An EconoPure™ White Paper

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Desalination Pre-Treatment with LFNano™

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EconoPure™ Water Systems

EconoPure™ Water Systems designs and manufactures highly economical, scalable, low-fouling membrane systems. The Company leverages the proprietary low-fouling nanofiltration ("LFNano™") system consisting of a unique membrane element that is designed to avoid particulate fouling, biofouling, and scaling. As the name suggests, the LFNano™ utilizes proven nanofiltration (NF) membrane technology and applies proprietary processes to enhance performance and decrease cost (both capital and operating). The LFNano™ requires much less pre-treatment and little or no process chemicals as compared to typical membrane systems. It provides the exceptional quality treatment associated with membranes, without the hassle of extensive pretreatment systems. The LFNano™ is an ideal solution for desalination pre-treatment.

Introduction

Desalination is a growing water source that is becoming more important as population densities are leading to scarcity of fresh water supplies and greater pollution of these fresh water sources. There are many methods of desalinating seawater and brackish ground water and they all benefit from higher quality feed water to the desalting process step. The pre-treatment process is how the feed water is conditioned prior to the main desalination step. Higher quality water can lead to less fouling on the main desalting step and save costs in maintenance and chemicals and replacement parts.

Problem Statement

Pretreatment has been called the black art of desalination as it is so critical to the success of a desalination plant. The famous case of the Tampa Bay desalination plant led to a reexamination of desalination in the United States. The pretreatment system at the Tampa Bay plant could not handle the variability in the seawater throughout the year and it was stressed to the point of failure. That plant was taken offline for 3 years and the pretreatment system was totally rebuilt. Stories like that are familiar in the desalination industry highlighting the critical nature of this process step. If the pretreatment is right, the plant is simple.

Existing Options

Typically the pretreatment step removes suspended matter leaving the dissolved matter to the main desalting step (either reverse osmosis (RO) membrane or thermal). However, a very high level of suspended solid removal is required for efficient operation of the desalting step. Even with removal of suspended solids, dissolved organics can still lead to significant fouling on an RO stage desalting step. Removing much suspended matter is simple and cheap but getting to the levels required by reverse osmosis membranes is complex and costly. Figure 1 below shows notionally the relative costs for removing *much* suspended matter and *virtually all* suspended matter.

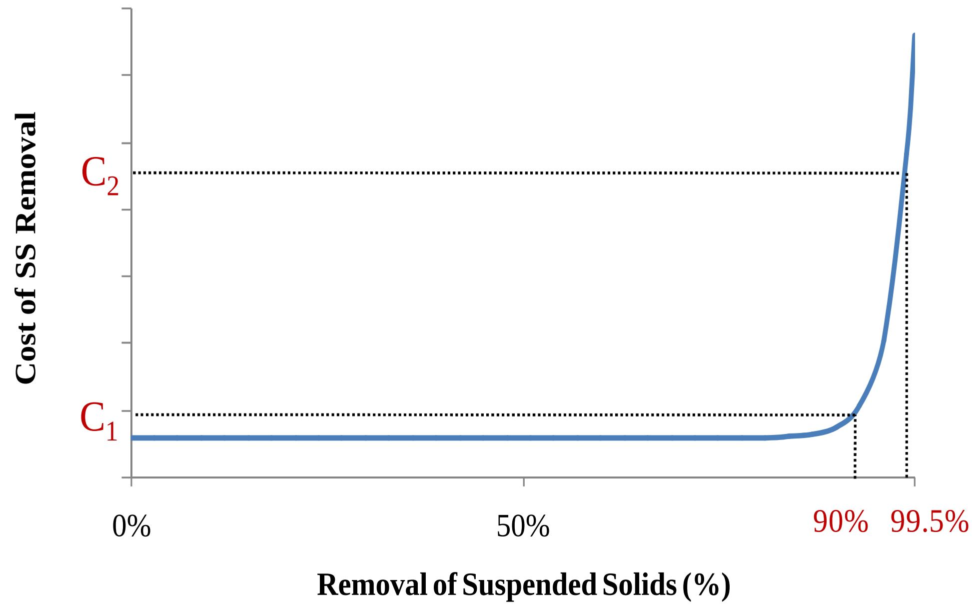


Figure 1 – Cost of Suspended Solids Removal (notional)

Smaller particles are much more costly to remove and they impart more problems on the downstream stages. In Figure 1 the notional cost curve shows that removal of a lot of suspended solids from a source water is simple and inexpensive, shown as 90% removal and C_1 as the cost. Conversely most desalting steps require far more removal to operate. This is shown as 99.5% and C_2 as the cost, which is much higher than the cost (C_1) to remove 90% of the suspended matter. The LFNano™ from EconoPure™ can operate with far more suspended matter in the water than current desalting steps and in many cases will not require any process ahead of it.

Low-Fouling Nanofiltration (LFNano™)

The basis for the LFNano™ is the nanofiltration membrane or NF membrane. Figure 2 shows a range of physical separation technologies and what they can remove from the water. The first three are often used in pre-treatment ahead of a desalting step but rarely is the nanofiltration (NF) membrane used in pre-treatment.

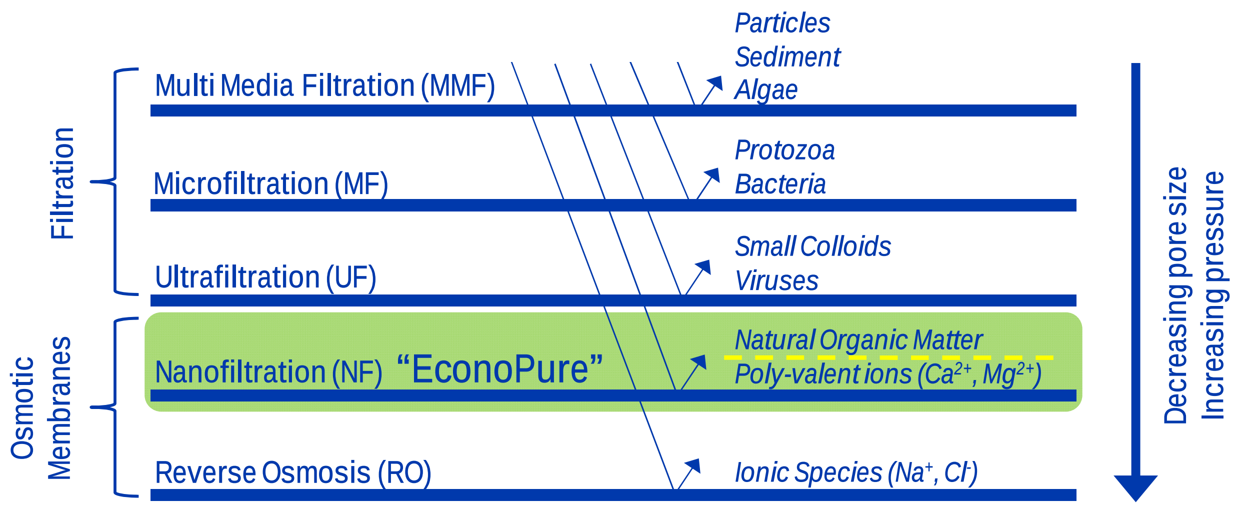


Figure 2 – Physical Separation Media Chart

NF pretreatment is generally not used as the NF membrane itself requires significant pre-treatment *in the traditional format*. However, the Low-Fouling Nanofiltration (LFNano™) eliminates this requirement, as the LFNano™ can avoid the effects of fouling that plague traditional NF systems. This allows a cost effective, high-quality pre-treatment with an NF membrane ahead of traditional desalting stages.

Virtually all source waters require the removal (or neutralization of) of every contaminant in Figure 2 above the yellow dashed line and very few require removal of those below the line. With NF pre-treatment the later desalting stages can avoid biofouling caused by natural organic matter and the scaling that is associated with hardness or poly-valent ions in the feed water. Scaling can lead to expensive maintenance steps and in the case of reverse osmosis it can even lead to irreversible fouling and require replacement of the RO membranes.

Fouling Avoidance

The LFNano™ avoids fouling in several ways. First, it has a unique spiral membrane design that creates consistent velocity past the membrane. This consistent velocity does not allow dead spots to occur where contaminants can deposit and grow. The unique membrane element from EconoPure™ has a parallel channel feed spacer eliminating the traditional cross-woven spacer that leads to low-flow spots and subsequent fouling.

Second, the LFNano™ benefits from a particulate coating on top of the membrane. The addition of particles to the membrane element is counter-intuitive as membrane systems strive to eliminate particles from the feed water. However, the LFNano™ can handle the suspended solids and the coating is comprised of high surface area particles such as diatomaceous earth or bentonite or zeolite. This thin coating (though many times the thickness of the active membrane) on the membrane can create a surface area above the membrane that is 700 to

1,200 times the surface area of the membrane. Tiny particles (called colloids) will adhere to the particles rather than imbed into the membrane. This keeps the fouling on the particles, which are easily removed, and away from the membrane. Figure 3 shows a schematic of this with microscopic view of the high-surface area particles on the membrane.

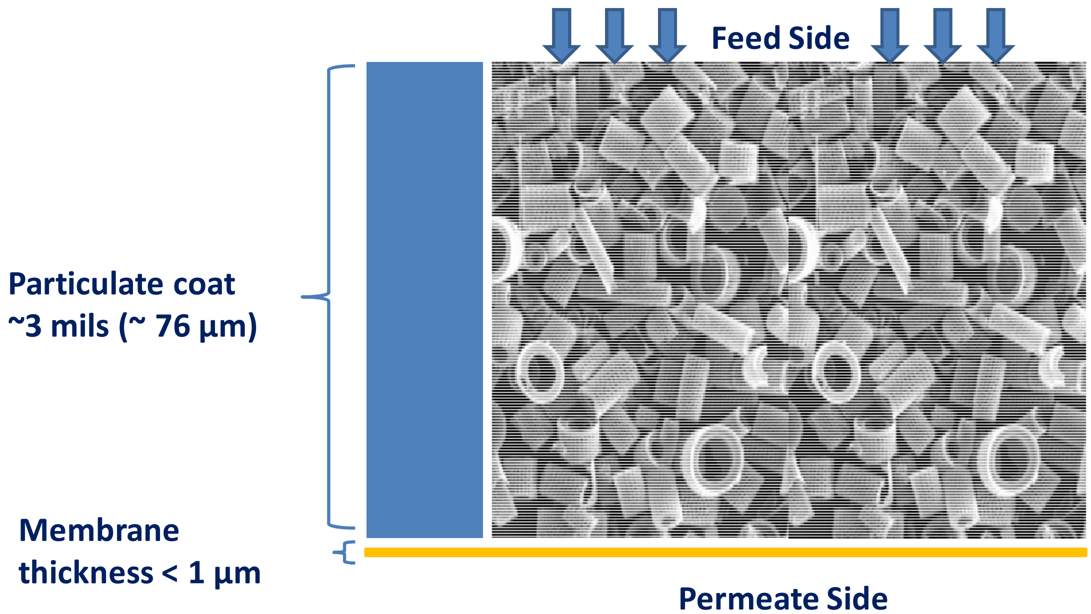


Figure 3 – Membrane with Coating (particulate not to scale)

The smallest particles are trapped in the coating of these anti-fouling particles. Certainly the anti-fouling particles eventually get plugged themselves but that takes quite a bit longer than blocking the thin membrane. This slow rate of fouling as compared to the unprotected membrane creates the desired result.

Third, the LFNano™ benefits from a rest cycle that extends the performance and mitigates the effects of fouling. The rest cycle is an infrequent relaxing of the pressure difference on the membrane. This release of the differential on the membrane stops the 'suction' pressure and allows the particulate coating to decompress and crack. This periodic decompression opens the outside of the coating that might be loaded with fine particulate. The particulate coat eventually becomes so full of contaminant particles that it must be cleaned off, but the interim rest cycle restores the flux considerably and flattens out the flux decline curve. Figure 4 shows some actual data from an LFNano™ system in operation. The chart shows the specific flux (measure of throughput) over time. The reduction in specific flux is a common measure of fouling as the contaminants block flow through and to the membrane. The downward slope indicates fouling, but the rest cycles partially restore the flux greatly flattening out the decline curve.

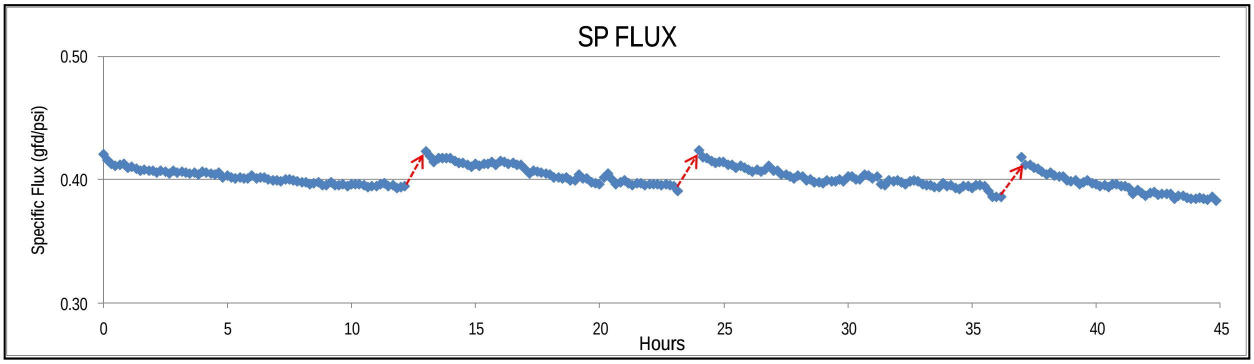


Figure 4 – LFNano™ Rest Cycle and Flux Restoration

The red arrows on Figure 4 show the effects of this rest cycle on the flux. Declining flux is how the fouling manifests itself and the restoration of the flux is the mitigation imparted by the LFNano™. The overall flux trend is still down (it is called the *Low* fouling nanofiltration not the *No* fouling NF) but far less so than without this system.

The rest cycle of the LFNano™ contrasts to the backwash cycle of a low-pressure filtration pre-treatment as a means of flux restoration. The ultrafiltration (UF) and microfiltration (MF) systems commonly used in pretreatment today require a frequent backwash cycle to maintain flux. This backwash cycle is a very mechanically complex process requiring seven (7) valves working together every 20 to 60 minutes. By contrast the LFNano™ rest cycle requires a single valve operated one to four times per day. The simplicity of controls and the reduction in maintenance is great. Figure 5 shows schematically the two processes with the automatic valves shown in red. Automatic valves represent moving parts and therefore points of failure.

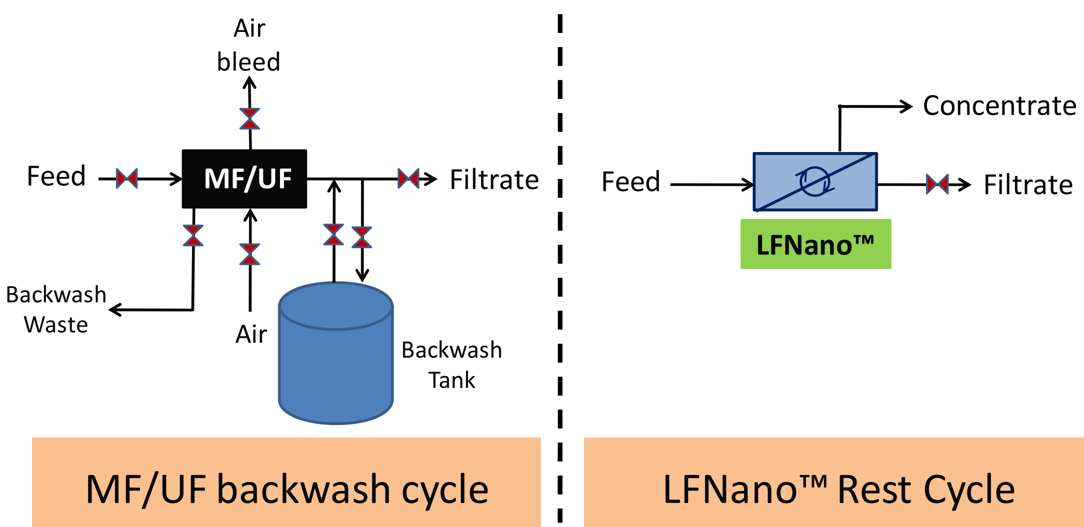


Figure 5 – Backwash Cycle vs. LFNano™ Rest Cycle

Lastly, the LFNano™ benefits from a high, constant feed water velocity. The unique design allows the disconnection of recovery (ratio of permeate to feed flow) and velocity that plagues existing cross-flow membrane systems. The LFNano™ can choose a desired velocity to aid in preventing contaminant particles from fouling the membrane, and independently choose the recovery rate. This is something a once-through membrane system cannot achieve.

Water Quality - Reverse osmosis membrane systems require very clean water, virtually devoid of suspended matter. The traditional measure of suspended matter is total suspended solids, but that is too crude a measure for RO membrane systems. Even turbidity does not adequately show the fouling potential of the water as it does not really account for size variations and color. As much of the pretreatment used for RO systems is MF and UF filters, a more targeted metric was devised for membrane systems called the Silt Density Index or SDI. This is measured by testing the fouling of a 0.45 micron filter over time. The index ranges from zero to 6.66. Zero means very low fouling potential and 6.66 means very high fouling potential.

RO manufactures require the SDI below 5 and preferably below 3 for the system to operate with a modicum of time between membrane cleanings. The NF permeate for even relatively loose NF membranes has measured SDI results below 0.10 (effectively zero as is likely from the inability to completely clean the equipment). With such low suspended matter the RO membranes avoid the effects of fouling for very long intervals.

Further, the LFNano™ has been tested in waters that do not even show up on the SDI scale (> 6.6) and produced water below 0.10 or within the margin of error of the SDI test system. Given this performance the economic profile of NF pretreatment is bolstered considerably.

Energy - With a tighter pre-treatment membrane (NF) it is thought that the energy requirements will be greater. The LFNano™ will require slightly more energy than MF or UF membrane pre-treatment, however, the savings in pressure required on the downstream RO stage more than overcomes the additional energy required in pre-treatment. At a host site for an LFNano™ pilot the host plant had microfiltration (MF) pre-treatment to an RO stage. The RO stage routinely ran with a clean membrane at about 100 psi and when fouled about 200 psi. Because of the non-linear nature of the fouling, the average pressure over the membrane cleaning cycle was about 140 psi.

The 40 psi of additional pressure can be attributed to membrane fouling. Now, with NF pretreatment the RO stage can avoid fouling entirely as the NF removes the foulants from the water. That is, the RO stage will operate at the clean pressure (100 psi) the entire time, thus saving approximately 40 psi of pressure from the system. Now, the NF pretreatment system tested at this site required about 25 psi on average. The MF requires about 10 psi on average so the NF requires an incremental 15 psi for pretreatment but saves 40 psi on the RO stage. This does not include the incremental energy expended in the backwash cycles for the MF stage.

It is also important to note that for seawater pretreatment, the pressure will be less than 100 psi, allowing for the use of inexpensive plastic and fiberglass for the majority of components and piping. Given the corrosive nature of seawater, this reduces the need for large amounts of expensive stainless steel, keeping the overall system cost down.

Typical LFNano™ Treatment

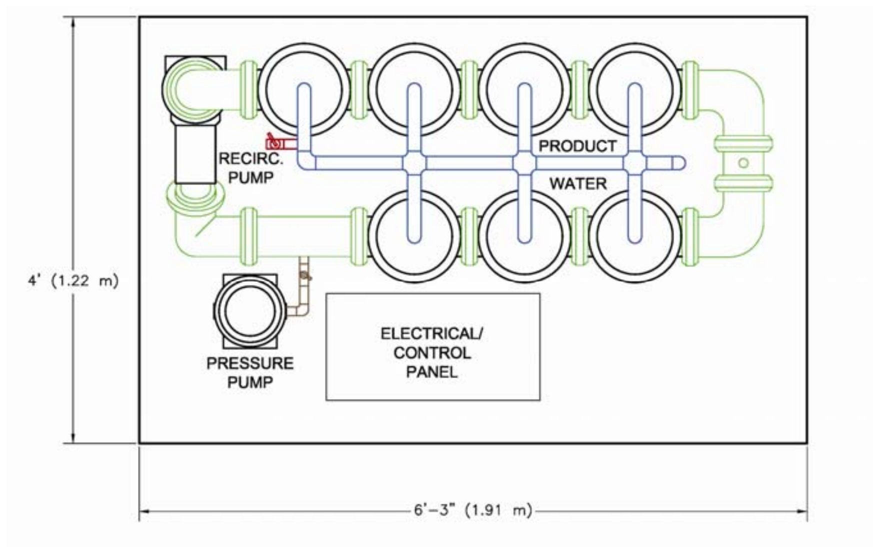
Contaminant	**Rejection %**
Divalent ions (Ca^{++}, Mg^{++}, etc.)	40% to 60%
Monovalent ions (Na^{-}, Cl^{+})	10% to 15%
Viruses and other biologicals	99.99% or more
Large contaminants (organics, pesticides, heavy metals, etc.)	90 to 95% or more

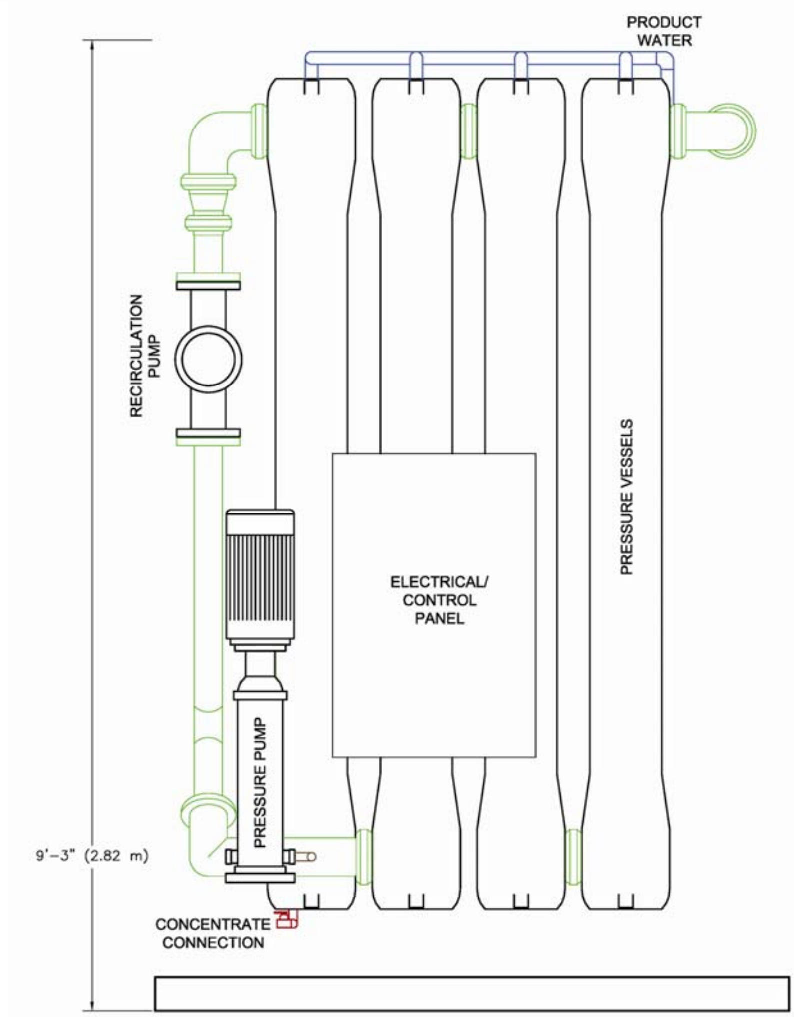
Benefit 1 - **Effective** – The nanofiltration membrane produces exceptional quality product water, removing nearly all contaminants to very high levels in one step. Alone, the NF membrane addresses all separation needs short of desalting. This makes it the most thorough pretreatment available for desalination.

Benefit 2 - **Easy** – The low fouling nature of the LFNano™ system requires little or no pretreatment itself, minimal if any process chemicals and infrequent cleaning. The system is inherently flexible in adjusting to operational needs, flow demands and varying feed water quality. The system contains minimal valves and industry standard pumps. The result: desalination pretreatment that is easy to operate and easy to maintain.

Benefit 3 - **Economical** – The LFNano™ is the economical alternative to the extensive pretreatment, operational complexity, and frequent cleaning of current systems. Savings result from lower use of energy and chemicals and greatly reduced operator attention and skill. As a pretreatment for RO, the LFNano™ offsets the standard complex pretreatment systems.

The inherent modular nature of the LFNano™ allows for custom-configurable systems to meet any requirement. Standard skid based systems treat up to 50,000 gallons per day (190 m^3/d), but custom configurations can be developed for any application. The below figure is typical of an LFNano™ system – in this case about 30,000 gallons per day (114 m^3/d) of treatment.





Plan and Profile View of Seven-Vessel LFNano™ System

Summary

The LFNano™ by EconoPure™ Water Systems is an ideal solution for pretreatment for a desalination plant. The NF membrane is the best possible pretreatment for desalination as it removes 'everything but the salt' allowing the downstream desalting stage to concentrate on what it does best. In summary, the LFNano™ gives the following benefits for desalination pretreatment:

- Lower lifecycle cost of desalination
- Lower energy use for SWRO plants
- Lower chemical use for SWRO plants
- Simpler operation allowing less operator skill and attention
- Compact size allowing a smaller footprint for the entire process
- The compact size and the low-fouling feature allow the system to accommodate highly variable source waters with little to no adjustment.

"The next great water technology company will be the one that finds a solution to membrane fouling."

Christopher Gasson
Editor, Global Water Intelligence
October, 2010