Purification of Brackish Water using Hybrid CDI-EDI Technology

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Abstract

A new class of technology using capacitance based de-ionizer will be presented using all solid state electronics. The mechanism for ion removal during purification and waste water regeneration is very similar to a hybrid combination of Capacitive Deionization (CDI) and Electro deionization (EDI), This new version is called EWP X3 A (patent pending).

Minerals are the major components of TDS (total dissolved solids) for brackish water found in various brackish supply and waste water applications. These contaminants can be removed using a new refinement in Capacitive Deionization Technology where nano electrode materials are used in combination with a semi permeable coating. The semi-permeable coating that is used that is held away from the surface of the electrode: This technology can purify water economically up to 10,000 ppm at 98% purification and 85% recovery. The purified water will be within compliance limits. The footprint of the technology is much smaller than other ion exchange and membrane technologies.

This is a technology that doesn't use chemicals used for regeneration like softeners , has minimal preventative maintenance with an electrode that isn't replaced unlike membranes, high recovery (80+%), high ionic rejection (98%), low power use, highly acceptable use of activated carbon, nanotubes and nanofibers, low pressure drop and feed pressure, competitive capital cost.

The technology uses a hybrid electrode comprised of activated carbon, nano materials and a semi-permeable coating. These hybrid electrodes still are electrically charged using a DC power supply and have different polarities. The minerals/metals in the water have polarity charges, which are attracted to the opposite polarity of the electrode, thus removing the minerals from the water. These minerals can either diffuse through a semi-permeable coating onto the hybrid electrode or be electrochemically attracted to the electrode by the classical DCI mechanism; creating the purified water.

The ionic contaminants during regeneration fall off the electrode at a higher concentration that the feed water. can be discharged and flushed away using 3 different mechanisms a) though the spacer out a flow hole, b) in between the coating and the electrode out a flow hole or c) diffusion from the electrode through the semi-permeable coating and out the flow hole. The result of the 3 flow mechanisms is a quicker flush time, faster regeneration times, improved purification and more pure water produced daily at higher recoveries.

Case Studies will be presented on brackish water, brackish waste water and normal supply waters. Each case study will show a water analysis before and after; including a characteristic of preferential removal for the primary pollutants of arsenic, fluoride, nitrates and Chromium to non-detect limits. One case study demonstrates an option to vary the operating conditions to adjust taste. Five years of longevity operating data will also be presented.

Myths of CDI

1. CDI is not been around a long time, not been fully developed and thus a risk.

Of course this is not true. CDI has been fully developed for at least 5 years because we have longevity data from existing installations.

2. Electricity and water must be dangerous.

If current used unit of area is usually measured in milliamps and no electrical charge appears in the water—only across the electrodes.

3. It can't soften water and remove the primary pollutants simultaneously.

The fact that the technology reduces total dissolved solids fairly linearly means that it removes all the ions in the same way. While it has a slight preferential removal for some components, the mean deviation from average is only +/- 7%.

4. Why is the capital cost so much higher than RO.?

In fact on a feed flow basis when evaluating for 2,500 ppm feed, EWP is +/- 20% on capital, far less on operating costs, very little maintenance. Capital costs will be similar and operating costs less with greater benefit to the consumer.

5. CDI is not effective for removing primary pollutants

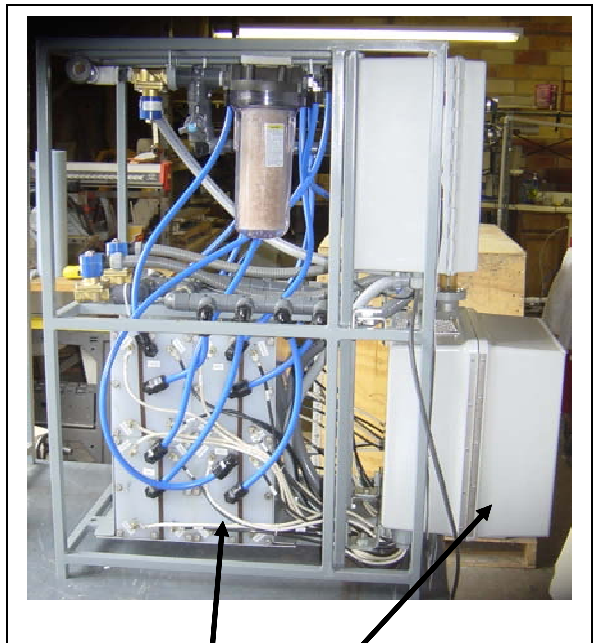
EWP removes more contaminants than any other single technology on the market.

99.5% removal of some primary pollutants
Nitrates
Ammonia
Perchlorate
Arsenic
Fluoride
Chrome
Iron (less than 10 ppm feed)
Organic Acids (eg Humic and Tannic Acid)

6. CDI can’t be cost effective for large systems

The flows can increase in multiples of 5 gpm with development of a modular cell pack and power supply

<u>5 GPM System</u>



Picture of
5 gpm cell pack
power supplies

<u>Benefits</u>

- All solid state electronics, no parts to wear out or maintain
- High recovery of 80+%
- No chemicals, no membranes or media to replace
- Cost effective on capital. Low operating costs
- Small footprint (half the size of RO)
- Removes the primary pollutants better than any other single technology
- Small POU. POE sixes to large commercial systems
- Very simple to maintain

How does EWP X3 Work?

EWP X3 is classified in a technology space called Capacitive Deionization (CDI). CDI has been around since 1950. *The basic concept for separating compounds that are dissolved in water using electrical means is quite old.* The technology started to be refined in a 25 year period from 1980 by approximately 12 inventors. It's just that EWP X3 is now refined with the most installed systems (1,000) of any of the inventors in consumer, commercial and industrial applications.

Various Dissolved salts and Silica in water are the major components of TDS (total dissolved solids). These dissolved salts need to be removed on many applications, or they will form deposits. Ultimately this will affect equipment performance, safety and taste of the water. (Figure 1)

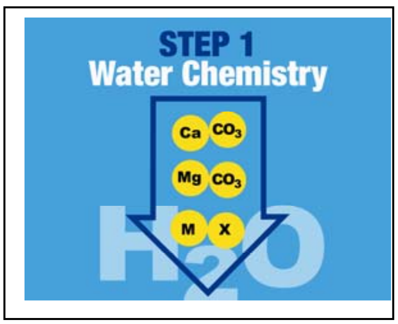


Figure 1

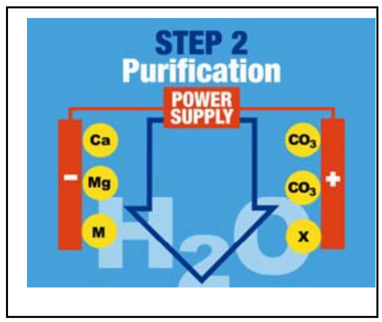


Figure 2

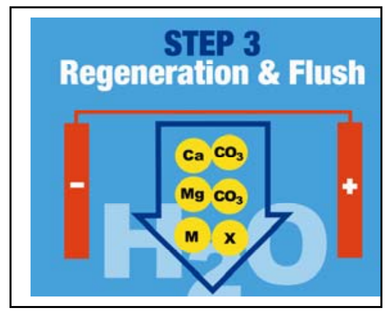


Figure 3

The Electronic Water Purifier makes patented technology available to generate highly purified quality water by removing these dissolved salts electronically.

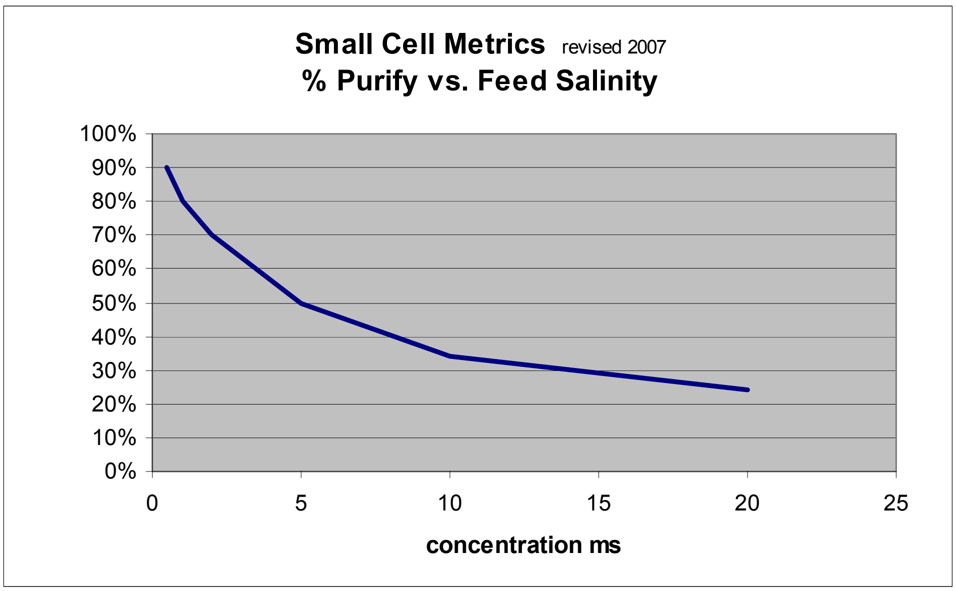
Electrodes used are made from activated carbon that has a coating and a conductive material. When these electrodes are layered using a DC power supply, the individual electrodes are charged with different polarities. The dissolved salts in the water have polarity charges and are attracted to the opposite polarity of the electrode, thus removing the dissolved salts from the water. These dissolved salts are adsorbed though a process we call electrochemical diffusion" through the coating and onto the activated carbon electrode surface creating the pure water. (Figure 2)

When sufficient dissolved salts are deposited on the electrodes, the electrodes are regenerated initially by shorting the electrodes to ground. The contaminants fall off the electrode in the same chemical form as was removed. After the regeneration, the waste at 2 times the original concentration is discharged through a valve. The waste is discharged to a drain. (Figure 3) Upon completion of this cycle, the polarities are reversed for normal operation.

General Operating Characteristics of Capacitive De-ionization

1. *The faster the flow, the less average purification*
2. *The electrodes are one pass and made from activated carbon and are not made from any aerogel material which has to use serpentine flow because of its inefficiency to purify and regenerate*
3. *If flow is increased by 50% the decrease in average purification will be 10%. This might be an acceptable trade-off.*
4. *If the feed salinity increases above where you start, the percent purification (or the outlet TDS will increase from where you started.*

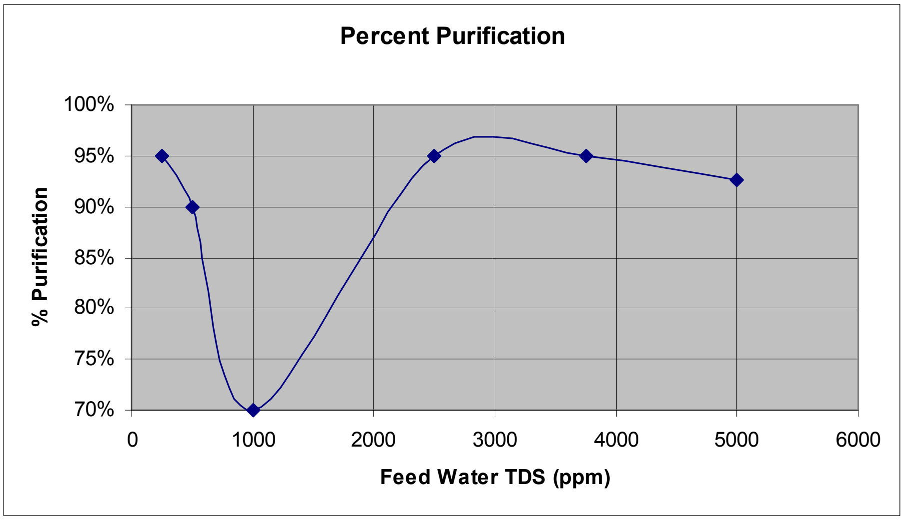
Figure 4



5. *For every 1,250 ppm in feed salinity, another cell in series is needed to maintain high levels of purification*

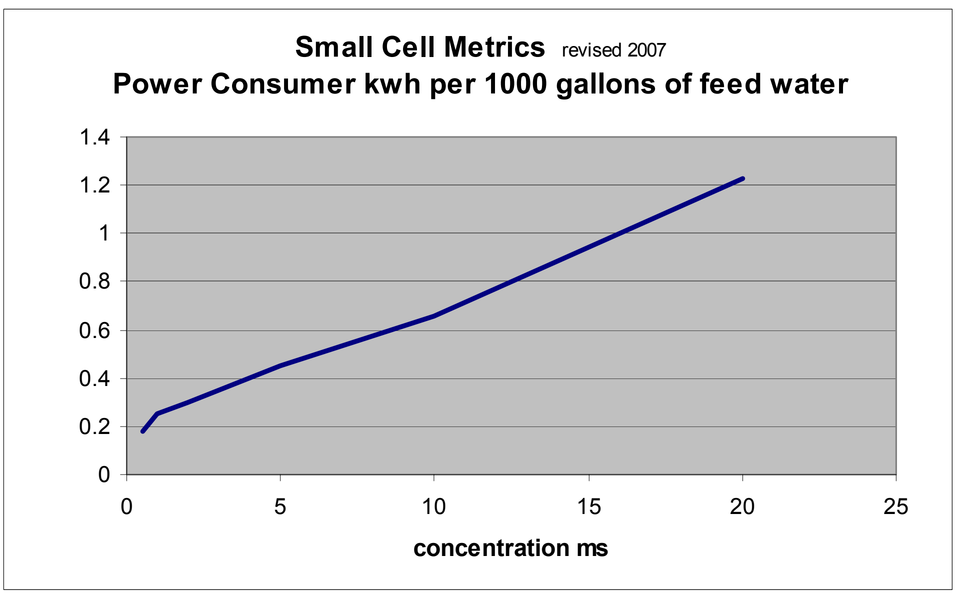
One can see from Figure 4 that at 1,000 ppm the purification is 80% (200 ppm) and at 2,500 ppm the purification 65% (875 ppm) To achieve a purification of less than 500 ppm there are 2 choices: either 1) the flow has to decrease to achieve a higher purification This means the capital investment is higher because the total daily flow output will be less; or 2) the alternative is to maintain constant flow by adding another cell in series--perhaps flow at a higher flow speed. Figure 5 shows the effect of adding cells in series to maintain the rated flow per cell.

Figure 5: Adding Cells in Series to maintain purification



6. *The power consumed is small.*

Figure 6: Power Consumption



7. *Any contaminant that will absorb into activated carbon will absorb in the electrode such as petroleum hydrocarbons, alcohol etc... And will take away surface area for ion exchange. The exception is organic substances that completely dissociate in water*
8. *Freezing should not damage the electrode.*
9. *recovery can be set to 80% to 85% by throttling a manual valve after the waste water discharge valve. This is possible because the purification flow rates are extraordinarily high and the waste flow per gram of carbon can*

be less. This will decrease the volume of waste water discharge and will also increase the concentration during the initial purification stage—which will decrease the amount of purification slightly.

The recovery can be set high because of the high flows used during purification. Figure 7 shows the relationship in flow per gram of carbon in the electrode.

Figure 7: Comparison of various materials and flow rate

Type of Material	Flow Rate (ml/min/gram of carbon)
Aerogel	*2 to 4*
CDI	*4 to 8*
EWP X3	*15 to 20*

10. *For mineral deposits left on any of the cell surfaces, a mild acid such as citric acid can be used to restore performance to the original factdory standards.*

Process Description

The new class of EWP is called X3 because the technology has evolved to use 1) a capacitive deionization principal to remove dissolved ions from water, but also emulates EDI where 2) a semi-permeable membrane and electrode are use. The device consists of multiple layers including chargeable coated electrodes or layers that work in response to an applied DC potential above 1 VDC nominally. Each electrode on the device contains a conductive surface sandwiched between layers of activated carbon. A non-conductive spacer material separates the plates from each other. These electrodes are alternately connected to the two sides of a DC power supply via appropriate connecting leads.

The device works on the principles of capacitive deionization to purify water, with the application of a low voltage DC potential to attract and discharge ions on the electrode surface. The high surface area carbon electrode layers attract and hold ions from a solution on its surface, flowing through the device. The positive ions are attracted to the negatively charged plate (anode), and the negative ions are attracted to the positively charged plate (cathode).

Eventually, all the charged sites are filled and the device must then be regenerated by discharging the irons from the electrode surfaces. shorting of the electrodes and reversing the polarity of the applied DC potential. Once a substantial amount of the new displaced ions are flushed into the waste stream, after a length of time, the unit begins to charge once again by attracting ions from the feed solution under the influence of the reverse potential. This action then begins a reversible service cycle.

What makes this device different that any CDI or EDI on the market today is 3 different flow mechanisms. The electrode and semi-permeable coating are not in contact with each other and it doesn't use chemicals to regenerate like EDI. The flow can be along the spacer, diffusion between the semi permeable coating and electrode and between the semi permeable coating and electrode. This results in shorter regeneration times (more purified water daily), faster flush with a greater concentration of contaminants in the waste water and 25% less power consumption.

Figure 8: Cell Construction Diagram

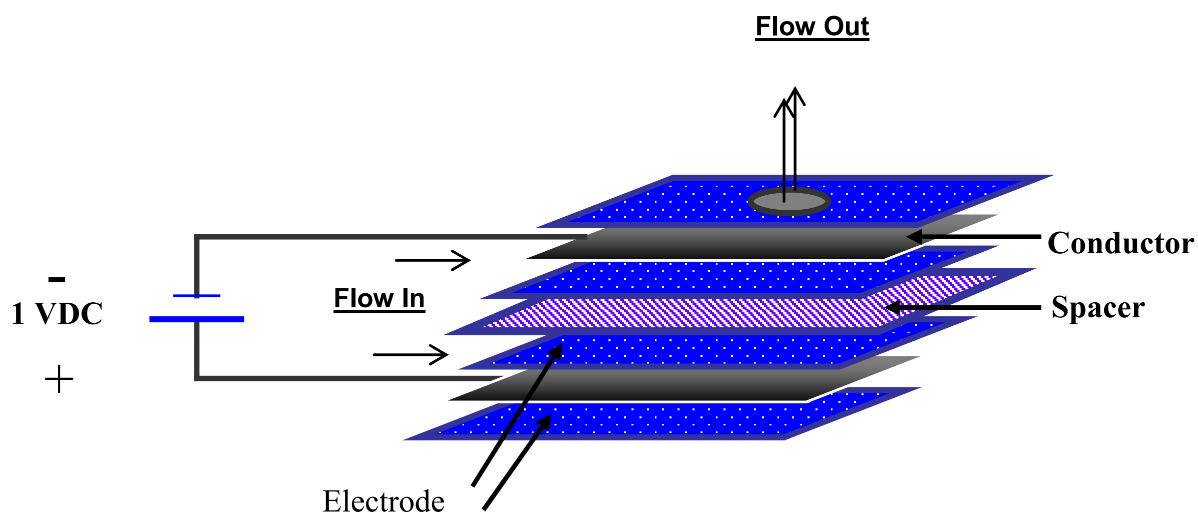


Figure 9: Single Stage Process Flow Diagram

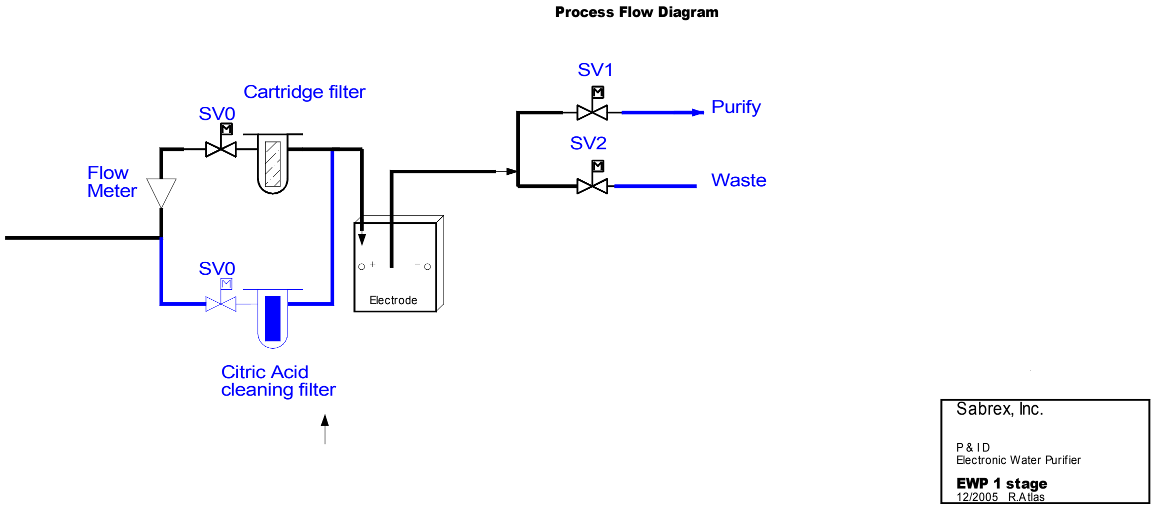
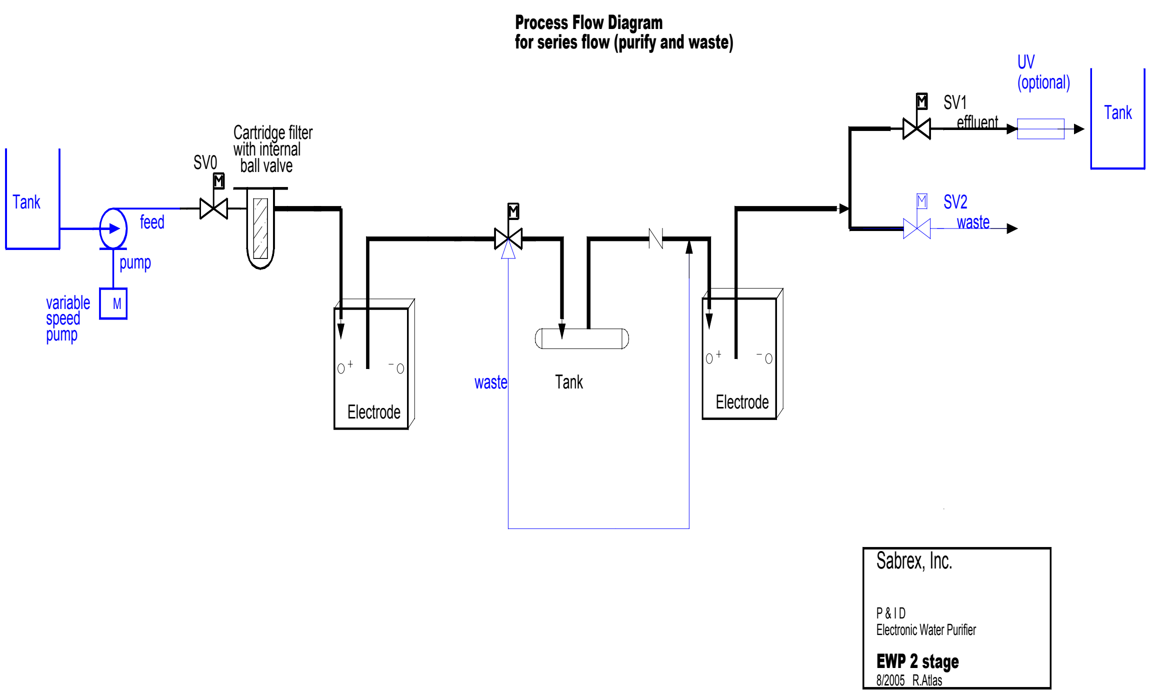


Figure 10: Cells in Series



Example 1: Waste Water Example in Coal Bed Methane

During the field test we demonstrated that the water could be purified to the acceptable discharge Standards. A TDS of 270 ppm can be achieved from a starting feed water TDS 2,500 with 85% recovery and with blending an SAR of 1 can be achieved. Over a 10-year span the total cost of capital and operations will be $.05 per barrel of water processed.

A test was run at flows of 5 gpm with two 5 gpm systems in series. Solids were filtered using a 30 micron filter.

We achieved the following results:

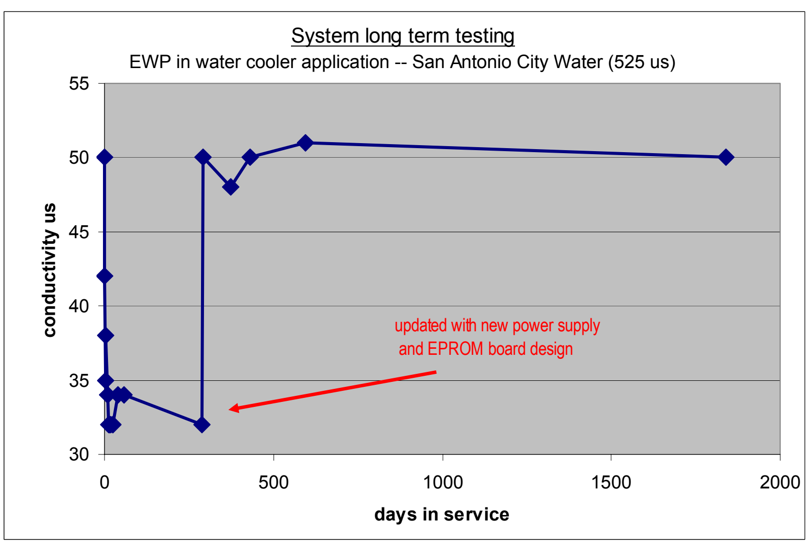
Figure 11: Results of CBM test

Feed Conductivity	2,500	ppm
Estimated Feed SAR	24	
Purified Effluent	270	ppm
SAR (Sodium Aborbtion Ratio)	3	
Waste Water (reject) conductivity	5,750	ppm
% Purification average	90%	
Recovery	85%	
Power Consumption	4.0	kwhr/1000 gal

Example 2: Cycle Testing for Supply Fresh Water

Much testing has been done on San Antonio City Water for over 5 years

Figure 12: 5 year Test on POU device



The only maintenance is a citric acid cleaning twice annually.

Example 3: Arsenic Test May 2006

A unit was installed at a house in New Hampshire on well water. This family had been following our technology for years and was purchasing 2 gallons of bottled water because they had Arsenic and Nitrates in their well water. Finally a Water Genie was installed under their kitchen sink. They did their own installation.

This test was run on a 20 gram cell that flowed at 300 ml/min (<50 GPD).

The results show a high removal of Arsenic, Nitrates and Fluoride The flow was adjusted to leave enough minerals in the purifed water to give an acceptable taste.

Figure 13: Arsenic and Flouride Testing on POU Device

	Before mg/l	After mg/l	reduction
TDS	260	63	76%
pH	7.75	6.8	13%
Turbidity	0.5	0.5	
Anion			
Chloride	7.44	3.7	50%
Fluoride	<.1	Non detect	100%
Nitrate (as N)	3.44	Non detect	100%
Nitrate/Nitrite (as N)	3.44	Non detect	100%
Metal Analysis			
Copper	<0.010	Non detect	100%
Iron	<0.010	Non detect	100%
Manganese	<0.010	Non detect	100%
Sodium	3.39	1.84	46%
Hardness	181	44.4	76%
Calcium	42.5	9.13	79%
Magnesium	18.2	5.24	71%
Arsenic	0.039	Non detect	100%

The customer says "I believe the basic technology in the EWP unit is sound. The results of sending my well water through the unit are what I was looking for when I first contacted you about purchasing a unit…..I have been able nearly duplicate the quality of water we used to buy from Poland Springs, a well know spring water provider here in New England. The unit removed the potentially dangerous arsenic and nitrates in the water, and left some of the calcium which helps the water to taste good. I feel like we are making our own 'spring water' right here in our home! With the flow setting we are using now, we can make all the drinking water we need for a day in less than an hour."

"The reason I was interested in buying this unit in particular, rather than a water softener which uses salts, or a reverse osmosis system, is that the EWP unit has significantly lower operating costs, as far as I can tell. The Reverse Osmosis systems require you to replace expensive filters at least yearly or perhaps more often. The water softener systems require you to buy salt and keep the brine tank properly filled. In addition, more and more states are putting limitations on how you have to deal with the salts from water softeners, especially when you have a septic system, as I do. The EWP unit puts back in the waste water only things it took out of the supply water, plus a little citric acid cleaning every now and again for preventative maintenance cleaning,

Example 4: Perchlorate Testing

Figure 14: The test results are as follows on POU RO vs. POU EWP

	RO		EWP	
Permeate (Purified water) Flow	110	ml/min	250	ml/min
Reject (waste water) flow	920	ml/min	129	ml/min
% Waste of Total flow	89%		66%	
TDS of feed water	340	mg/l	340	mg/l
TDS of purified water (Permeate)	102	Mg/l	22	Mg/l
% Purification	77%		94%	
Sodium Perchlorate in feed water	1.0	Mg/l	1.0	Mg/l
Sodium Perchlorate in Purified water (Permeate)	1.0	Mg/l	and	Mg/l
% Sodium Perchlorate removed	0%		100%	

The sample water was spiked with Sodium Perchlorate at 1 mg/l then tested. 100 liters sample was created for testing.

The perchlorate level was measured using an external analytical testing source. TDS was measured using an electronic conductivity meter.

The EWP outperformed RO on Removal of sodium perchlorate, purified water quality and the amount of wastewater.

Example 5: 6,000 PPM Brackish Water

A four stage system was built to purify 6,000 ppm brackish water to less than 750 ppm for household use.

Figure 15: Results of Brackish Water Test

Feed TDS	6,000	ppm
Effluent	750	Ppm
Recovery	70%	
Power	18	kwh/1000 gal

This system uses 4 cells in series. Purifies In series and flushes in series (figure 10).

Summary

The EWP X3 has developed into a range of consumer products for POU and POE as well as large commercial systems starting at 5 gpm and can be expanded to much larger flows. The technology has proven to be cost effective, low maintenance while removing a broad range of contaminants. It is starting to challenge the use membranes and media in many applications all over the globe.