to the membrane surface.

The membrane spacing algorithm is specified below:

$$S = \frac{FH}{kRV}$$

Where:

S is the space between membrane elements measured in inches
F is the flux of the system measured in gallons per square foot of membrane surface area per day
H is the height of the membrane elements in inches
R is the recovery (% of water flow exposed to membranes)
V is the velocity of the falling concentrate between the elements measured in feet per minute
k is a constant which is equal to 5,385.6 when flux is measured in gallons per square foot per day and height is measured in inches and velocity is measured in feet per minute.

The primary unknown of this equation is the velocity of the source water between the membranes. Theoretical values indicate this velocity could be on the order of 4 to 8 feet per minute in a still environment (with no currents). Lab tests completed by EconoPure™ support this velocity. With currents present, we expect an even higher velocity. However, to be conservative, 2.5 feet per minute (0.04 feet per second) is used for our analysis.

Thus, for a 40 inch tall (approximately one meter) membrane element with a 2% recovery and flux of 1.5 gallons per square foot per day with concentrate falling at 2.5 feet per minute we calculate the optimal spacing at 0.223 inches (about 6 millimeters).

$$0.223 = \frac{1.5 \times 40}{5{,}386 \times 0.02 \times 3}$$

Note though that the surface tension of the membranes will be the limiting factor for the minimum spacing. That is, even if the algorithm allowed a much closer spacing, the surface tension imparted on the water by the membranes would limit that spacing.

Pressure and Flux

As mentioned previously, the main parameter in determining the required pressure (depth) for the DEMWAX™ is the osmotic pressure of the source water. Osmosis is defined as the net movement of a solvent molecule (e.g. water) through a semi-permeable membrane from the side of lower concentration to the side of higher concentration to balance the concentrations. The osmotic pressure is the amount of pressure applied to the high concentration side of the semi-permeable membrane to prevent osmosis from occurring. In other words, the osmotic pressure creates a steady-state for two solutions where no movement occurs across the membrane. If the applied pressure is less than the osmotic pressure, natural osmosis occurs. If the applied pressure is greater than the osmotic pressure, then the flow of the solution from the high concentration to the low concentration occurs. This is reverse osmosis.

The theoretical calculation for the osmotic pressure of a solution is based on the summation of the molarity of the different molecules and the temperature of the solution. The molarity is defined as the number of molecules in the solution divided by the volume of the solution. In general, the osmotic pressure can be approximated by dividing the Total Dissolved Solids (TDS) in mg/l by 100 (e.g. 35,000 mg/l TDS = 350 psi (24 bar)).

It is important to note that the actual driving pressure required is a function of the removal by the membrane. If the membrane is removing 100%, then the pressure required is the full osmotic of the source water. If the membrane only removes 50%, then the required pressure is only 50% of the source water osmotic, as the product water has an osmotic pressure also.

For example, seawater with an osmotic of 350 psi (24 bar) passed through a membrane that removes 50%, results in a permeate with an osmotic of about 175 psi (12 bar). So the osmotic portion of the driving pressure is 175 psi. This is important in the discussion of nanofiltration membranes for use in seawater applications.

The other pressure component that determines the required depth in addition to the osmotic pressure is the transmembrane pressure (TMP). The TMP can be thought of as the 'friction loss' across the membrane added to the driving pressure needed to produce the required flow. Just like any 'conduit,' there is a certain amount of energy required to move the water through the membrane at a certain flow rate. In order to get a particular flow through the membrane, the pressure must be greater than the combination of the osmotic pressure and the TMP at that flow. For SWRO membranes the TMP can be as high as 120 to 150 psi (8.3 to 10.3 bar) for the normal high flux operations. However, in the low flux DEMWAX™ applications, it is approximately 20 to 40 psi (1.4 to 2.8 bar). For NF membranes it is even lower at approximately 10 to 20 psi (0.7 to 1.4 bar).

As the osmotic pressure is a fixed constant of the source water, technological advances in membrane construction can only improve (lower) the transmembrane pressure requirement. Since the DEMWAX™ system can accommodate any membrane, such advances can be easily incorporated if warranted. However, the transmembrane pressure for seawater applications is a small fraction of the total pressure required, so the system is near the theoretical minimum energy.

The resulting total driving pressure for seawater desalination applications of the DEMWAX™ system is approximately 370 to 390 psi (850 to 900 feet of depth or 259 to 274 m) based on a typical Pacific Ocean salinity. This will put the unit at a depth that is well below the depth of surface storms, and in a zone of very little or no light and generally reduced oxygen.

If, however, a location does not have the necessary depth for seawater reverse osmosis close to shore, one can use a DEMWAX™ unit with nanofiltration membranes to produce lower salinity water that is suitable for direct input into a traditional SWRO plant to remove the remaining salts at less total energy cost than traditional reverse osmosis. By submerging certain nanofiltration membranes to approximately 450 to 770 feet (137 to 235 m), the system will produce brackish water with 50 to 90% lower salinity.

This water can then be treated in a second pass by a traditional membrane process onshore at less total energy to achieve potable water. This will allow an operationally low-risk way for customers to demonstrate the efficacy of DEMWAX™ as they can bypass their existing pre-treatment system with the DEMWAX™ NF treated water.

Additionally, and very importantly, the lower salinity water delivered by the DEMWAX™ retrofit will expand the throughput of the existing desalination plant as flux rates and/or recovery will increase dramatically due to the lower salinity of the feedwater. Thus, the DEMWAX™ retrofit is effectively a technique for expanding the capacity of an existing plant without increasing operating costs or physical footprint.

Fresh surface water is generally low in dissolved solids (usually less than 1,000 mg/l), thus does not require significant osmotic pressure (about 10 psi). Using a mid-range (50% removal) NF membrane, the required driving pressure is on the order of 25 psi (55 feet or 16.8 m) for a medium range flux. However, depths required for the myriad of different applications can span a broad range depending on source water constituents, desired treatment and flux requirements.

Many fresh water bodies, especially in mountain regions, are exceptionally clean and require filtering out larger biological contaminants only. In this case, a 'loose' nanofiltration DEMWAX™ can be submerged into approximately 30 feet (9.1 m) of water. If a water source is high in calcium carbonate, such as the lower Colorado River in the United States, a depth in a reservoir of approximately 75 to 100 feet (22.9 to 30.5 m) can remove most of the calcium. However, as calcium carbonate is relatively harmless (though not to fixtures or water heaters) the DEMWAX™ can merely treat the water for larger molecular contaminants at a far lesser depth.

Virtual Peaking

As discussed in the previous section, the production rate per area of membrane, the flux, is a function of the total driving pressure applied. Once the minimum driving pressure is achieved to overcome the osmotic pressure and the initial TMP, then any additional applied pressure increases the flux. While the basic concept of the DEMWAX™ system is to have a low flux to minimize the pressure requirements and thus the energy used, there are applications where an increased flux may be beneficial.

Once such application is the provision of peaking capacity. The DEMWAX™ system configuration has the unique opportunity in a membrane treatment system to easily provide peaking capacity. The basic idea is that the DEMWAX™ unit would be designed and constructed to operate at the minimum depth and flux for energy efficiency during an average daily flow. However, the unit would actually be installed at a greater depth. During normal operations, the water level inside the pump well would be allowed to increase, such that the differential pressure would only be the minimum pressure required.

During a peak flow condition, the water level in the pump well would decrease, increasing the differential pressure and thus the flux. The only addition to the DEMWAX™ system is a second pump to handle the higher peak flow.

As an example, for the fresh surface water application with a loose NF membrane at a depth of 55 feet (16.8 m), an additional 20 feet (6.1 m) of depth would allow for a flow of approximately 50% greater during those peak demand periods. This increase would vary with the application and source water, but the increase in flux can be large for a relatively small increase in depth. This factor of peaking can significantly reduce a customer's need for large unsightly storage tanks.

Critical to the virtual peaking configuration is the efficient base load operation. Peaking electric power plants are defined by their lower efficiency and low capital cost. The DEMWAX peaking capacity does entail higher operating cost during peak operations (pumping product water from deeper) but does not impart any efficiency hit during normal operations. Thus it doubles as an efficient base load plant with additional peaking capacity for periods of greater demand.

General System Description

The basic components are the same for either of the primary applications and include the following:

- DEMWAX™ Module – Composed of membrane cartridges, wet well, and submersible well pumps.
- Mooring or support structure – The DEMWAX™ module can either be supported off the floor of the water body by a structure or can be moored and floated from the bottom
- Product water pipeline – The treated water is conveyed to the point of use through a pipeline
- Breathing tube – The process requires a pressure differential. The water column provides the high pressure, but the atmospheric pressure must be transmitted to the system. This is the function of the breathing tube.
- Electrical and control umbilicals – Power for the pump and instrumentation cable to provide control of the pump and system monitoring are required.
- Ancillary systems – These systems include the power source (shore based, buoy based or other), SCADA system, monitoring instruments, cleaning/fouling prevention systems, etc.

With the exception of the novel configuration of the membrane cartridges, all of the primary components are industry standard items, comprised of industry standard items, or based on existing technology. As such, the bulk of the system requires little or no development.

Figure 4 provides a schematic of the general DEMWAX™ plant configuration. This graphic shows one potential option. There are several other options that will be discussed in detail later within this document.

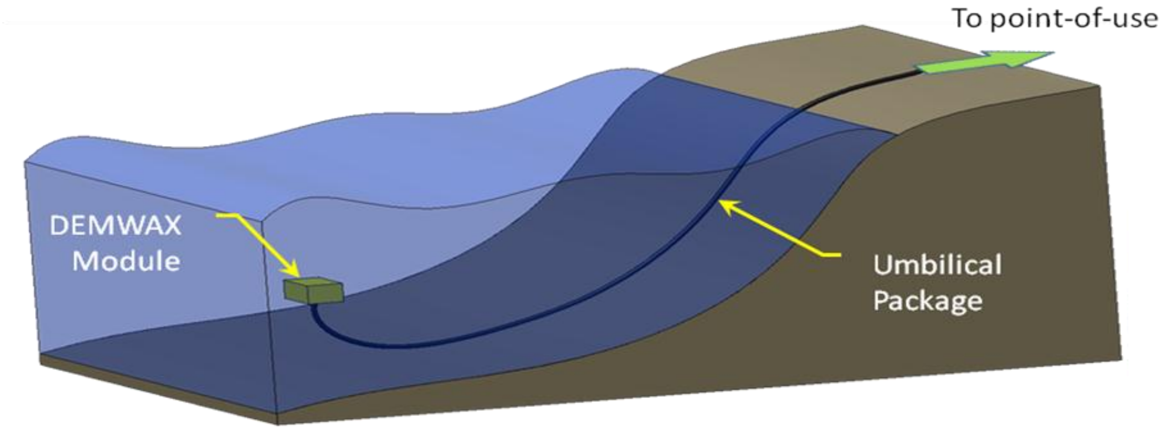

Figure 4 - General DEMWAX™ Plant Layout

Figure 5 shows a concept rendering of a DEMWAX™ module. In this image, the membrane cartridge is the green frame holding the membrane elements. The perpendicular channel at the top collects the water from the membranes and transmits it to the wet well (gray cylinder in the figure). The collection channel is formed with a series of gasketed spacers compressed to seal out the surrounding feedwater.

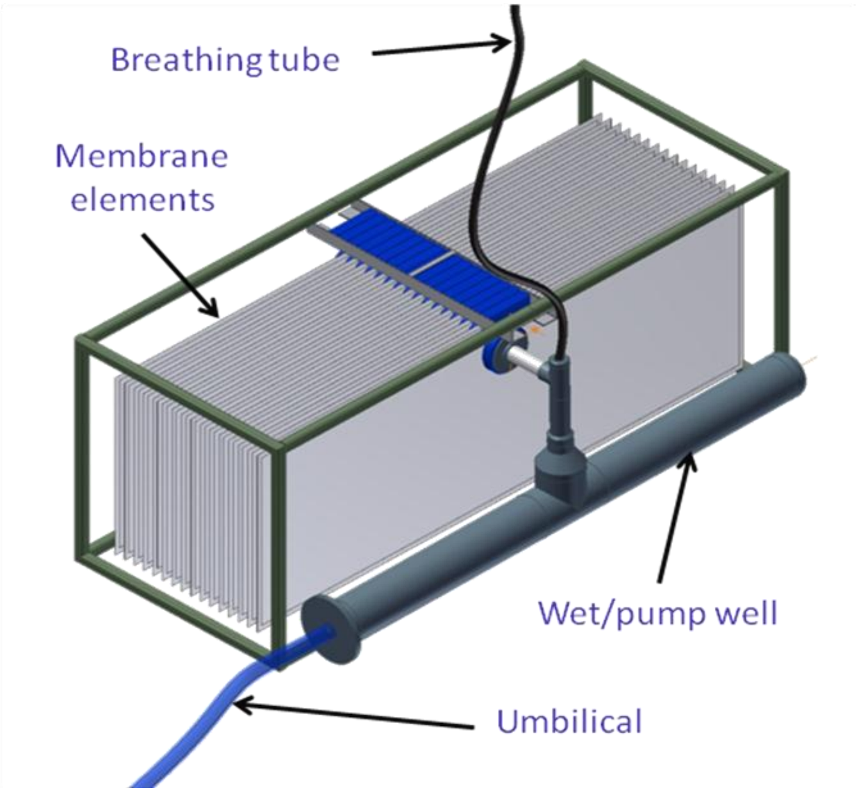

Figure 5 - DEMWAX™ System

The pump well at the bottom of the figure contains one or more submersible pumps to convey product water to shore. The breathing tube is connected to the wet well and goes to the surface to communicate atmospheric pressure to the product water side of the membranes. In this diagram the product water pipe is shown pumping down to the seafloor where it would follow the floor to the shore. This rendering shows the essence of the technology and does not include ancillary components like tethers to hold it in place above the ocean floor, floats to maintain its buoyancy and screens above it to shelter it from falling debris.

Figure 6 provides a basic process flow diagram for a seawater desalination version, although the fresh water version would be the same with the exception of the depth and the distance from shore.

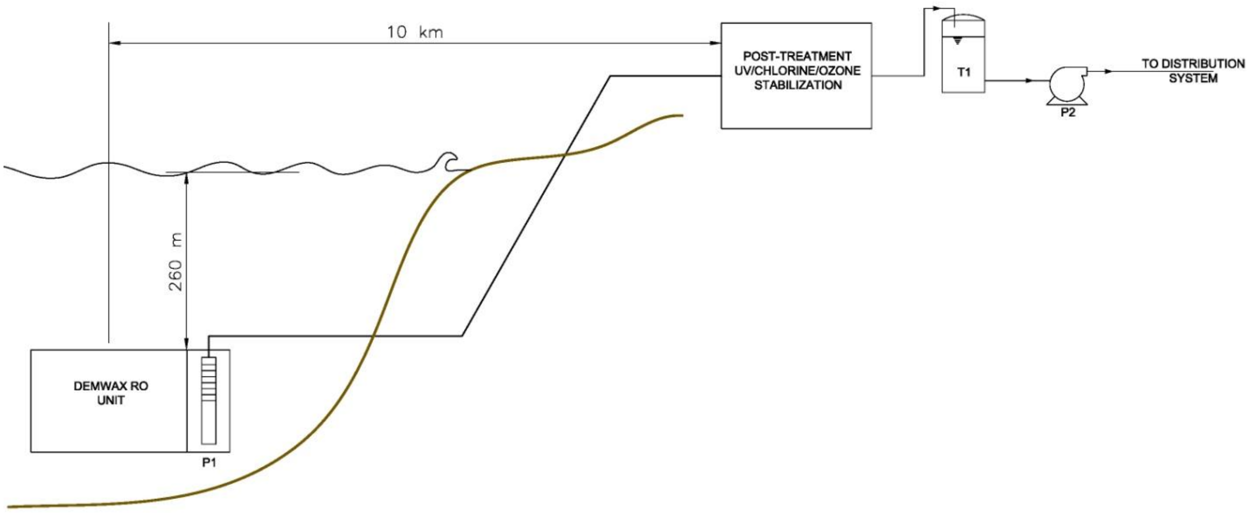

Figure 6 - DEMWAX™ Process Flow Diagram

Membrane Cartridge

The basic component to the system is the membrane cartridge. A typical cartridge will contain a number of membrane elements (vertically arrayed) with a support structure and method of collecting the permeate. Multiple cartridges can then be assembled in any desired quantity with the appropriate ancillary equipment and umbilicals to create the treatment plant.

The dimensions of the cartridge are variable depending upon the specific application. Typical flat sheet membrane is produced in 1 meter (40 inches) wide roles, so most configurations will include that dimension, or a portion of it to maximize the use of the membrane material. EconoPure™ will optimize cartridge design to provide a standard by which specific market offerings can be developed by downstream licensees.

Membrane Modules

A collection of membrane cartridges arranged with a central collection system is a membrane module. In smaller plants a module would contain the pump and connections to the umbilicals. As such, this is considered the smallest standalone component for a treatment plant. In large plants, multiple modules could be connected to central pumping system to maximize efficiencies.

The total number of cartridges within a module will vary. Typically, a module is sized based on a combination of several factors including:

- The total plant capacity – A complete plant would not likely be sized with just one train in case of downtime for maintenance. Therefore, even if it could be served by one or two modules, they may be split in to three or four to minimize flow reduction in maintenance situations.
- Ease of handling and shipping – Different installations will have different availabilities of equipment for installation and maintenance. As such the total size may be limited to meet these site specific requirements.
- Pump size – In general terms, the bigger the pump, the better the overall efficiency. Therefore, pump efficiency will inform optimal module size.

Competitive Advantages

The DEMWAX™ system offers many competitive advantages as compared to traditional seawater desalination and fresh surface water treatment systems. The value of the technology is derived from these competitive advantages. Many of these advantages have already been described in detail. The purpose of this section is to provide a concise summary of the concepts. The advantages are listed with a discussion of the primary applications, seawater and surface water, where warranted.

The primary competitive advantage is that the DEMWAX™ system is dramatically less expensive than existing methods of processing water. More detail on this efficiency is shown in this section.

Energy Efficiency

Seawater – "Half the water, half the pressure" is a general way to describe the DEMWAX™ efficiency. Relative to a typical 50%-recovery onshore SWRO plant the DEMWAX™ process saves half the energy by only pumping the product water and not the feedwater. Also, onshore SWRO plants pressurize feedwater to over twice osmotic pressure due to the concentrated brine accumulation from this recovery rate, while the low-recovery DEMWAX™ process only needs to overcome the pressure of the depth (equal to about osmotic pressure of the seawater) to transport the product water to sea level.

Surface water – The surface water DEMWAX™ has an energy advantage in not requiring the ancillary systems to backwash the membranes and pre-treat the water as compared to ultrafiltration membrane systems. It will also save energy in that the DEMWAX™ only requires pumping the product water rather than the feedwater.

No Pre-treatment Required

Seawater – Onshore plants force feedwater through extremely closely spaced membranes at high pressure and velocity. Suspended solids in the source water become abrasive projectiles that damage the membranes. Thus, traditional SWRO plants employ a costly pre-treatment process applied to all the feedwater (about twice the product water) which removes these organics and sediments. Suspended matter in the source water just falls harmlessly through the DEMWAX™ membranes, making any pre-treatment unnecessary.

Higher Quality Product Water

Surface water – The nanofiltration membrane used by the DEMWAX™ to treat surface water removes far more contaminants than ultrafiltration or microfiltration membranes which are becoming common today. The increasing level of man-made contaminants, such as dissolved pharmaceuticals, in water sources requires that a more robust treatment process be implemented and regulations are increasingly stipulating higher water quality. NF membrane treatment in the conventional spiral wound configuration would provide similar quality but that configuration requires pre-treatment, pressurizing the feedwater and sludge disposal, thereby giving DEMWAX™ a significant economic advantage.

Mitigation of 'Brine' Disposal

Seawater – Brine disposal is an issue that must be addressed in traditional reverse osmosis plants. Because of the low-recovery process, the DEMWAX™ system will only create 'brine' that is approximately 1 to 2% more concentrated than the surrounding ocean. Such low levels of concentration will mix back to ambient within a few feet of exiting the unit. In addition, this concentrate is at 850 to 900 feet (259 to 275 m) below the surface rather than in the vibrant ecology at the shallow depths of traditional reverse osmosis plant brine disposal.

Virtual Elimination of Sea Life Impingement and Entrainment

Seawater – The impingement and entrainment of sea life is another environmental hazard that haunts many power and desalination plant entitlement efforts. The velocity through the "intake" (or membranes) of the DEMWAX™ is two orders of magnitude less than that in typical desalination plant intakes. In addition, there is far less sea life at the depth of a DEMWAX™ system than at typical ocean intake depths of land based plants.

Surface water – Though the depth of the surface water application is in an area of significant life the extremely low velocities as compared to traditional water treatment intakes mitigates impingement potential.

Little Site Construction; Economies of Factory Assembly

Aside from the pipeline and a power cable back to shore, there is little site construction necessary. The majority of the DEMWAX™ modules and cartridges can be assembled at a factory with only minimal final assembly required at the site. The economies of factory production will eliminate uncontrollable site risks for much more content.

Virtual Peaking Capacity

By submerging the DEMWAX™ unit to a deeper depth than necessary, it will retain the capacity to produce more water in periods of higher demand *without increasing the unit energy costs during base load production*. Increasing the depth and maintaining the pumping rate will build natural back pressure on the product side of the membranes, thus limiting the production from the membranes and assisting in lifting the water to the surface. Pumping at a higher rate will vacate the built-up water on the low-pressure side by lowering the water level in the breathing tube. This will increase the pressure differential, thus increasing the membrane flux (rate of water flow per unit of membrane surface area) for those brief peak periods of demand.

No Moving Parts Subject to the Corrosive Feedwater

Traditional desalination plants incur significant capital and maintenance costs due to the handling of highly corrosive salt water and doubly concentrated brine. The DEMWAX™ system only exposes the outside of the polyamide (plastic) membranes to the feedwater, thus eliminating the corrosion potential on the pumps. Similarly, all surfaces exposed to the salt water will either be composed of non-corrosive materials or coated with such materials.

Use of Industry Standard Parts

There is little technology risk associated with the basic components of the system as the enabling aspect of the DEMWAX™ technology is the novel configuration of existing components. Flat sheet membrane that is currently rolled in the ubiquitous spiral-wound elements is used for the DEMWAX™ cartridges. Submersible pumps that have a long history in water well duty will be used to convey the permeate to the shore. Undersea pipelines are common in conveying many liquids and gases.

Reduced Land Requirements

As the DEMWAX™ system does not require shore based systems (save for any necessary post-treatment and storage) it will release valuable land for other uses. Land at the shore in dense population centers is often the most sought after land in the world, thus the alternative uses of such land are often of extremely high value.

Economic Restoration of Natural Surface Waters

There are surface water conveyance systems in the world that require far more power than the DEMWAX™ requires to produce water from the sea. As an example, the California State Water Project conveys *untreated* water from the Sacramento River Delta to Southern California at an energy cost of approximately 2.5 kilowatt hours per cubic meter. Similarly, the Colorado River Aqueduct requires approximately 1.6 kilowatt hours per cubic meter to convey *untreated* water to the coastal populations of Southern California. The DEMWAX™ will require about 1.2 kilowatt hours per cubic meter to convey *potable water* to shore which will not require further treatment as these other sources will (extra energy and chemicals). In addition to the energy efficiency proposition, there is an environmental value to restoring native water ways or utilizing those waters for inland purposes.

No Chemicals/Operational Simplicity

Seawater **–** Like a traditional water well, the DEMWAX™ system has only one mechanical system, the pump. This simplicity will make for lower operation and maintenance cost. Complicated automated valve systems, intake screening and filtering systems and high pressure pumps that contact feedwater and brine make traditional desalination plants extremely complicated and maintenance intensive. Also, the system does not require pre-treatment chemicals.

Surface water **–** The system has few moving parts. This lack of moving parts and simplicity makes for extremely straightforward operation and maintenance. The surface water application may require additional *in situ* cleaning mechanisms (aeration, ultrasonic or other) to minimize fouling between maintenance cycles. These systems and methods are well established and inexpensive. The surface water treatment application of the DEMWAX™ will eliminate the need for process chemicals used in traditional water treatment applications.

Mobile Plant

> The DEMWAX™ plants can be moved and are not fixed to a foundation. This will have value in temporary installations to cover shortages as well as for responding to natural disasters. This mobility also has value in permanent applications. While it would be optimal to leave in place for its entire useful life, its more mobile nature should generally influence its credit risk profile. That is, project sponsors will realize that default on financing repayment will result in more aggressive retrieval efforts than would be likely in a fixed foundation plant on land. As such, default risk or political risk can be priced more favorably than in a similar shore based desalination plant.

These competitive advantages are of varying value to customers and some are difficult to quantify. The environmental benefits while more difficult to quantify, will avoid costs, expand the market or accelerate adoption of this technology.

Applications

While EconoPure™ intends to focus on its primary applications of seawater desalination and fresh surface water treatment, there are many other possible applications for this revolutionary membrane configuration and process. This section summarizes the primary applications as well as some of the more interesting other applications.

Sea Water Reverse Osmosis

As discussed above, this system reduces energy consumption close to its theoretical limit for separating dissolved solids from source water. Seawater applications will only be available where there exists sufficient depth within an economic distance from the shore. The economics of this will depend largely on pipeline construction technologies. Large plants will be economic even using expensive steel pipes used in the oil and gas industry to great distances and it is clear that other less expensive materials (such as HDPE or soft irrigation hose) will take this economic distance much further. This will open up a tremendous market for this technology beyond those areas that already have sufficient depth. Currently, we see tremendous market opportunity in some dry, populated regions such as the entire west coast of North and South America, the Mediterranean Sea, the Red Sea, Japan and the South Pacific, the Eastern coast of India and much of Africa.

Pretreatment Retrofit

Pre-treatment retrofit application will likely be used when sufficient depth near shore does not exist in the vicinity of an existing desalination plant. In this case a DEMWAX™ plant outfitted with nanofiltration (NF) membranes at a lesser depth than required for the RO version and will reduce salinity from 50 to 90%. This water can then be conveyed to the existing SWRO plant and processed at much lower energy for the same quantity of water. Alternatively, more feedwater can be processed at the existing higher pressure and the effective capacity of the plant greatly expanded while mitigating much of the former environmental hazards.

Surface Water Treatment

This application will supplant existing surface water treatment technologies such as media filtration and ultrafiltration membrane systems. Best candidate water sources for this application are lakes and reservoirs with about 50 feet (15.3 m) of depth, but solutions can be developed for shallower lakes or rivers. The DEMWAX™ cartridges outfitted with nanofiltration membranes will be used for this application to provide higher quality product water with no process chemicals or sludge disposal.

Sulfate Removal for Offshore Oil Production

Water is sometimes injected into underground formations to raise the pressure of the well. Offshore oil production uses seawater for this. Seawater high in dissolved sulfates can cause scaling problems as the sulfates react with elements in the formation waters. This scaling can impede water injection and thus oil production. The sulfates are often removed from the seawater before it is injected into the formation, but this process is expensive and requires significant space on the platform. By using the DEMWAX™ process with nanofiltration membranes, a production company can remove the sulfates and free up space on the platform and lower energy consumption significantly. This application has the potential to be an early adopter as it will not require lengthy umbilicals to shore (only the length of the depth).

Industrial Cooling Water

Tremendous amounts of water are used in industrial processes, with power generation being the most water intensive of these. The seawater DEMWAX™ will produce much colder product water (5 to 6 degrees C) than surface water normally used by these processes. Both NF and RO membranes will provide a very low hardness water, reducing scaling within plant processes. This will enhance the cooling capacity for a like volume of water.

Additionally, where an industrial cooling process, such as power generation, is near a large population, the water can be secondarily used in municipal drinking water supply. This dual use enhances the value attributable to the DEMWAX™ process. There is already a growing trend to combining power and desalination plants in arid regions. The traditional intake structures will also be bypassed, eliminating sea life entrainment.

Industrial Process Water

Tremendous amounts of water are used in industrial processes in locations where sources of clean water are not readily available. Many of these processes require certain levels of treatment specific to their uses. DEMWAX™ systems can be configured with any flat sheet membrane and as such have tremendous flexibility to provide custom water solutions. One particular example of this application is in the oil and gas recovery and refining industry, where the DEMWAX™ system can provide extremely clean water with less maintenance, space and energy for about the same capital expense.

Rapid Response/Disaster Relief

A rapidly deployable version of the DEMWAX™ can provide potable water after natural and man-made disasters. This system will be pre-assembled to be deployable quickly in response to disasters. This application will utilize either the seawater (RO) or the fresh surface water treatment (NF) membranes. The simplicity of the system allows little labor effort to operate and does not require chemicals to be transported into a disaster zone.

Storm Water Treatment

The general basis of the hydrologic cycle is that fresh water is supplied to land in the form of precipitation that fills rivers and infiltrates into the groundwater. Many municipalities are now looking to capture the water within rivers as a new fresh surface water source before it flows to the ocean and is ‘lost.’ Some of these municipalities, City of Los Angeles for example, are looking to ‘harvest’ this stormwater for use during the dry seasons. Projects have already been identified to build large underground reservoirs to capture and store storm water to offset the use of potable water for irrigation. However, the local regulations prohibit use of this water for any irrigation in which there might be human contact, unless it has been filtered and disinfected. This means that expensive filter systems must be installed and operators trained to operate them. The basic surface water DEMWAX™ system provides distinct advantages over traditional systems in the quality of the product water, the ease of operation, and that it can be located directly within these underground chambers.

Conclusion

The quest for energy efficient and environmentally benign methods of extracting potable water from seawater has witnessed a series of incremental advances over the past two decades. Many experts in the field believe we are at the end of the road for improving the efficiency of seawater desalination. However, the new paradigm represented by the DEMWAX™ will dramatically improve efficiency while testing the physical limits of efficiency. It will do this while also improving the environmental profile by mitigating brine disposal and sea life impingement/entrainment issues.