OEM Engineering Manual Electropure™ XL & EXL Series EDI

Contains information for the successful system engineering, design, installation, operation, and maintenance of SnowPure's "Electropure™ XL and EXL" EDI products by an OEM pure water system integrator.

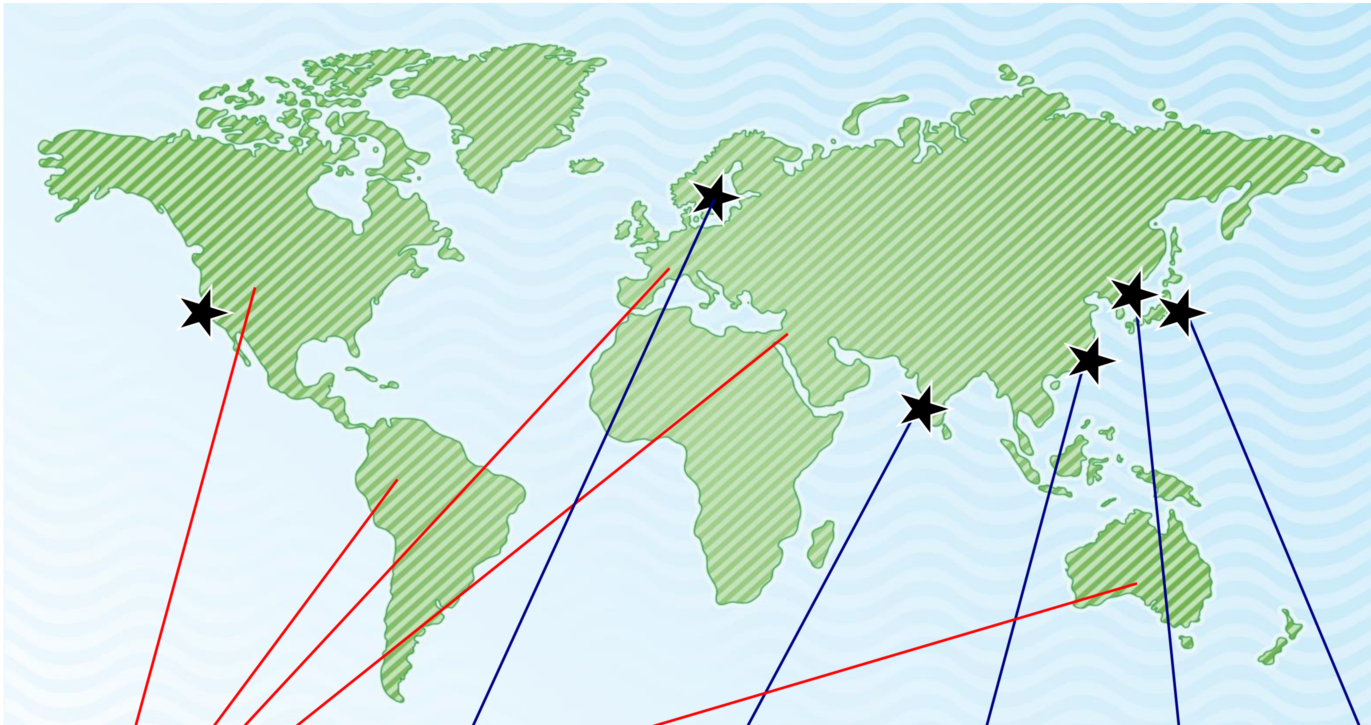
Manual: Version 3.2.2

Updated: October 2013

Photo: EXL-700

Worldwide Locations and Contacts

★ Locations of Service Centers



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Chapter 1: Electropure™ EDI Technology

Electropure™ EDI Description

The need to satisfy the increasing demand for high purity water can be achieved using SnowPure LLC's proprietary Electropure™ electrodeionization (EDI) equipment. SnowPure, formerly Electropure and HOH Water Technology, pioneered EDI in the 1980's. The O'Hare patent[1], issued in 1984, forms the basis of all EDI technology.

EDI process systems replace conventional DI mixed resin beds to produce deionized water. Unlike DI resin, EDI does not require shutdowns for replacing resin beds or for resin regeneration using chemicals. Because of this, EDI:

- minimizes water quality upsets and
- minimizes operating costs.

EDI removes ions from aqueous streams, typically in conjunction with reverse osmosis (RO) and other purification devices. Our high-quality modules continually produce ultrapure water up to 18.2 MΩ.cm. EDI may be run continuously or intermittently.

Advantages of EDI over Conventional DI

- EDI is Continuous, does not require shutdowns or changeovers
- Provides water of consistent quality
- EDI does not require chemicals (as does DI resin regeneration)
- Electropure™ EDI modules are the smallest and lightest per unit flow on the market; EDI skids are therefore compact
- Requires little energy
- Economic use of capital—saves operating expense

Process of Electrodeionization

The Electropure™ EDI design combines two well-established water purification technologies—electrodialysis (ED) and ion-exchange resin deionization. Through this revolutionary technique, dissolved salts can be removed with low energy cost and without the need for chemical regeneration; the result is high-quality pure water of multi-MΩ.cm resistivity which can be produced continuously at substantial flow rates.

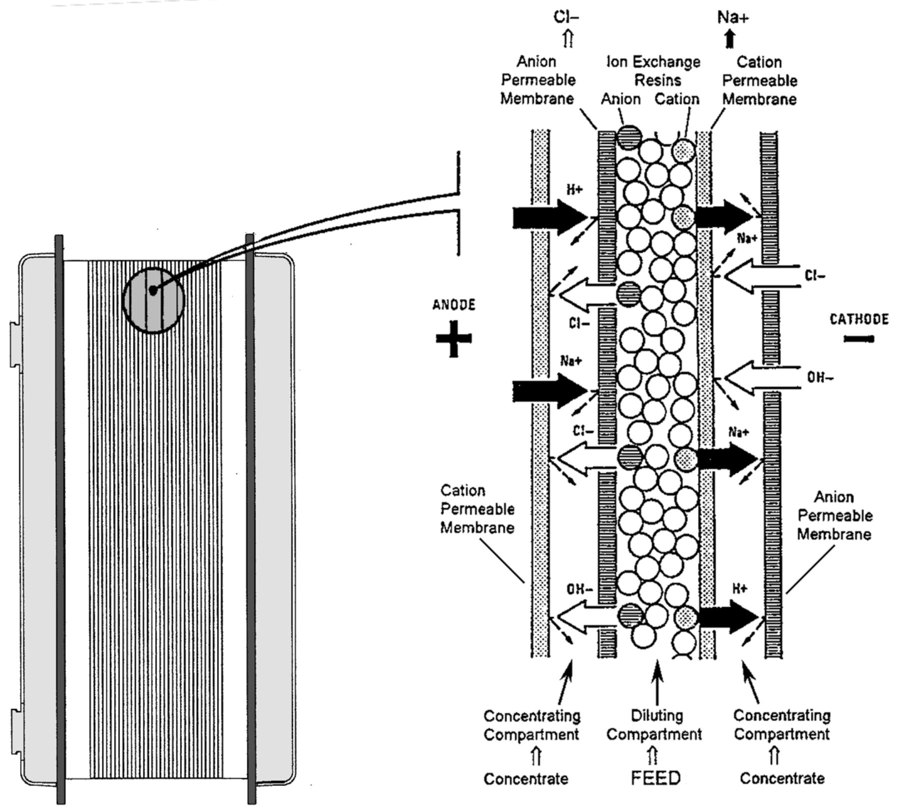
Electropure's EDI removes ions from water by forcing them out of the feed stream into adjacent streams via an electric potential. EDI is different from ED by using resins in the diluting chambers—the resins allow for more efficient migration of ions in very low conductivity water. The resins operate in steady state; they act not as an ion reservoir but as an ion conduit.

[1] US 4,465,573

Electropure™ EDI Technology Overview

Figure 1: Schematic Diagram of the Electropure EDI Process

Figure 1: Electropure EDI Technology



The electrodeionization process uses a combination of ion-selective membranes and ion-exchange resins sandwiched between two electrodes (anode (+) and cathode (-)) under a DC voltage potential to remove ions from RO-pretreated water.

Ion-selective membranes operate using the same principle and materials as ion-exchange resins, and they are used to transport specific ions away from their counterions. Anion-selective membranes are permeable to anions but not to cations; cation-selective membranes are permeable to cations but not to anions. The membranes are not water-permeable.

By spacing alternating layers of anion- and cation-selective membranes within a plate-and-frame module, a "stack" of parallel purifying and concentrating compartments are created. The ion-selective membranes are fixed to an inert polymer frame, which is filled with mixed ion-exchange resins to form the purifying chambers. The screens between the purifying chambers form the concentrating chambers.

This basic repeating element of the EDI, called a "cell-pair," is illustrated in Figure 1. The "stack" of cell-pairs is positioned between the two electrodes, which supply the DC potential to the module. Under the influence of the applied DC voltage potential, ions are transported across the membranes from the purifying chambers into the concentrating chambers. Thus, as water moves through the purifying chambers, it becomes free of ions. This is the pure water product stream.

The RO feed to the Electropure™ EDI module is split into three separate streams:

1. Product stream (up to 99% water recovery)
2. Concentrate stream (typically 10%, may be recovered as RO feed*)
3. Electrode stream (10 l/h, 0.05 gpm, <u>always</u> to drain)

> ** Note: for recovery of the concentrate stream, we recommend use of a break tank and pump, and we recommend against a direct connection.*

The electrode stream flows past the anode and cathode sequentially. The anolyte-bathing stream first flows past the anode (+) through a compartment, formed by a gasketed monofilament screen, which is located between the anode and an adjacent anion-selective membrane. In this compartment the pH becomes acidic, and O_2 (gas) and a small amount of Cl_2 (dissolved) are generated. This acidic stream then flows into the cathode compartment, formed between the cathode (-) and its adjacent cation-selective membrane. In this compartment the pH becomes neutral, and H_2 (gas) is generated. Thus, the waste stream expels the unwanted chlorine, oxygen, and hydrogen gas from the electrodes. <u>The unique Electropure™ electrode system is designed to be non-scaling since neither stream becomes high in pH. The Electropure™ anode is further engineered to minimize the amount of chlorine (a strong oxidizer) formed.</u>

Details of the Electropure™ EDI Process

Water from all sources contains impurities including dissolved salts, which are composed of negatively charged ions (anions) and positively charged ions (cations).

Typical ions include sodium, calcium, magnesium, chloride, sulfate, nitrate, carbonate, bicarbonate, etc. Over 98% of these ions can be removed by appropriate reverse osmosis (RO) treatment. Water sources also contain organics, dissolved gases (e.g., O_2, CO_2), trace metals, and weakly-ionized inorganic compounds (e.g., boron and silica), which must be removed for use in most industrial processes. The RO system (and its pretreatment) also removes many of these impurities.

RO permeate (the EDI feedwater) should "ideally" range from 1-6 μS/cm (conductivity), or a FCE = 1-9 μS/cm. Ultrapure (deionized) water ranges from 2.0-18.2 MΩ.cm depending on the application. Typically, fewer ions in the EDI feed leads to the highest quality EDI product water.

Electropure's EDI process removes the unwanted ions from the water by adsorbing them on the resins in the purifying chambers, and then transports them into the concentrate stream. The exchange reaction takes place in the purifying compartments of the module where the anion-exchange resins trade their hydroxyl ions (OH^-) for the anion of the dissolved salt (e.g., chloride, Cl^-). The cation-exchange resins trade their hydrogen ions (H^+) for the cation of the dissolved salt (e.g., sodium Na^+).

The adsorption step removes the ions from the influence of the water, whose residence time in the module is limited (approximately 10-15 seconds). When adsorbed, the ions are only influenced by force of the external DC potential.

The DC electrical field is applied via the anode (+) and cathode (-) arranged at either end of the stack. The DC potential attracts or repels the adsorbed ions, forcing movement along the surface of the resin beads, through the membranes into the concentrating compartments. The DC potential also "splits" water molecules to form hydroxyl ions and hydrogen ions:

$$H_2O = OH^- + H^+$$

In Figure 1, the ion-exchange membranes are represented by the vertical lines labeled in terms of their ionic permeability. Since these ion-selective membranes do not allow water to permeate through them, they are barriers to water flow.

The negatively-charged anions (e.g., OH^-, Cl^-) are attracted to the anode (+) and repelled by the cathode (-). The anions pass through the anion-selective membrane and into the adjacent concentrate stream. They are blocked by the cation-selective membrane on the far side of the chamber, and are thus trapped and carried away by the water in the concentrate stream. The positively-charged cations (e.g., H^+, Na^+) in the purifying stream are attracted to the cathode (-) and repelled by the anode (+). The cations pass through the cation-selective membrane and into the adjacent concentrate stream, where they are blocked by the anion-selective membrane, and are carried away.

In the concentrate stream, electrical neutrality is maintained. Transported ions from the two directions neutralize one another's charge. The current draw from the power supply is proportional to the number of ions moved. Both the "split" water (H^+ and OH^-) and the intended ions are transported, and therefore add to the current demand.

As water moves through the two types of parallel flow compartments, the ions in the purifying compartments become depleted and are concentrated in the adjacent concentrating streams, which carry the removed ions from the module.

The use of ion-exchange resins in the purifying and/or concentrate compartments is one key to the Electropure™ EDI technology and patents. An important phenomenon occurs in the ion-exchange resins in the purifying compartments. At localized areas of high potential gradients, significant amounts of H^+ and OH^- are produced by the electrochemical "splitting" of water. The local production of H^+ and OH^- within the mixed ion-exchange resins results in constant replenishment of the resins and membranes without the addition of chemicals.

The water splitting is important in keeping the EDI module bacteria-free, and in keeping the EDI module in a "polishing" state so it can effectively remove silica and boron.

Proper pretreatment of the EDI feed water is a basic requirement for optimum performance and trouble-free operation of the EDI process (in fact with any resin-based deionization process). Contaminants in the feed water can negatively affect the deionization module and either require maintenance or lessen module lifetime. Therefore, the quality of the RO system and its pretreatment is critical.

EDI Model: Serial Removal of Ions:

Ionic species are not all removed by the EDI process with equal efficiency. This fact impacts the quality and purity of the product water.

- Easy ions are removed first.

The ions with the strongest charge, the smallest mass, and the highest adsorption to the resins are removed with the highest efficiency. These typically include: H^+, OH^-, Na^+, Cl^-, Ca^{+2}, and SO_4^{-2} (and similar ions).

Upon entry into the first section of the EDI module, these ions are removed preferentially to other ions. The relative quantity of these ions affects the removal of the other ions. The pH approaches 7.0 in this section since the H^+ and OH^- ions become balanced.

The first section of the EDI module is known as the "working bed."

- Moderately ionized and polarizable ions are removed next (e.g., $HCO_3^- + CO_2$).

CO_2 is the next most common EDI feedwater constituent. CO_2 has complex chemistry depending on the local concentration of protons, and is considered moderately ionized:

$$CO_2 + H_2O = H_2CO_3 = H^+ + HCO_3^- = 2H^+ + CO_3^{-2}$$

Since the pH is forced to be near 7.0 in this section, most of the CO_2 is forced into the bicarbonate (HCO_3^-) form. Bicarbonate is weakly adsorbed by the anion resin, so cannot compete with "easy" ions such as Cl^- and SO_4^{-2}.

In the second section of the EDI module, CO_2 (in all of its forms) is removed preferentially to weaker ions. The amount of CO_2 plus HCO_3^- in the EDI feed strongly affects the final resistivity of the product water and the efficiency of silica and boron removal. In this manual, the term "CO_2" means the total of CO_2 plus HCO_3^-.

In the Electropure™ EDI products, it is found that as long as CO_2 (in all forms) is less than 5 mg/l, high quality ultrapure water can be achieved. If the feedwater CO_2 concentration is greater than 10 mg/l, it can interfere with the total removal of ions and strongly impacts the EDI product quality and the silica removal.

- Weakly ionized species are removed last (e.g., dissolved silica and boron).

Species such as molecular silica are difficult to remove using any deionization process because they are very weakly ionized and difficult to adsorb onto the ion-exchange resin.

If all of the "easy" ions are removed, and all of the CO_2 is removed, the EDI module can focus its force on removing these weakly ionized species. The residence time available in this third section of the module is important. The longer the residence time available in the module, the higher the removal efficiency. A long third-section residence time can be achieved by minimizing the conductivity of the RO product (the quantity of "easy ions to be removed), ensuring a pH close to 7.0, and minimizing the quantity of HCO_3^- and CO_2 in the RO product.

The second and third sections of the EDI module are known as the "polishing bed."

- The different species in the EDI feed, and their concentration, affect the EDI performance and efficiency.

Effects of Contaminants in EDI Feedwater:

Critical contaminants that adversely affect the EDI process include hardness (calcium, magnesium), organics (TOC), particulates and suspended solids (SDI), active metals (iron, manganese), oxidants (chlorine, ozone), and carbon dioxide (CO_2).

The pretreatment process designed for the RO/EDI system should remove these contaminants from the feedwater as much as possible. Minimum requirements and recommended levels are given in the EDI feedwater section (below). Good system design will further lower the levels of contaminants to enhance EDI performance. Suggested water treatment strategies are listed later in this manual.

Hardness can cause scaling in the reverse osmosis and EDI units. If this occurs, it will take place in the concentrate chambers at the high-pH surfaces of the anionic membrane. Pressure drop in the concentrate stream increases, and current efficiency is reduced. The Electropure EDI module is designed to avoid scaling; however, minimization of inlet hardness will lengthen the time between cleanings.

Organics (TOC) adsorb to the surfaces of the resins and membranes. This causes fouling of the active sites. Fouled resins and membranes are inefficient at removing and transporting ions. Stack electrical resistance will increase.

Particulate matter (SDI), colloids, and suspended solids cause plugging and fouling of the membranes and the resin in the chambers. Plugging of resin interstices increases the pressure drop across the module.

Iron and other active metals (e.g., Mn) may catalyze resin oxidation, and may strongly and permanently adsorb to, and reduce the capacity of, the internal resins and membranes. This happens even in sub-ppm concentrations.

Chlorine (Cl_2) and **Ozone** (O_3) attack ion-exchange resins and membrane and cause decrosslinking, which results in reduced capacity. Chloramine is a related oxidant. Oxidation will increase apparent TOC, and the byproducts cause fouling of the anionic resin and membrane, reducing the ion-transfer kinetics. Oxidation decrosslinking also causes the resins to disintegrate and the pressure drop across the module will increase. Module lifetime will be lessened. The ideal concentration level for oxidants is zero.

CO_2, Carbon Dioxide has two effects. First, $CO_3^{=}$ reacts with Ca^{+2} and Mg^{+2} to form carbonate scale. This scaling varies with the concentrations, temperature, and pH. Second, since CO_2 varies in charge depending on its pH, and its removal by RO and EDI both depends on charge, its removal efficiency varies. Even low levels of CO_2 (below 5 ppm) can affect the resistivity of the product water and the removal efficiency of silica and boron.

Glossary of Terms

Anion: an ion (electrically charged atom or group of atoms) that carries one or more negative charges, e.g., Cl^-, OH^-, SO_4^{-2}.

Anode: a positively (+) charged electrode that attracts anions, typically a coated titanium.

Anolyte: the stream of water containing anions and gases collected at the anode.

Cathode: a negatively (-) charged electrode that attracts cations, typically made of stainless steel.

Catholyte: the stream of water containing cations and gases collected at the cathode.

Cation: an ion that carries one or more positive charges, e.g., Na^+, NH_4^+ and Ca^{+2}.

Concentrate Stream: the flow of water through the parallel concentrating compartments, where ions are collected.

Conductivity: the electrical measurement of water's ability to conduct an electrical current, which is dependent on the concentration of ions in the water and its temperature. Units are microsiemens/cm or μS/cm or micromhos/cm, and are normalized to 25°C.

DC current: current that does not change direction. Amperes in an EDI are proportional to the number of ions moved, including split water ions.

DC potential: voltage that does not change polarity. Electrodeionization is only possible with this form of driving force. There will be some AC component to the DC voltage.

Electrode: a metal plate (anode or cathode) that conducts an electrical field and catalyzes electrochemical reactions. Electrodes are connected directly to a power supply via a 3-wire connection.

Electrode Stream: a stream of water that emanates from the electrodes, and includes ions and electrochemical byproducts. The Electropure technology uniquely combines both electrode streams in series. This waste stream is small, about 10 l/h.

Feed water: the water that is plumbed into the EDI module, typically RO permeate. It supplies the product compartments, concentrating compartments, and electrode stream.

GPM (gpm): gallons per minute. A measurement for the flow of water. 1.0 gpm is equivalent to 227 liters/hr. 4.4 gpm is equivalent to 1.0 m^3/hr.

Ion-exchange Membrane*:* a membrane containing ion-exchange groups that is selectively permeable to either anions or cations, and is impermeable to water.

Ion-exchange Resin*:* resin beads containing ion-exchange groups that selectively adsorb either anions or cations.

Megohm*:* (technically, Megohm.cm or MΩ.cm) the unit of measurement typically used to quantify the ionic purity of product water produced by a deionization system. It is a measurement of electrical resistance. Ultrapure water with no impurities may reach 18.24 MΩ.cm at 25°C.

pH: the measurement of the concentration of the hydrogen ion (H^+). pH values are expressed as a logarithmic scale from 0 to 14. A value at or near 0 is very acidic, a value at 7 is neutral, and a value at or near 14 is very basic. The ideal pH feed to an EDI is 7.0-7.5.

Polarization: the splitting of water molecules into H^+ and OH^- ions with an electrical current. This will occur when relatively few ions are present in the diluting compartments and the applied voltage is excessive, causing water to dissociate in order to conduct current. Fluctuation of pH in the module is typically associated with polarization. Polarization of water regenerates the ion-exchange resins.

ppb: parts per billion, or µg/liter. A unit used to quantify very low levels of specific ions of interest, such as silica, in high-purity produced water.

ppm: parts per million, or mg/liter. The unit used to identify the total dissolved solids (TDS) in water, and is typically used to quantify the purity of feed water entering the EDI module. At low conductivity, 1 ppm is approximately 2 microsiemens/cm.

Product (Purified) Stream: the flow of water through the purifying compartments. This is where deionization occurs. This was formerly known as the Dilute Stream.

Purified Water: Technically, water purified to USP standards. Purified Water is a precursor to USP Water-for-Injection (WFI).

Resistivity: the electrical measurement of water's ability to resist the flow of electrical current. *Resistivity increases as the concentration of ions decreases.* It is highly affected by temperature. This measurement is associated with the level of deionization achieved with EDI. Ultrapure water with no impurities may reach 18.24 MΩ.cm at 25°C.

Salt: a chemical compound derived from an acid by replacing hydrogen ion wholly or partly with a metal or electro-positive cation. Examples of salts:

Acid	Ion	Salt
HCl	Sodium (Na^+)	NaCl
H_2SO_4	Calcium (Ca^{+2})	$CaSO_4$
HNO_3	Magnesium (Mg^{+2})	$Mg(NO_3)_2$
H_2SO_4	Potassium (K^+)	$KHSO_4$

TOC: Total Organic Carbon. A quantitative measure of the level of organic compounds in a water sample. Expressed as ppm, or mg/liter. TOC includes all organics, and therefore the removal of TOC varies.

USP Purified Water: Water meeting USP (U.S. Pharmacopeia Monograph) quality and process requirements (now also EP and JP) that has been purified by membranes, distillation, ion exchange, electrodeionization, and other suitable processes, typically from sourcewater complying with US EPA drinking water regulations, and contains no added substances.

SnowPure EDI Intellectual Property

SnowPure, LLC, formerly HOH Water Technology, holds the O'Hare patent (US 4,465,573) that forms the basis of all EDI technology. It has improvement patents in the works, and patents issued on its proprietary ion-exchange membrane technology (e.g., US 6,503,957).

Other companies hold intellectual property regarding the application of EDI technology in systems. SnowPure, LLC does not knowingly recommend to its customers the use of others' intellectual property, and assumes no obligation on behalf of its customers as they build, install, or operate EDI in systems of their design as part of their business.

EDI Technology Summary

SnowPure's patented electrodeionization (EDI) modules have proven to be an effective component of a continuous deionization process. Electropure™ EDI is an economic alternative to DI mixed resin bed systems and has several advantages. Though the capital cost of an EDI system may be higher than a resin bed system, the operating cost and other process advantages favor the use of Electropure™ EDI.

Chapter 2: Product Description and Guide

Electropure™ EDI Advantages:

The Electropure™ EDI series of modules is designed to be an economic component in an OEM's pure water systems.

Electropure™ modules are designed with the following advantages over other EDI modules:

- ❖ Unique Thin-Cell Technology.
- ❖ Unique Thin-Concentrate Technology ("filled-cell" not required).
- ❖ Unique Acidic Concentrate prevents scaling.
- ❖ No resins in concentrate to foul (disadvantage of "filled-cell")
- ❖ Unique Non-scaling Electrode System.
- ❖ Control over Electropure™ Electrode System.
- ❖ Enable a Simple EDI System℠ to be built.
- ❖ No concentrate recirculation needed.
- ❖ Lightweight and compact.
- ❖ Waterproof electrical attachment on the opposite face.
- ❖ Stack and bolts hidden internally.
- ❖ Membrane is a proprietary membrane made by SnowPure.
- ❖ The internal design has been improved over many years.

Electropure™ EDI Product Guide:

Electropure™ EDI modules come in a variety of product lines, and a range of models with flow sizes from 10 lph to 8 m^3/h (2 gph to 35 gpm). Each module has a recommended product flow range. Modules can be arrayed in parallel to produce a system of almost unlimited size (largest system to date is 400 m^3/hr (1760 gpm). Our high-quality modules deliver 10-18.2 MΩ.cm water depending on feed and operating conditions.

Current Electropure™ EDI Product Lines:

EXL	High Capacity	Since 2009
XL-R	Improved Torqueing	Since 2006
XL-SR	Sanitary (TC) Fittings	Since 2006
XL-HTS w/SS covers	High Temperature Stable	Since 2004
Zapwater	Laboratory (10, 20 l/h)	Since 2005

Legacy Electropure™ EDI Product Lines:

EPM/EPX (some repairs)	Status: Legacy	Since 1984 (until 2001)
XL (made to order)	Status: Legacy See XL-R	Since 1999 (until 2006)
XL-S (made to order)	Status: Legacy See XL-SR	Since 1999 (until 2006)

The table below shows the flow ranges for the Electropure™ EDI series of modules.

Product	Flow Range, gpm	Flow Range, m^3/h	Operating Voltage, VDC	Dimensions* WxHxD in	Dimensions* WxHxD cm
XL-100-R	¼ to ¾	80 to 150 l/h	48	8.5x22x6.5	22x56x17
XL-200-R	½ to 1½	100 to 300 l/h	100	x7.5	x19
XL-300-R	1½ to 4½	300 to 1000 l/h	150	x10	x26
XL-400-R	2½ to 7	.6 to 1.5	200	x11.5	x29
XL-500-R	6 to 10	1.3 to 2.3	300	x14.5	x37
EXL-600	15 to 24	3.5 to 5.5	300	12.4x24x10.5	31x60x26
EXL-700	26 to 35	6.0 to 8.0	500	12.4x24x15.4	31x60x38

* see dimensional drawing for exact dimensions in inches and cm

Module Restack

The XL and EXL series are designed to be disposable units. It is more environmentally sound and economic to replace a module than to ship it roundtrip to the facility for a "restack."

Applications and Purity Specifications

Ultrapure water is used for microelectronic and semiconductor production, for biomedical and laboratory use, by pharmaceutical compounders, as pretreatment for distillation, for boiler water makeup during power generation, in the food and beverage industry, and anywhere in general industry where DI water is advantageous.

Below are typical industry ionic content specifications. These do not represent all of the specifications for the water in these industries, only those relevant to EDI.

Semiconductor Ultrapure Water:

Test	Units	Attainable	Acceptable	Alert	Critical
Resistivity, 25°C	MΩ.cm	18.2	18.2	18.0	17.9
Silica, dissolved	ppb	<0.1	<0.1	>0.5	>1.0
Boron	ppt	50	100	400	>500

(source: Balazs UPW Guideline, 2004, complete guide available at www.snowpure.com)

Electronic Grade Water (ASTM D-19):

	Type E-I	Type E-II	Type E-III	Type E-IV
Resistivity (minimum, Megohm.cm)	18 (95% of time), no less than 17	17.5 (90% of time), no less than 16	12	0.5
SiO_2 (total maximum, µg/L)	5	10	50	1,000
Particle count (per ml)	1	3	10	100
Viable bacteria (max, ml)	1/1,000 m/L	10/1,000 m/L	10 m/L	100 m/L
TOC (max, µg/L)	25	50	300	1,000
Endotoxins (EU/ml)	0.03	0.25	n/a	n/a
Copper (max, µg/L)	1	1	2	500
Chloride (max, µg/L)	1	1	10	1,000
Nickel (max, mg/L)	0.1	1	2	500
Nitrate (max, mg/L)	1	1	5	500
Phosphate (max, mg/L)	1	1	5	500
Potassium (max, µg/L)	2	2	5	500
Sodium (max, µg/L)	0.5	1	5	1,000
Sulfate (max, mg/L)	1	1	5	500
Zinc (max, µg/L)	0.5	1	5	500

(SOURCE: Osmonics Pure Water Handbook, 2nd Edition, 1997)
(SOURCE: ASTM International: www.astm.org.)

Type E-I: This water will be classified as microelectronic water to be used in the production of devices having widths below 1.0 µm. It's intended that this be the water of ultimate practical purity produced in large volumes and for the most critical uses.

Type E-II: This water may be classified as microelectronic water to be used in the production of devices having dimensions below 5.0 µm. This water should be adequate for producing most high-volume products, which have dimensions above 1.0 µm and below 5.0 µm.

Type E-III: This grade of water may be classified as macroelectronic water to be used in the production of devices having dimensions larger than 5.0 µm. This grade may be used to produce larger components and some small components not affected by trace amounts of impurities.

Type IV: Electronics-Grade Water may be classified as electroplating water for non-critical use and other general applications where the water is in constant contact with the atmosphere because of tank storage.

Power Generation Boiler Water:

Test	Units	Typical
Resistivity, 25°C	MΩ.cm	10-13
Silica, total	ppb	5-20

(specifications depend on boiler pressure and use)

ASTM Reagent Water:

Water Type:	I	II	A	B
Resistivity, MΩ.cm	18.2	1.0		
TOC, ppb	10	50		
Na, Cl, ppb	1	5		
Silica, ppb	3	3		
Heterotrophic Bacteria/100 mL			1	10
Endotoxin, EU/mL			<0.03	<0.25

USP Pharmaceutical Water:

Requirements vary depending on national laws (e.g., USP). USP Water for Injection WFI requires the final treatment to be either distillation or a membrane barrier (e.g., RO) in the US. USP Purified Water is water meeting USP quality requirements that has been purified by distillation, ion exchange, electrodeionization, and other suitable processes. USP is now aligned with other standards under WHO: The International Pharmacopoeia (PhInt). EDI can be used as a preferred unit operation in either USP water system.

Summary[2] of Key of USP 29 Specifications for
Purified Water (PW) and Water for Injection (WFI)

Quality	[units]	UPS Sterile Purified Water	USP Sterile Water for Injection
Conductivity	[µS/cm (25°C)]	< 1.3	< 1.3
pH	[ ]	5.0-7.0	5.0-7.0
TOC	[ppb C]	< 500	< 500
Bacteria		< 100 [CFU/ml]	< 10 [CFU/100ml]
Endotoxins	[EU/ml]		< 0.25
Final Processes		"Any"	Distillation, RO
Typical Systems		RO-EDI	RO-EDI-RO RO-EDI-Distillation

[2] Note that full U.S. Pharmacopeia standards, rules, and regulations are available from their website www.usp.org, and that new USP guidelines are issued annually.

Chapter 3: Normal Operation, Conditions, and Specifications

Standard Operating and Testing Conditions

Electropure EDI module performance depends on a variety of operating conditions including the OEM's system design. For this reason, SnowPure tests its modules before shipment under standard conditions; we base our quality program on manufacturing process control and final testing. SnowPure does not guarantee specific performance in the OEM's system, as it has no control over the design or operating conditions. SnowPure has confidence based on its module design and standard product testing that excellent performance can be achieved.

The effects of various process variables on quality are discussed in subsequent chapters.

Standard testing conditions: Electropure™ EDI modules are tested with water that is treated with active carbon, softening, and fine filtration, followed by standard RO operating at 65% recovery. RO permeate ranges from 2.0 to 5.0 ppm TDS, and includes <5 ppm CO_2 and about 150 ppb silica. Temperature ranges from 18-35°C. Applied voltage and water flows are set at the published nominal for each module. Results of this test are available for each module, and records are kept in our files for each module.

At the customer's request, SnowPure will retest a field module under its standard conditions to confirm quality.

Glossary of Terms

- Applied Voltage: the DC voltage across the anode and cathode of each module. The voltage required depends primarily on the number of cells in the module.
- Current: the DC current through each module. The current depends on the ion load in the EDI feed, on the module recovery rate, and on the amount of water splitting. Current is roughly independent of the number of cells.
- Module Resistance: applied voltage divided by current, typically expressed in ohms.
- Power Requirement: electrical power needed to supply the necessary current and voltage. Typically expressed as kW/gpm.
- Feed stream: feed to the purifying compartments for conversion to product. May also include feed to the concentrate and electrode compartments.
- Purified product stream: product from the purifying compartments.
- Concentrate stream: flow in the ion-collecting concentrate compartments. Typically 10% of feed flow.
- Electrode stream: flow to the anode and cathode compartments. Typically constant, independent of the EDI model. See specifications.
- Recovery: product stream flow divided by the total feed flow. Typically 99% if the concentrate stream returns pre-RO. May be 90% if concentrate is sent to drain.

Operating Feed Water Specifications

The following are requirements to operate within SnowPure's limited warranty. Optimum performance from Electropure™ EDI modules will result if values that are more stringent are set as design goals.

Specification	Notes	Working Range	Optimum Performance
Feedwater Source	RO water, direct feed, or with intermediate break tank plus filter		
EDI Feed Conductivity	Ionic load determines size of the working bed and polishing bed within the EDI	**1-20 µS/cm**	1-6 µS/cm
Feedwater Conductivity Equivalent**	FCE = Conductivity + 2.79* CO_2 +1.94* SiO_2 *see note below***	**< 33 µS/cm**	< 9 µS/cm
pH	Low pH feedwater typically indicates the presence of CO_2 which will decrease quality.	**5.0-9.5**	7.0-7.5
Total CO_2	Combined CO_2 and HCO_3^-	**<5 mg/l as CO_2**	<2 mg/l
Temperature		**5°C to 35°C**	20 to 30°C
Hardness	Ca^{+2} and Mg^{+2} as $CaCO_3$	**<1.0 ppm at 90% recovery**	
Organics	TOC	**< 0.5 ppm**	Not Detectable
Metals	Fe, Mn, transition metals	**< 10 ppb**	Not Detectable
Silica, SiO_2	Typically dissolved, reactive	**< 0.5 ppm**	< 0.2 ppm
Oxidizers	Cl_2 and O_3, typically	**Not Detectable**	Not Detectable
Particles	Recommended direct feed particle-free RO permeate, or 1 µm pre-filtration of feed from intermediate tank		
Inlet Pressure	Depends on flow and temperature	**5 bar (75 psi) max**	2-3 bar typical
Outlet Pressure	Concentrate and Electrode outlet pressures to be lower than the Product outlet pressure		

** FCE example:

FCE = Conductivity + 2.79(CO_2) + 1.94*(SiO_2), so if conductivity=5.0 µS/cm, CO_2=3.5 mg/l, SiO_2=0.5 mg/l, then FCE = 5.0 + 2.79*(3.5) + 1.94*(0.5) = 15.7 µS/cm.*

Cost of Power for the EDI Module

A typical XL-500-R module operating at 300VDC and drawing 2 amps will cost under $1.00 per 8-hour period. This assumes that the power supply is 85% efficient and the local utility charges $0.12 per kW-hr. See Appendix #7 for the power and cost calculations.

DC Power Supply Requirements

The power supply should be a regulated DC power supply with enough power to cover typical and extreme operating conditions.

SnowPure recommends setting the voltage (driving force) and allowing the current to float (follow the RO permeate conductivity as it changes).

Voltage output should be controllable. The voltage range should include the regeneration conditions. The power supply should have current-limiting capability to protect itself and the EDI module(s). Each module may be separately fused.

Current depends on the conductivity of the EDI feed and the concentrate flow. There should be excess current capability designed in to cover higher currents in case module regeneration is needed, or if RO permeate conductivity increases with system age.

For protection the system must have an automatic interlock to turn the power OFF in case of NO WATER FLOW. It may be controllable from a remote source such as a PLC or the system control computer. The interlocks may be a combination of logic, flow, and pressure switches. The power supply may have internal diagnostics and an alarm relay output.

AC noise (ripple) can be up to 5%. AC low- and high-frequency ripple may affect the readings of local electronic instruments, such as conductivity or resistivity meters.

Power supply should conform to UL, CSA, or CE requirements as local code requires. Local code may require features such as power factor correction (PFC) and EMI shielding. If NEMA rating is required, the NEMA enclosure must have enough heat removal to keep the power supply cool. Typical power supply efficiency is 85-90%, so AC input power will be about 10-15% higher than the rated power of the supply.

Module(s)	Recommended Operating Voltage (Range) DC	Typical Current with 3 ppm RO feed	Maximum Voltage	Maximum Current with 15 ppm RO feed
1 XL-100-R	48 VDC	2 Amps	80 VDC	8 Amps
1 XL-200-R	100	2 Amps	150 V	8 Amps
1 XL-300-R	150	2 Amps	200 V	8 Amps
1 XL-400-R	200	2 Amps	300 V	8 Amps
1 XL-500-R	300	2 Amps	400 V	8 Amps
3 XL-500-R	300	6 Amps	400 V	24 Amps
EXL-600	300	3 Amps	400 V	8 Amps
EXL-700	500	3 Amps	600 V	8 Amps
20 EXL-700	500	60 Amps	600 V	160 Amps

Note: the power supply should be sized for the maximum requirements if possible.

Projection Program: EDICAD™

Contact SnowPure for a copy of our EDICAD™ design and projection program. This Excel®-based program allows Qualified OEM Pure Water System Integrators to enter a water analysis and system requirement to estimate the EDI system performance.

The EDICAD™ program predicts physical parameters such as pressure drop, voltage, and current. It also predicts water quality and silica removal.

EDICAD™ alerts the user to potential feedwater problems with alarms.

This program can be used to improve your design, to learn how Electropure™ EDI reacts to changes in feedwater, and give you the ability to give your Customer estimated performance as part of your bids.

Chapter 4: Effects of Process Variables

Applied Voltage

Voltage is the driving force, which pushes and pulls the impurity ions from the feed streams into the concentrate streams. The local voltage gradients also cause H_2O to split into H^+ and OH^- ions. The constant formation and high local concentration of these ions allows the state of the resins in the "polishing" section within the EDI module to be in the full H and OH form, and fully able to remove species such as CO_2 and silica. These also prevent the growth of bacteria within the EDI module. Excess H^+ and OH^- ions are pulled from the feed streams into the concentrate streams, which also compete with any impurity ions for transport sites.

Optimum Voltage

The optimum voltage depends first on the number of cells in the module. Normal operating voltage range is approximately 5 to 8 Volts/cell. See the power supply requirements for the recommended voltage range for operation. The optimum voltage also depends on:

1. Temperature
2. Concentrate conductivity
3. Concentrate flow rate (recovery).

Quality vs Voltage

There is an optimum voltage to achieve the highest quality water. At voltages lower than this, the driving force is inadequate to move the ions across the purifying chamber resin bed and then across the membranes before the product stream exits the module. At voltages higher than optimum, the overvoltage creates excess water splitting, leading to excess current, causing ion polarization and thus backdiffusion, which lowers product water resistivity.

Within the range set for each module type, the optimum voltage depends on the ion load and on the water recovery rate. Higher ion loads in the feed and higher recovery rates lead to a higher ion concentration in the concentrate chambers, which lowers the resistance of the module—the lower stack resistance leads to a lower optimum voltage.

See the section on silica removal regarding how voltage affects silica removal and prevents silica fouling.

Current vs Feed Conductivity

Typical current draw for an XL module at nominal voltage is 1-4 amps with a feed conductivity of 2-10 µS/cm. Current may be as low as 0.5 amp. Current at high feed conductivities (15-20 µS/cm) will lead to currents as high as 6 amps, or higher.

Fundamentally, current is proportional to the total number of ions moved. These ions include the impurity ions in the RO permeate, such as Na^+, Cl^-, and HCO_3^- plus the ions caused by water splitting, H^+ and OH^-. The water splitting rate depends on the local voltage gradients, so that higher voltages across the resin chambers leads to higher quantities of H^+ and OH^- to be moved.

A portion of the current is then directly proportional to the ion content of the feed (TDS, or µS/cm). The other portion of the current, proportional to water splitting, increases non-linearly with overvoltage. The "current efficiency" is the fraction of the total current that is required to move the impurity ions in the EDI feed.

If the module current is higher than expected, it could be because the voltage is set higher than optimum, and excess water splitting results in the excess current.

Current also depends on the concentrate conductivity, and therefore on the module water recovery. The nominal concentrate flow is 10% of the feed flow. If the concentrate flow is lower than recommended, the concentrate will be more conductive and the current will increase. In this case, lower the voltage to find the optimum.

Steady State Operation

Normally, an EDI module will start up with high quality product water. This is because the EDI module has excess mixed bed ion-exchange resins in it in the H and OH form, in the "polishing" section.

However, after operating conditions have changed, a module will take between 8 and 24 hours to reach a new steady state. The true steady state is defined as reaching a mass balance on the ions entering and leaving the module. At steady state, the kinetics of ion migration match the ion feed rate. Steady state for trace ions such as silica may take as long as 2-4 weeks.

If voltage is lowered or ion load is raised, the internal ion-exchange resins will begin to adsorb the excess ions. In this condition, fewer ions leave the module than enter. Eventually a new steady state is reached. During this time, the "working ion front" progresses in the resin bed from near the bottom of the module upward.

If voltage is raised or ion load is lowered, the resins will lose some of their excess ions to the concentrate stream, and more ions will be exiting the module than enter it. During this time, the location of the "working ion front" grows closer to the inlet of the module. This latter is the mechanism of the "regeneration" procedure.

An ion balance done on the module(s) during operation is a valuable tool in determining if the EDI system is operating at steady state.

@ Steady State: Total Ions Out = Total Ions In
Module Filling with Ions: Total Ions Out < Total Ions In
Module Recovering from Overload: Total Ions Out > Total Ions In

Ionic Species

The ability for EDI to remove ions from a stream depends in part on the properties of the ionic species. In a standard resin bed, the adsorption strength and kinetics depend on the ionic size, the degree of hydration, and on the type of resin.

In EDI, the ionic charge is even more important since this is the driving force to move the ions along the resin surfaces to the membrane, and through it.

Ionic Size

The following ionic sizes are the effective sizes[3] in aqueous solution at 25°C. These sizes include full hydration. The larger the effective size the slower the diffusion rate—making removal by EDI more difficult. The larger the effective size, the more distributed the charge thus making adsorbtion by the resin more difficult.

Ionic Radius, Å	Cations	Anions
≤ 3.0	K^+, NH_4^+	Cl^-, NO_3^-
3.5		OH^-, F^-
4.0-4.5	Na^+	SO_4^{-2}, CO_3^{-2}
6.0	Li^+, Ca^{+2}, Fe^{+2}	
8.0-9.0	H^+, Mg^{+2}, Fe^{+3}	

Ionic Charge

The higher the ionic charge the stronger the applied voltage will pull the ion through the membrane. This is counterbalanced by higher degrees of hydration and larger, heavier molecules which slow diffusion.

Selectivity Coefficients of Ions for Resin

The table below shows the selectivity of different ions for resin[4]. This is a measure of their adsorption strength to the resin. Strong adsorption means low leakage through a resin bed or an EDI module.

Cation	Selectivity Coefficient		Anion	Selectivity Coefficient
Li^+	0.8		$HSiO_3^-$	
H^+	1.0		F^-	0.1
Mg^{+2}	1.2		HCO_3^-	0.5
Na^+	1.6		OH^-	0.6
Ca^{+2}	1.8		Cl^-	1.0
NH_4^+	2.0		NO_3^-	3.3
K^+	2.3		I^-	7.3

Easy Ions (Na^+, Cl^-, Ca^{+2}, H^+, and OH^-)

Sodium (Na^+), Chloride (Cl^-), Calcium (Ca^{+2}), Hydrogen ion (H^+), and Hydroxyl ion (OH^-) are considered easy ions for EDI. All of these ions are adsorbed well by the resin and have a charge that is definite and difficult to polarize. These ions are fairly easy to remove in the "working" section of the EDI module.

[3] Lange's Handbook of Chemistry, 12th Edition, Table 5.2
[4] Lange's Handbook of Chemistry, 12th Edition, Table 5-34, 5-35

Large, Weakly-charged Ions (Carbon Dioxide, Silica, Boron)

Carbon Dioxide (CO_2), Silica (SiO_2), and Boron (H_3BO_3) all have weak anionic charge under normal operation and pH. Because of this, they are weakly adsorbed to the resins and the applied voltage has little driving force.

To effectively remove these ions, other system strategies are used.

1. Minimize the ionic content of the feed
2. Minimize the CO_2 and HCO_3^- in the feed
3. Maximize the removal of silica and boron by the RO

If the total ion load to the EDI is lowered, the working section of the module will be small, and the polishing section relatively larger. The larger polishing section will aid the removal of the hard-to-remove ions.

CO_2 can be removed by the RO if the pH of the feed is raised (the pK_1 of carbonic acid (H_2CO_3) is 6.35). Hence, with moderately high pH, bicarbonate ion can be removed. Of course, hard cations (Ca^{+2}, Mg^{+2}) must be removed first to operate the RO at high pH.

CO_2 can be removed as a gas after the RO (see Liqui-Cel®), which is helped with low pH (so the CO_2 is not in ionic form).

The pK_1 of silicic acid (H_2SiO_3) is 9.8. The pK_1 of orthoboric acid (H_3BO_3) is 9.3. Only with pH > 10 are silica and boron charged. This is the theory behind the HERO™ membrane process.

In an EDI system, raising the pH of the feed is counter-productive. The addition of NaOH before the EDI simply raises the ion load for the working section of the EDI, and the pH returns to 7.0 by the end of the working section. The size of the polishing section is now smaller. Therefore, we do not recommend raising the pH of the EDI feed.

See Appendix #8 for a more in-depth discussion of silica removal.

Temperature

Pressure Drop vs Temperature

Pressure drop depends on temperature mostly due to the effect on the viscosity of water. The table below shows the absolute viscosity of water (cP) at temperatures of interest, and the relative viscosity (based at 25°C). Pressure drop will increase or decrease proportionally to the viscosity. Note that at 5°C the viscosity of water is 70% higher than at 25°C.

Temperature	**Relative Water Viscosity**	Pressure Drop Factor
5°C (41°F)	**+70%**	1.70
15°C (59°F)	**+28%**	1.28
20°C (68°F)	**+12%**	1.12
25°C (77°F)	**0%**	1.00
30°C (86°F)	**-10%**	0.90
35°C (95°F)	**-19%**	0.81

Stack Resistance vs Temperature

As temperature increases, the resistance of the stack will decrease. At a given voltage, current will increase. One cause of this phenomenon is increased ionic activity at higher temperatures. All other things being equal, the stack resistance will change about 2% per 1°C.

The quality optimization will depend on other factors (below), and so the optimum setting of the voltage will change with temperature.

Quality vs Temperature (re-optimization of operating conditions)

There is an optimum temperature for operation.

As temperature increases to 35°C, product quality will generally increase since ions are more mobile and move more easily. Higher than this, quality will lessen due to increases in ionic "leakage." This is caused by lower adsorption of the ions to the internal ion exchange resins. In addition, the actual ionic resistivity, uncompensated for temperature, will increase and there is less accuracy in the reading (see section below).

- ✓ A lower voltage is required at higher temperatures to move the ions into the concentrate. As a guideline, reduce voltage by 10% for each 10°C above 25°C.

As temperature decreases toward 15°C, product quality may lessen. Some of this is due to errors in resistivity measurement temperature compensation; some improvement is due to the greater adsorption of the ions to the internal ion exchange resin. As temperature decreases further, the activation of diffusion through the membrane will become larger and quality will decrease.

- ✓ At low temperatures, a higher voltage will be needed to continue to split water effectively, and move sluggish ions faster. As a guideline, increase voltage by 10% for each 10°C below 25°C.

Resistivity Measurement Correction with Temperature

Resistivity measurements change strongly with temperature, and are normally corrected to a standard temperature (25°C). Impurity ions in water have a higher electrical conductance at higher temperatures because the ions are more mobile. Similarly, Ultrapure water has a lower electrical resistance as temperature is raised because water dissociates into H^+ and OH^- more.

- ✓ The correction for temperature in the meters is large, and is subject to errors. A high quality resistivity meter is recommended.

The correction for resistivity with temperature for ultrapure water is 5-7%/°C. (The correction for conductivity with temperature for tap water and RO permeate is about 2%/°C.) In both cases the temperature correction is large and large errors may be introduced. Accurate temperature compensation becomes more important as working temperatures are different from 25°C.[5]

Hot DI water is the most difficult to measure accurately.[6]

Temperature, °C	Uncompensated Resistivity, MΩ.cm[7]
15	**31.8**
25	**18.2**
35	**11.1**

- ✓ At low temperatures, a higher voltage will be needed to continue to split water effectively, and move sluggish ions faster.

Flow

Pressure Drop vs Flow

There are three module pressure drops to consider:

1. Feed to Product
2. Concentrate Inlet to Outlet
3. Electrode Inlet to Outlet

The pressure drop will increase on each of these streams as the flow to each is increased. Pressure drop is defined here as measured near the inlet and outlet fittings of the module.

Electrode Pressure Drop: at 0.05 gpm (10 lph) the pressure drop will be approximately 15 psi (1.4 bar). If pressure drop rises much above this, then the inlet may be fouled or blocked with debris. The inlet water must be finely filtered. This flow should be independent of the size of the module and the number of cells since there is only one anode/cathode per module. Note: the electrode pressure drop was reduced for all XL modules in mid-2005.

Nominal Flow (gpm) Electrode	Nominal Flow (lph) Electrode	Normal Pressure Drop Electrode
0.050	10	13-17 psi (0.9 -1.1 bar)

[5] Ultrapure Water, Jan/Feb 1996 (written by Thornton Associates, Inc.)
[6] Ultrapure Water, Dec 1994 (written by Thornton Associates, Inc.)
[7] Ultrapure Water, Jul/Aug 1989

Concentrate Pressure Drop: The concentrate flow will be different for each EDI model, and maybe for each design and each operation. SnowPure recommends the concentrate outlet be set to 10% of the EDI product flow.

If the concentrate pressure drop increases during operation, it may need cleaning or it may have debris in the concentrate inlet. **The inlet water must be finely filtered**.

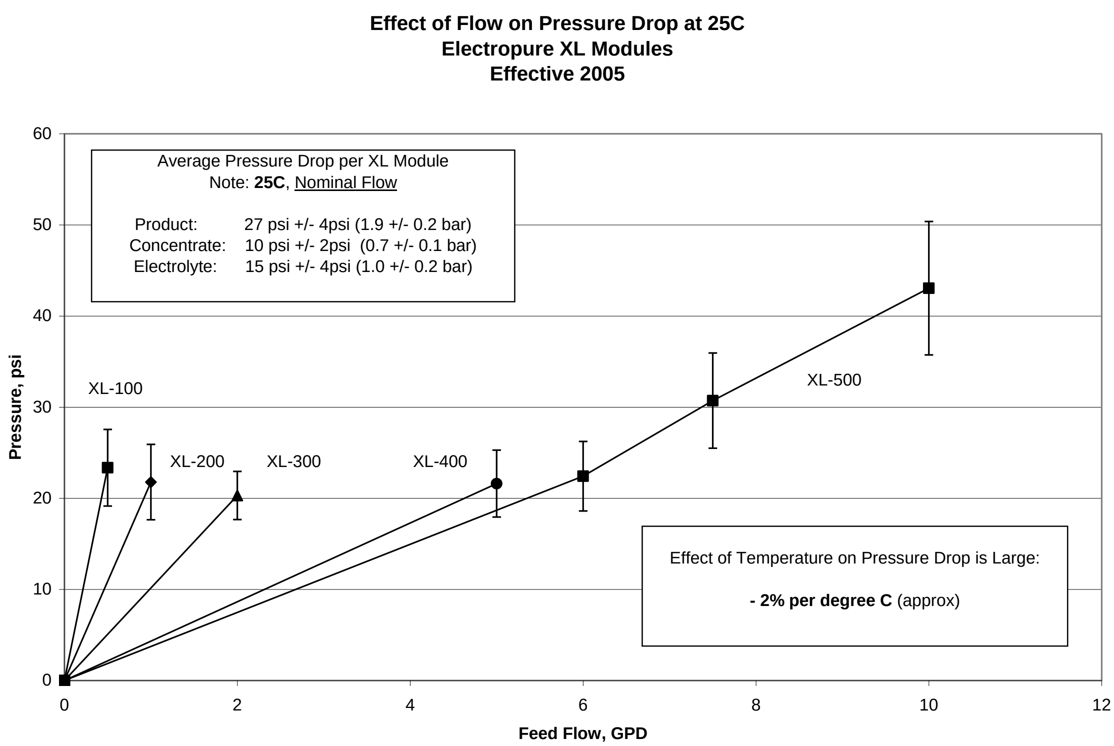
The table below gives estimates of initial pressure drop for the modules.

Model Number	Nominal Concentrate Outlet (gpm)	Nominal Concentrate Flow (lph)	Initial Concentrate Pressure Drop At 25°C
XL-100-R	0.05 gpm	10 lph	5-7 psi (0.3-0.5 bar)
XL-200-R	0.10	20	6-8 psi (0.4-0.6 bar)
XL-300-R	0.25	50	7-9 psi (0.5-0.6 bar)
XL-400-R	0.50	100	8-10 psi (0.5-0.7 bar)
XL-500-R	0.75	200	9-11 psi (0.6-0.8 bar)

Feed-Product Pressure Drop:

The Feed-Product pressure drop increases with flow. The pressure drop is close to being linear (first-order) with flow; that is, twice the flow will cause twice the pressure drop.

Figure 2: XL Pressure Drop



For a new module, pressure drop will be as low as 20 psi (1.4 bar) at the low end of the flow range (e.g., 6 gpm for XL-500-R) or as high as 45 psi (3 bar) at the high end of the flow range (e.g., 10 gpm for XL-500-R).

Figure 2 above shows initial feed-product pressure drop. The measurements are made very close to the inlet and outlet fittings.

- ✓ Pressure drop will change dramatically as the water temperature varies from 25°C.
- ✓ There can be substantial pressure drop in manifold lines. Avoid undersized tubing with metering valves, flowmeters, solenoid valves, elbows, and tees.

Effect of Outlet Pressure on Quality and Internal Leakage

Plate-and-frame modules are sealed with internal gaskets, and there will be some internal leakage. In an EDI module, if the concentrate leaks into the product stream then the product resistivity will suffer.

- ✓ Product Outlet pressure must be greater than Concentrate Outlet pressure.

To ensure that internal leakage does not impact product quality, the product outlet must have a higher pressure than the concentrate or electrode streams outlets. This way, any internal leakage will not add ions to the product stream.

For the simplest, easiest system, there should be no back-pressure applied to the concentrate stream outlet. In systems with valves to manually control the concentrate backpressure, the result is often complication and operator error.

To send the concentrate stream to the inlet of the RO, the outlet is ideally first plumbed into an ambient "break" tank then pumped independently into the RO inlet pretreatment line. When this is done, the EDI module can approach 99% recovery.

Feed Conductivity

Product Quality (at design and maximum flow):

The product quality depends on the ability of the module to remove ions from the purifying chamber before they exit the module. More feed ions will result in lower product quality. This is true for both general ionic conductivity (NaCl) and weak ions (silica, boron, and bicarbonate).

Additional ions add a load that has two results: the first is that the depth of the working bed within the EDI module lengthens—causing the polishing bed to shorten. The initial quality deterioration occurs in lower removal of weakly charged species.

- ✓ Reducing feed conductivity helps improve silica and CO_2 removal.

The second result is that the module current increases as feed conductivity increases. Moving more ions takes more electrons. The current increase is not linear because the current also moves water, which has been split.

- ✓ Increased feed conductivity increases current.

Chapter 5: Water Quality Optimization

Fundamentals

Voltage driving force

There is an optimum voltage for each operating condition. One may apply too much or too little voltage for a specific condition. A typical voltage range is given for each module—the optimum should be in this range.

If the voltage is too low, then the driving force is too low and not enough ions can be moved from the feed stream into the concentrate stream. In addition, water is not being split effectively and the ion exchange resins in the polishing bed section may not be free of impurity ions and fully capable of trapping and moving silica for example.

> When the voltage is initially lowered, the ion-exchange bed within the module will begin to fill with ions until it reaches a steady state. During this time, more ions will be entering than leaving the module. The symptom is that the concentrate will not have as many ions as normal. Steady state may take 24 hours to achieve—during this time, product resistance will decline slowly.

If the voltage is too high, then too much water is split and the voltage driving force becomes ineffective. A symptom of this is excess gas production in the electrode stream, and excess current draw. Excess voltage also causes a phenomenon called "concentration back-diffusion". In this state, ions are forced to diffuse from the concentrate streams into adjacent purifying chambers to achieve electrical neutrality.

> When the voltage is initially raised, the ion-exchange bed within the module will begin to discharge ions until it reaches steady state. During this time, more ions will be exiting than entering the module. The symptom is high conductivity in the concentrate stream. Steady state may take 24 hours to achieve. During this time, product resistance will improve slowly.

Current densities

The current density in the **working** section of the bed (lower portion of the EDI module) is high, caused by movement of the primary ions in the feed. There is relatively high electrical resistance in the concentrate stream since the water there is RO-quality water with 1-20 µS/cm.

In the **polishing** section of the bed (upper portion of the EDI module), the concentrate stream is full of the ions it picked up in the working bed. At 90% recovery, the conductivity will be about 11 times the feed concentration. It can therefore be in the range 11-220 µS/cm. The voltage drop is now higher across the resins in the purifying chambers (where there are very few feed ions remaining). The net result is a higher rate of splitting water and higher concentration and transfer of protons (H^+) and hydroxyls (OH^-) in this region. This results in better polishing, better removal of carbon dioxide and silica, and higher product resistivity.

The product quality is optimized if the module is in balance and does not have extreme internal current densities. The quality of the continuous regeneration of the polishing portion of the bed is critical for achieving the highest resistivities.

Ionic balances and pH

Electrical neutrality must be maintained on an ionic level. It is not possible for more cations to diffuse than anions.

Because of this, counterions matter highly. If the ions in the feed are made up of a highly mobile cation and a slow anion, then the EDI "kinetics" will adjust to the rate of the slowest ions. In addition, the mobile protons (H^+) and hydroxyls (OH^-) will play a role in adjusting the ionic balance. If there is a large mismatch in the ions in the feed, then there will be large pH shifts between the product and concentrate streams. The quality will not be optimized.

Therefore, pH highly influences quality. At lower pH, excess protons will diffuse as the counterions to the feed anions. The feed cations will not be as effectively removed.

At higher pH, there will not be protons to act as fast counter-cations. However, the carbon dioxide will be more highly charged (carbonate) and therefore more mobile. The silica, too, is more charged and mobile.

The recommended pH for optimal operation is 7.0 with minimal CO_2 present.

Affecting the location of the "ionic front"

As said above, the location of the ionic front (the interface between the "working bed" and the "polishing bed" sections of the EDI module) is important to the quality of the product.

For the highest resistivity water, and the lowest silica, the variables must be set to maximize the depth of the polishing bed.

- ✓ The ionic load must be minimized.
- ✓ The product flow rate should be at the high end of the given range.
- ✓ The voltage should be at the optimum (not too high or too low).
- ✓ The concentrate outlet flow should be correct (e.g., 90% recovery) to effectively remove ions from the surfaces of the membrane in the concentrate chambers. This will also use more of the applied voltage across the critical purifying chambers.
- ✓ The load of carbon dioxide should be minimized.
- ✓ The pH should be at 7.0.

To save energy, if lower quality water is sufficient for the application, one can extend the depth of the working bed and limit the depth of the polishing bed. This is achieved by:

- ✓ Lowering the voltage.
- ✓ Lowering the concentrate flow (higher recovery)—this lowers the resistance of the stack. This can also be achieved with concentrate recirculation or salt injection. Note: the risk is hardness scaling in the concentrate.

Chapter 6: System Design Schematics and Safeguards

The system design is the responsibility of the OEM.

Our goal in this section is to lay out how one can put together a system with the proper features and components. If the OEM chooses not to include equipment or controls in order to drop the cost, then it is at its own risk. Important factors include:

- EDI pretreatment (feed water quality control)
- system protection and controls
- system design for easy operation
- minimum required system components
- optional system components (and the benefits)
- design for safety

The optimum system depends on the customers' need. Some systems will be optimized to provide 10 MΩ.cm water at the lowest capital cost, and some systems will be optimized to provide the highest resistivity and the lowest silica.

Electropure EDI Pretreatment Philosophy

<u>Pretreating the feedwater for the EDI is extremely important</u>.

Module lifetime, module performance, module maintenance frequency, and the cost of power all depend on the impurities in the feedwater. Pretreatment is as important for the success of the EDI as it is for the success of the RO. See the EDI feedwater specifications.

Module cleaning frequency is minimized by providing better pretreatment for the EDI. This includes minimizing fouling organics (TOC), scaling hardness (Ca^{+2}), and fine particulates. The decisions on pretreatment level will be a capital-operating cost decision between the OEM system designer and their customer.

Electropure EDI Simple System Philosophy

<u>Electropure EDI believes that a simple EDI system serves the customer best</u>.

A simple RO-EDI system (with no EDI concentrate recirculation) avoids excess costs and makes the EDI more robust and more reliable.

Electropure EDI modules are designed such that all streams may be fed directly from the RO, assuming it produces 1-20 µS/cm. Because of this, a very simple EDI system can be designed and built.

The more complicated systems with concentrate recirculation require control of conductivity, circulating flow, and the balancing of pressure. These require a pump, valves, conductivity- and flow-meters, and possibly a softener. A brine injection system may seem advantageous, but requires the maintenance of a chemical source, and lessens the "no-chemical-addition" benefit of EDI.

Problems associated with concentrate recirculation include the buildup of all ions which include scale-forming ions such as Ca^{+2}, SO_4^{-2}, silica, etc. A circulation system may also harbor bacteria and require a UV (254 nm) system.

EDI System Protection and Controls

To protect the EDI module(s) and to ensure long lifetime, automatic system protections are necessary. Some are simply good engineering. The most critical protection is preventing the application of power to the module without water flow. Non-compliance with this rule will certainly result in irreversible damage to the EDI module. The critical measurements and alarms are:

1. **Electrode flow above a Minimum**
2. **Concentrate flow above a Minimum**
3. **Product flow above a Minimum**
4. **RO is operational**
5. **RO conductivity is below a Maximum**
6. **Temperature is within limits**
7. **Pretreatment all working properly (no alarms)**

Below is a list of the components typically used in an optimum RO-EDI system. Beyond that find a typical P&ID (process and instrumentation diagram) for a single-module system. For multiple modules, the modules are plumbed and powered in parallel—the rest of the concepts are the same.

Component Description of an Optimum EDI System

These descriptions relate to the P&ID following this section.

Activated Carbon: Removes chlorine and some chloramines from feed water to protect the reverse osmosis membranes, ion exchange resins, and ion selective membranes from chemical degradation. It also removes many organic solvents and pesticides, preventing them from passing through to the RO membranes and into the EDI modules.

Softener: Removes hard cations from the feedwater (Ca^{+2}, Mg^{+2}) in order to prevent scaling in the RO and the EDI. Softening allows higher recovery in the RO system. Softening also allows the feedwater pH to be raised in order for CO_2 and silica to be more effectively removed in the RO and EDI. Will also remove iron (Fe) and other transition metals that catalyze the oxidation of the PA membranes and bind irreversibly to the resins in the EDI.

- ✓ Note that the use of chemical anti-scalant in the RO increases the hardness passage through the RO membrane, and this is fed to the EDI. To minimize EDI cleaning frequency, the EDI feed hardness should be minimized.

Sediment Filter: Removes undissolved matter from feed water to prevent the reverse osmosis membranes from fouling.

Gas Removal Module: For the highest quality resistivity, gases should be removed from the EDI feedstream. Of particular importance is removal of CO_2. Lower levels of CO_2 will allow the EDI module to remove silica (SiO_2) more efficiently. The gas removal module may be a gas-transfer membrane unit such as Liqui-Cel®. Best placed after the RO, but may be before. These can be purchased as an option from SnowPure.

Reverse Osmosis System: Removes the bulk of dissolved salts and organics. When properly maintained, an RO system can reject up to 98-99% of the ions and TOC. Proper RO pretreatment is critical for low-maintenance EDI operation. The membranes will most likely be high-rejection thin film composite (TFC). Reverse osmosis splits the RO feed water into two streams—product water and concentrate water. Only the product water is fed into an EDI module. The RO concentrate has too much hardness and other impurities.

Pressure Regulators: Used to regulate the applied pressure to the reverse osmosis membrane, and to the EDI module.

Pressure Gauges: Measure the operating pressures of the RO and EDI streams. See specifications for minimum and maximum operating pressure.

Sample Valves: Small "testcocks" valves allow a person to sample the water in the system during normal and troubleshooting times. Recommended to sample from both product and concentrate streams, ideally from the concentrate of each module in a multiple module system.

Flow Meters: Measure the flow rates of the various streams. May send signals to a controller.

Flow Switches: Ensures that the EDI unit receives power only when water flow is present. If too little or no water is flowing to the EDI module, the flow switch would cause the system to shutdown. This can be done directly with the power supply interlock system or through a controller. See SnowPure for detailed schematics.

Conductivity Monitors: Measure and display the quality of the product from the RO and EDI components. The RO product is typically measured in conductivity (µS/cm) or total dissolved solids (ppm), and the EDI product is typically measured in resistivity (MΩ.cm). The monitor may interface with the controller as part of the system's protection mechanism. These meters may be purchased as options from SnowPure.

Controller: Optional system to control startup and automatic operation. May control the power supply directly. May include EDI control algorithms to optimize EDI performance. Should include protection schemes to shutdown power if any of the EDI flows are low. Should alarm if RO conductivity rises above a set point, or if EDI resistivity drops below a set point. In autoflush mode, should divert RO product to drain until initial conductivity quality is attained—this prevents the EDI from being overloaded with ions and reduces EDI maintenance. May have other safeguards based on customer need. May communicate with a master factory controller.

Power Supply: Source of DC power for the potential across the EDI module that drives deionization. Should be current limiting, and be capable of being shut off by the system controller or directly through an interlock system. To protect the EDI module(s), power should be shut off if flow to any of the EDI module streams is below a set point.

Pressure Relief Valve: Protects against excessive pretreatment pressure fluctuation.

EDI Module(s): Act as a polisher by means of SnowPure's electrodeionization technology. It splits the RO product flow into two streams, EDI product and EDI concentrate. There is a small (0.05 gpm) EDI electrode stream that goes to drain. EDI modules may be operated in parallel for greater flow.

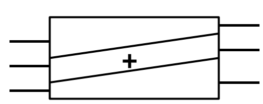
- ✓ The EDI concentrate may be diverted back to the RO feed (option 1) or it may be reclaimed for other uses, or sent to drain (option 2). There is no need to recirculate the concentrate—one time through makes for a simple system.

- ✓ The pressure of the EDI product should be higher than the EDI concentrate to prevent back-leakage and loss of quality. It is recommended to use (diaphragm or needle) valves and rotameters upstream of the EDI module to control concentrate and electrode outlet flows. Upstream valves minimize downstream outlet pressure. When set properly these controls help maximize efficiency. It is very important to remember that any back pressure will have an effect on product quality and if too great, damage may occur.

Gas Vent: Note that the electrode waste stream contains water and gas. The gases include Cl_2 (mostly dissolved), H_2, and O_2. These must be vented safely. This is the responsibility of the OEM and customer. Note that the LEL (lower explosion limit) of H_2 gas is 4% (v/v) so the gases must be dispersed with proper dilution. Normal margin of safety is 25% of the LEL, or under 1% (v/v).

P&ID Designation for an EDI Module

The symbol for an EDI module in a P&ID has not been defined to date. The symbol below is proposed. This is similar to an RO module symbol yet reflects the several plumbing connections and the electrical nature of the EDI module.



This symbol would be connected in the following manner in a P&ID:

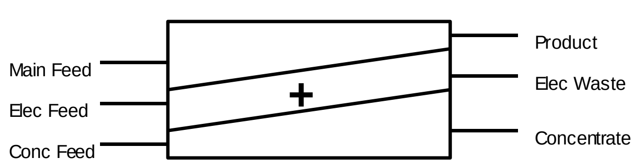
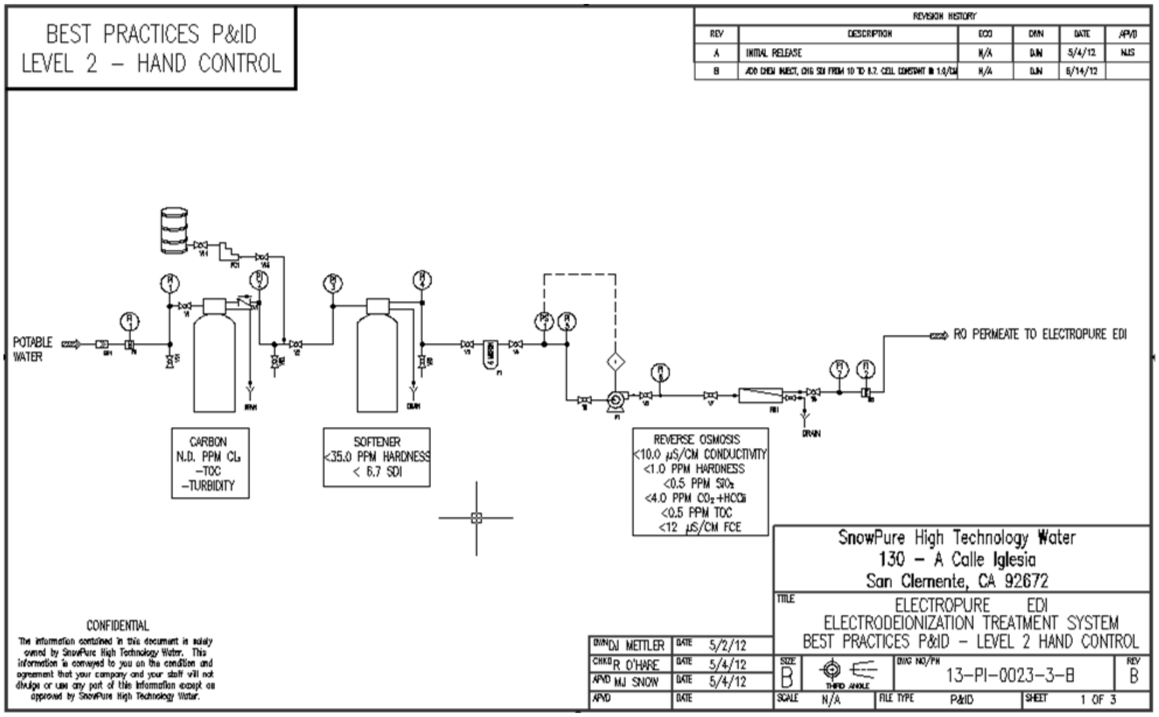
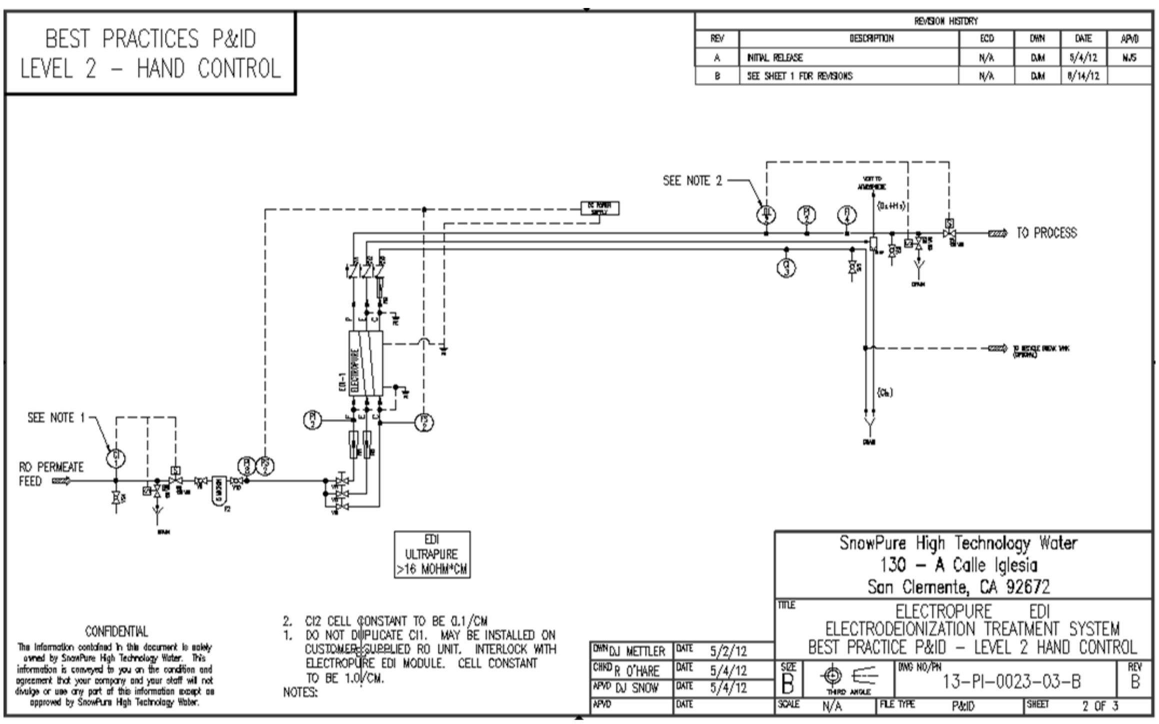


Figure 3: Best Practices P&ID of a Simple EDI System





Note: SnowPure will provide 4 levels of BP P&ID's in .dwg form to its Qualified OEM customers.

Designs with Multiple Modules

Multiple modules can be installed on a skid in a parallel array to achieve a higher flow system. This concept allows virtually unlimited flow.

All Electropure modules of the same model will have similar hydraulics. Because of this the feed, concentrate, and electrode may be manifolded to feed multiple modules with a single piping system. Pressure drop variation between modules should be less than +/- 15%.

The manifold design should be such that all modules see the same inlet pressures and therefore produce the same feed flow rates. Where possible, the manifold should be symmetric. Electropure recommends that manifold piping be properly sized to minimize pressure drops in the manifolds.

Flow switches can be installed at each module to alert for alarm conditions (above). Alternately, a single flow switch can be used in each of the three main feed streams to the module skid. If multiple, independent flowstreams are present, a flowswitch should be installed in each.

Power can be applied in parallel. A single DC power supply or rectifier with voltage control can operate multiple modules in parallel. It is recommended that current be measured for each module as a monitoring device. With a single module, the current-limiting feature will protect the module; with multiple modules attached to a single power supply the current to each should be fused and may be alarmed.

Sampling valves (testcocks) on the outlets of each module (concentrate and product) are helpful in diagnosing the performance of individual modules on a skid.

SnowPure provides Best Practices (BP) P&ID's for multiple module systems to its Qualified OEM Customers in .dwg format.

Designs with 2-Pass RO Systems

Both 1-pass and 2-pass RO can be used to feed an EDI system.

1-pass RO systems have the benefits of lower cost and lower complexity, and are good for most EDI applications. If CO_2 is high, then RO-GTM-EDI makes a perfect, chemical-free, all-membrane purification system. 1-pass RO is often used for pharmaceutical and general industrial applications.

2-pass RO systems have the benefits of much greater purification, and inherent removal of CO2 and hardness and silica and TOC foulants. After 2-pass RO, the EDI systems need very little maintenance, and have the highest performance. 2-pass RO is often used for power plants and electronics, where silica levels are critical.

The conductivity of a typical 2-pass RO system is often around 1 µS/cm. If the feed to the EDI is too low, there may not be enough conductivity for the concentrate to function properly, leading to high stack electrical resistance.

- Rules of thumb: If the RO permeate (feed to the EDI) is 1-5 μS/cm, operation can continue with no problem. If the RO permeate is under 1 μS/cm, some special system configurations might be considered. The goal for the concentrate outlet should be ideally 10-100 μS/cm. A mass balance on the system can be used to calculate the concentrate outlet based on the recovery and the inlet concentrations.

In order to optimize the design of a 2-pass RO-EDI system with less than 1 μS/cm, there are several system design options:

1. Feed the concentrate and electrode streams with permeate from the 1st pass RO (e.g., > 5 μS/cm). Or, feed the concentrate and electrode streams with concentrate from the 2nd pass RO (e.g., > 10 μS/cm). The choice of which depends on the conductivities of each, and the concentrations of the impurity ions in each.
2. Inject NaCl brine (good salt[8]) into the concentrate/electrode streams to a level around 10-100 μS/cm based on achieving 40-100 μS/cm in the concentrate outlet—this is generally not an ideal system because of maintenance costs.
3. Circulate the concentrate stream with a feed-and-bleed system. This is not recommended since NaCl injection is simpler and better, and avoids buildup of hard ions which results in scaling, and concentrate recirculation may also lead to bacteria outbreaks in the loop.
4. Remove the 2nd RO pass entirely, or install it in parallel with the 1st RO pass to increase capacity (RO-EDI).
5. Install the 2nd RO pass after the EDI as a final membrane barrier in USP24 water-for-injection applications (RO-EDI-RO).

Installation Notes

Safety

Please read and understand the Safety Section of this manual before installation.

Please **train your colleagues** regarding the safe design and operation of EDI modules. Key safety topics are the use of electricity around water, and the handling of the gases produced at the electrodes.

Handling the Module

The module is designed to be compact and lightweight. However, **do not lift by the plumbing or electrical connections**. Do not lift by the end covers. There are 8 lifting and mounting points on the aluminum frames.

Mounting Options

See the “Mounting Methods” drawing in Chapter 10.

[8] If NaCl brine is used, it must be of the highest quality and must have few impurities. Iron and silt are present in cheap “rock salt”, which must be avoided. Often “silica” is added to “salt” to allow the crystals to “flow”. These can be harmful to the EDI module over time.

Mount the modules so that the face bolts are accessible for periodic torqueing with a torque wrench.

The module can be mounted in different ways. The most popular way is to install L-or U-brackets on the skid, which provide a secure track for module to sit in. The module may be mounted on a single, central rectangular rail. The module is then secured at the top via either two of the mounting holes on the top. The module may also be suspended by 3/8" rods through the same four holes on the top.

> ► Do not bolt both the front and rear of the module to fixed points as this can constrain and stress the module hardware during torqueing. One of the endplates needs to be able to move to allow unrestricted torqueing.

Module Orientation

SnowPure's EDI modules are designed to be installed in an upright, or vertical, position. Gases can become trapped in the chambers and interfere with ion removal if mounted in a horizontal position.

Pipe and Tubing Connections

The standard modules are provided with 1" female pipe thread (FNPT) fittings for the main feed and the product. These connections are made of high strength engineering plastic.

It is very important that the threads are protected before installation to prevent damage and subsequent leaks. Secure the fittings with a tool to prevent twisting them during threading. If the fittings are not "backed up" during tightening, they may crack and need to be returned to the factory for repair.

Use Teflon® tape or pure TFE paste for sealing the threads. **Do not use pipe dope (sealant) made for metal threads as it often contains solvents that will weaken the polymer fittings.** Even "FDA-approved" pipe sealants contain these solvents. The use of pipe dopes with solvents will void the SnowPure warranty. SnowPure has some approved pipe sealants that do not harm the EDI materials.

Do not over-tighten the threads. Starting with the second full thread and continuing over the length, wrap Teflon thread tape in the direction of the threads. Overlap each wrap by one-half the width of the tape. Screw the male fitting into the 1" female port (be sure to backup this fitting) on the module and tighten by hand. Using a strap wench only, further tighten the connection an additional one to two threads past hand tightness. Avoid excess torque as this may cause manifold or fitting damage. Read the full threading instructions accompanying the module.

1" Sanitary Quick-Disconnect connections are an option. This product option comes with two 1" Sani-tech™ flange fittings, complete with endcaps for protection, Buna-N seals, and True Union clamps.

The tubing connections for the concentrate and electrode are 3/8" and 1/4" (see module drawing), and are push-in-type, self-sealing connections. The electrode outlet tubing is colored "yellow." A metric tube conversion kit is available as an option.

See the drawings in Chapter 10.

Grounding

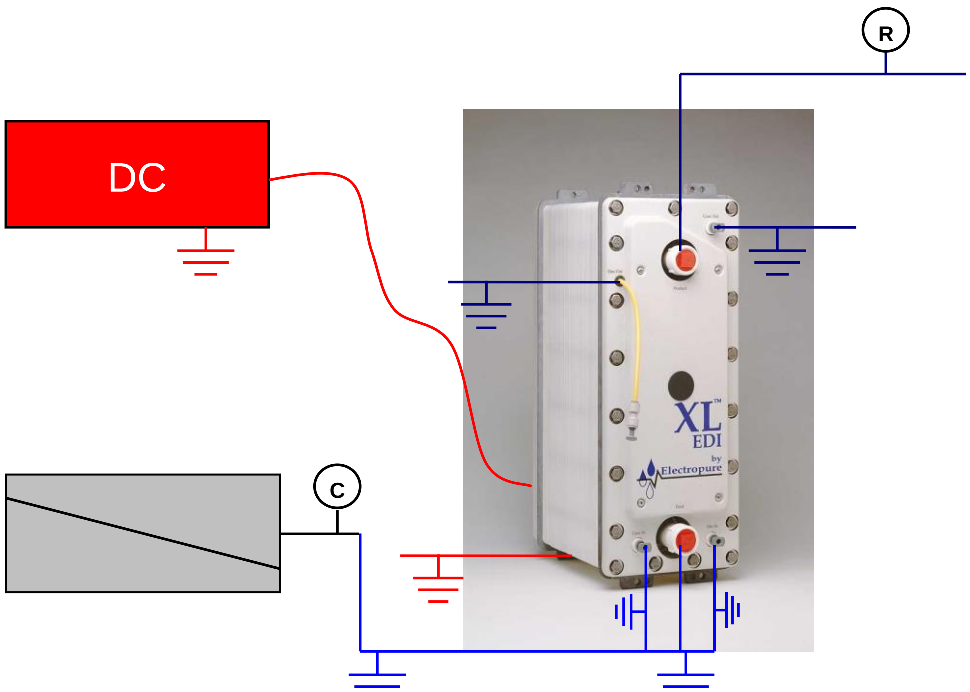
Two types of grounding are very important for the EDI.

The module itself is grounded to the frame via the mounting, and to the power supply through the main DC electrical connection. All conductive parts of the module are grounded together to the green wire of the connection. This should be grounded to a suitable ground by a qualified electrician.

Since the water streams are also conductive, current can flow through the water stream to ground. It is good design to provide a "T" plumbing connection in the various feed and outlet streams, through which a conductive piece can be connected directly to ground (e.g., stainless steel rod with wire attached).

Note that electrical measuring devices, like conductivity and resistivity probes, can give erroneous readings if their streams either measure stray current/voltage or measure resistance to ground via the conductive piece.

The DC power supply may contain high- or low-frequency AC component (ripple) which should be measured.



Power Connection & Wire Conventions

The DC power supply needs to be properly connected to the anode and cathode of the module. The anode, which attracts anions, is (DC+) and the cathode, which attracts cations, is (DC-). The voltage difference between the two poles generally may float relative to ground, and this depends on the design of the power supply.

The **(o) ground** is always **GREEN**.
The **(DC-) Cathode** is **BLACK**.
The **(DC+) Anode** is **WHITE or RED**.

The connection between the module and the power supply is a water-tight gold-plated, three-connector fitting. The module is provided with a keyed male fitting at the bottom of one face of the module. A 12 foot (4 meter) power cord, with female connections, is provided with each module. The GREEN (ground), BLACK (DC-), and WHITE/RED (DC+) wires at the end of the power cord should be connected to the appropriate terminals and ground of the DC supply. A 30-foot (10 meter) optional cord is available as an option.

Bolt Torque

Bolt torque is extremely important for the XL series to maintain high product resistivity and to prevent leakage. EXL does not typically need to be torqued.

The XL bolts require a 9/16-inch socket. Use of a 14-mm socket is possible, but may be slightly undersized. The EXL modules use 19-mm sockets (3/4”).

Plate-and-frame devices often require torqueing for proper sealing. If the modules become loose, water from the concentrate can leak and form crystals. It is the customers’ responsibility to prevent leakage and crystal formation. Electropure XL modules are equipped with special spring washers to help maintain torque between maintenance cycles. EXL modules are equipped with permanent internal o-rings to prevent external leaks.

The XL bolts should be torqued at the following times:

1) After it has been mounted to the skid
2) Before operation at the customers' site
3) After water pressure has been applied
4) Periodically (weekly) for the first month until all of the internal plastic parts have fully compressed, and
5) Whenever the product quality declines slightly.

The module is torqued at proper levels at the factory before shipping. After the module is installed and before the module is operated, the torque should be reset per the procedure in the technical manual. Torque only when there is no water flow to the module. It is important to use the torque sequence in order to prevent distortion of the hardware and to assure an even internal pressure level.

► Torque the bolts only when the module is depressurized. If there is internal pressure during torqueing, the level of torque will incorrect.

Too much torque will result in deformation of the stack. Too little torque will result in internal and external leaks, and poor EDI performance. The recommended torque for most XL modules is 20 ft-lbs (27 N-m). Maximum torque for HTS modules is 10 ft-lbs (13 N-m). Failure to follow maximum torque recommendation can result in severe damage to the module hardware.

Recommended Torque Settings:

Module	Target Torque
XL (all)	**20 ft-lbs (27 N-m)**
XL-HTS (all)	**10 ft-lbs (13 N-m)**
EXL (all)	**20-25 ft-lbs (27-33 N-m)**

Failure to keep the torque at the minimum can result in irreversible leakage and the formation of corrosive crystals formed from leaking concentrate.

It is important to use the torque sequence in order to prevent distortion of the hardware and to assure an even internal pressure level.

With good torque method and sequence, the endplates will remain parallel. Avoid “bowing” the endplates. Change the torque level slowly and evenly, in small increments. Take care to stop torque wrench rotation when each bolt reaches the required torque, do not over-rotate (or over-torque) individual bolts since this will cause adjacent bolts to loosen.

Module Startup

The key to proper startup is to run as little water through the modules as possible during the plumbing checkout before applying power. The more water and ions that go through the modules the longer the initial regeneration procedure will be.

1. Make all mechanical, plumbing, and electrical connections.

2. Ensure that there is a Y-trap or filter just before the EDI system. This will prevent construction debris from entering the EDI modules. If the EDI is fed from a separate tank, the prefilter should be very fine to prevent silt from entering and fouling the modules.

3. Have data sheets and a startup notebook on hand. Record initial data and any observations. Call Technical Service at SnowPure with any questions.

4. Bleed all air out of plumbing system by first filling the manifold(s) and modules slowly with water, then pulsing water to all three streams to knock bubbles loose. The manifold(s) should be designed to have no dead legs that can trap air. Removing the air at startup is important because airlocks in only some of the modules will prevent all modules from getting the same flow of water.

5. Check all plumbing connections for leaks and repair.

6. Apply DC power after as little time as possible. If too much water (with ions) is sent through the module(s) before power is supplied the excess ions will need to be removed with a longer regeneration procedure.

7. Check to be sure all three (3) streams for all modules are flowing at the recommended, design flows.

8. Check that the pressure drops of all three (3) streams are approximately correct.

9. Check all modules for startup current. The amperage may be higher than normal on startup and should drop to a nominal level within 1 hour. All modules should have similar currents to one another.

10. Check that the ion concentrations in the concentrate streams are all high. If the module(s) are running at 90% recovery, then the concentrate should have about 10 times the concentration of the feed. Perform a mass balance on the inlet and outlet ions to determine if the module(s) are regenerating (excess ions in outlet) or underpowered (too few ions in outlet).

11. Check all system permissions and interrupts. Check all flow sensors to ensure that minimum flows are set properly and the correct signals are presented to the control system.

12. If not immediately, then after about one (1) hour, the product resistivity should rise to the proper level. If excess ions were introduced during the startup procedure, then a regeneration cycle may be required before quality is achieved.

13. Check torque in the un-pressurized state (with no pressure) and re-adjust. Follow up with the recommended periodic torque procedure.

14. Leave a maintenance manual at the site with the customer.

Chapter 7: Cleaning and Maintaining your EDI Modules

Feed Water

Electropure's EDI feed water specifications are designed to minimize any maintenance that the module may require for normal and sustained operation. Some service may be required if substandard feed water is introduced to the module and/or insufficient power is applied during operation.

Key foulants are TOC, hardness, silt particles, and iron.

Hardness (scale) deposits

If feed high in specific solutes is introduced into the EDI, deposits (hardness scale) may form within the concentrating compartments, and consequently, product water quality will diminish. Water high in hard ions (Ca^{+2}, Mg^{+2}), dissolved CO_2, and high in pH contributes to rapid scaling. To remove carbonate scale, the concentrate stream must be cleansed with an approved acid solution. See Appendix #1 for procedure for acid cleaning.

Ion-exchange resins (TOC organic fouling)

Feed water containing organic (TOC) contaminants will foul the ion-exchange resins and membranes with a film that can deleteriously affect ion transfer rate, and therefore product water quality. When this occurs, the purified stream must be cleansed with an approved non-ionic organic remover. This may be either an approved non-ionic surfactant or an approved caustic based cleaner. See Appendix #2 for procedure for organic cleaning.

Particulate fouling

Coarse debris in the EDI feed will block portions of the flow distribution, and unequal distribution of water within the module will lead to lower performance. Fine particles (e.g., silt) in the EDI feed will foul the resins and the concentrate streams. A very fine filter is recommended before the EDI especially if the EDI is fed from an RO tank and not directly from the RO permeate. A good, strong water flush of the plumbing before installation of the EDI modules should prevent debris from entering the modules. See the feedwater specifications for particulates.

Power and Regeneration

If an EDI module operates without power or with insufficient power, the resin beads and membranes can become saturated with ions and the purity of the product water will diminish. To purge the resin of ions, initiate the flow of water through the module and gradually increase the voltage of the power supply. The module will draw more current than normal as ions are transported out of the system and the resins are regenerated. Caution: care should be taken not to exceed the output limitations of the power supply if over-current protection is not provided.

Electrode Connectors

The electrode connectors should be periodically inspected for corrosion or loosening caused by ambient conditions. This would add resistance to the stack and impede the current flow, resulting in decreased quality of product water. Further effects could result in the same conditions associated with insufficient power as mentioned above.

Bolts

The bolts that secure the cells and endplates together are factory-set at 27 N-m (20 ft-lbs) of torque. After some period of time, it will be necessary to reset the torque. Check and retorque the bolts:

1) after it has been mounted to the skid,
2) before operation at the customers' site,
3) periodically **(weekly)** for the first month until all of the internal plastic parts have fully compressed, and
4) whenever the product quality declines a little.

Too much torque will result in deformation of the stack. Too little torque will result in internal and external leaks. Be sure to torque evenly to keep the ends parallel.

See Appendix #3 for procedure for torqueing bolts.

Exterior Cleaning

If the exterior of the module needs cleaning please:

- ✓ Do not use acetone or any solvent except water.
- ✓ Turn the electrical power OFF for safety.
- ✓ Use only a damp cloth, perhaps with a light, mild detergent.
- ✓ Do not rub as to remove the safety stickers.

Chapter 8: Problem Solving and Troubleshooting

Trouble-Shooting Guide		
PROBLEM	POSSIBLE CAUSES	CORRECTIVE ACTION
Product Water Resistivity Low	**Power:** (1) No power at electrodes. (2) Voltage set too low or too high. (3) One electrode connector loose. (4) Polarity of electrodes reversed.	Activate power supply and check voltage at electrodes. Ensure correct polarity and continuity.
	Water Flow: (1) Flow of water through module below minimum. (2) Flow of water through module above maximum.	Readjust concentrate & electrode valves, and feed water pressure.
	Feed water: not to specifications.	Check RO product quality, especially TDS, Cl_2 and CO_2.
	Module: fouled or scaled.	Clean module according to Appendix #1 or #2.
	Torque: too low.	Retorque per Appendix #3.
Product Flow Low	**Purifying stream**: fouled.	Check organic (TOC) contaminant concentration in feed water. Is there a y-trap or filter to prevent debris from entering EDI?
	Feed water pressure: too low.	Increase feed water flow rate. Clean module according to Appendix #2.
	Temperature: too low.	Note viscosity of water at feed temp
Concentrate Flow Low or Off	**Valves:** incorrectly set.	Increase flow through valves.
	Concentrate streams: scaled.	Check RO product for hardness, CO_2 pH. Clean module according to Appendix #1.
Module Emits Too Much Gas	**Voltage:** set too high.	Reduce voltage.
Product Water pH High or Low	**Voltage:** set too high.	Reduce voltage.
Module Draws Excessive Current	**Conductivity** too high in feedwater	Check TDS of RO product.
	No flow of water through module.	**Ensure flow of water through module, otherwise it will be destroyed!**

Chapter 9: Auxiliary Equipment and Options

Option: Quick disconnect, sanitary fittings. Option comes with 1" Sani-Tech^{tm} Sanitary Fittings on Feed and Product Ports, rather than 1" threaded female FNPT. Includes sanitary cap, seal, and clamp. Similar to Tri-Clover^{tm} fittings.

Option: Stainless Steel Covers. Module comes with brushed stainless steel face covers, rather than standard covers.

- ✓ Ideal for Showcase and Demo EDI systems.
- ✓ Ideal for Pharmaceutical installations.

Option: Longer power cord (30 feet/10 meters) available. Standard cord is 12 feet (4 meters) long (3-wire).

Option: DC Power Supplies. A variety is available.

Option: Liqui-Cel® Membrane Contactors. For removing CO_2 gas from EDI feedstream. Call SnowPure for literature and pricing.

Option: Resistivity and Conductivity Meters. Include alarms and relays.

Option: Flowswitches. Designed for modules to open the circuit when flow drops below a specified level. Come passive or with a relay circuit.

Option: Flowmeters. Designed for modules. Rotameter type for single module systems.

Option: Torque wrench, including correct socket.

Option: XL Metric tubing conversion kit. Converts ¼" and 3/8" standard tubing to metric tubing for all XL tubing connections.

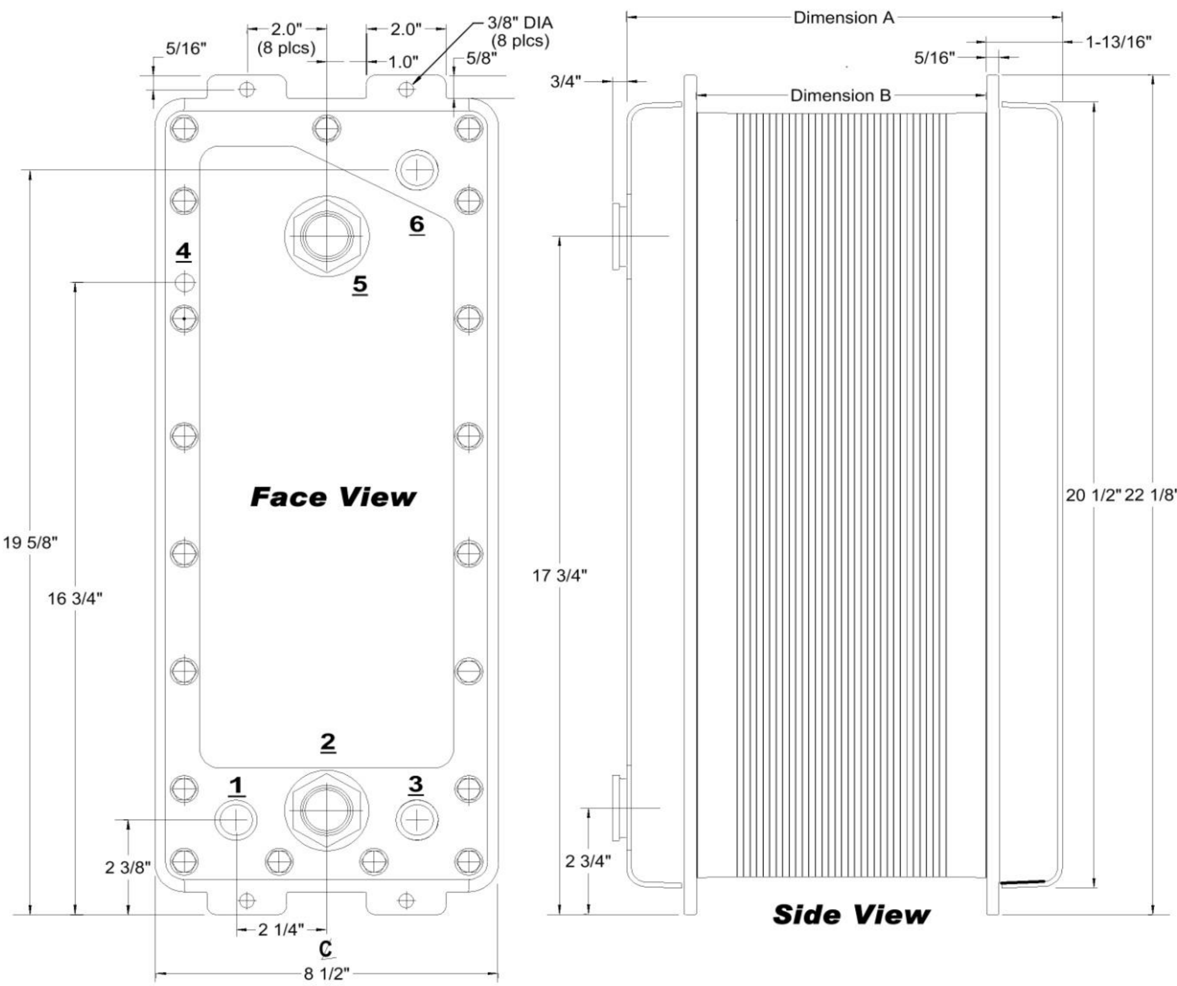
Option: +GF+ union halves that match the EXL feed and product adapters.

Speak with Customer Service at SnowPure for pricing and availability.

Chapter 10: Electropure Module Dimensions

Figure 4: XL™ EDI Module Drawing & Dimensions

EDI Module Dimensions (XL, XL-R)



Flow Connections (Pipe and Tubing Size)
1. Concentrate Inlet 3/8" Tube (Push In Fitting)
2. Feed Inlet 1" FNTP
3. Electrolyte Inlet 3/8" Tube (Push In Fitting)
4. Electrolyte Outlet 1/4" Tube (Yellow)
5. Product Outlet 1" FNTP
6. Concentrate Outlet 3/8" Tube (Push In Fitting)

Model	(dim A)	(dim B)
XL-500	14.5" (370mm)	11.0" (280mm)
XL-400	11.5" (290mm)	8.0" (200mm)
XL-300	10.0" (255mm)	6.5" (165mm)
XL-200	7.5" (190mm)	4.0" (100mm)
XL-100	6.5" (165mm)	3.0" (75mm)

Dimensions +/-0.2" (+/-5mm)

Electropure EDI
February 29, 2008

Figure 5: EXL™ EDI Module Drawing & Dimensions

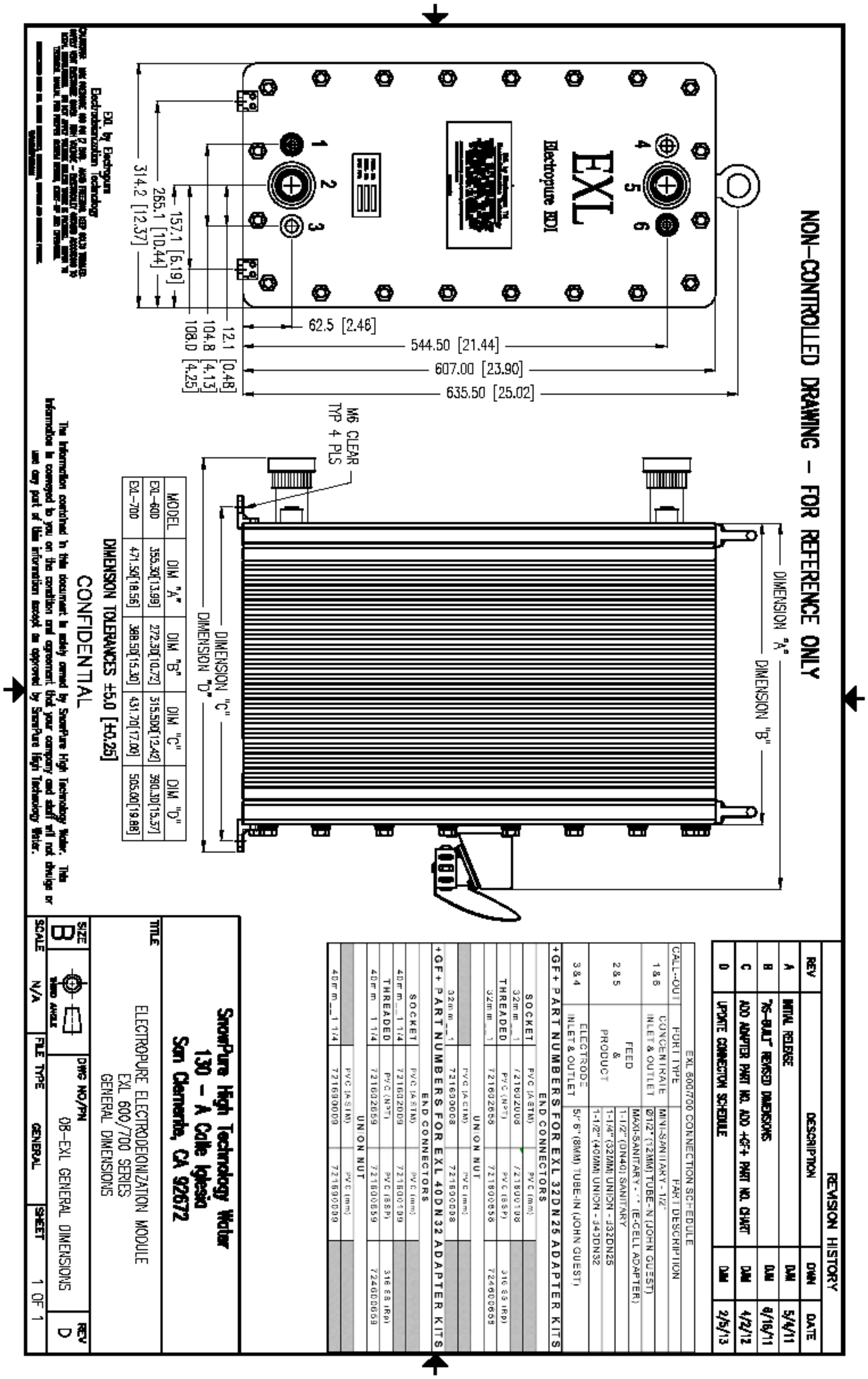


Figure 6: XL Mounting Options

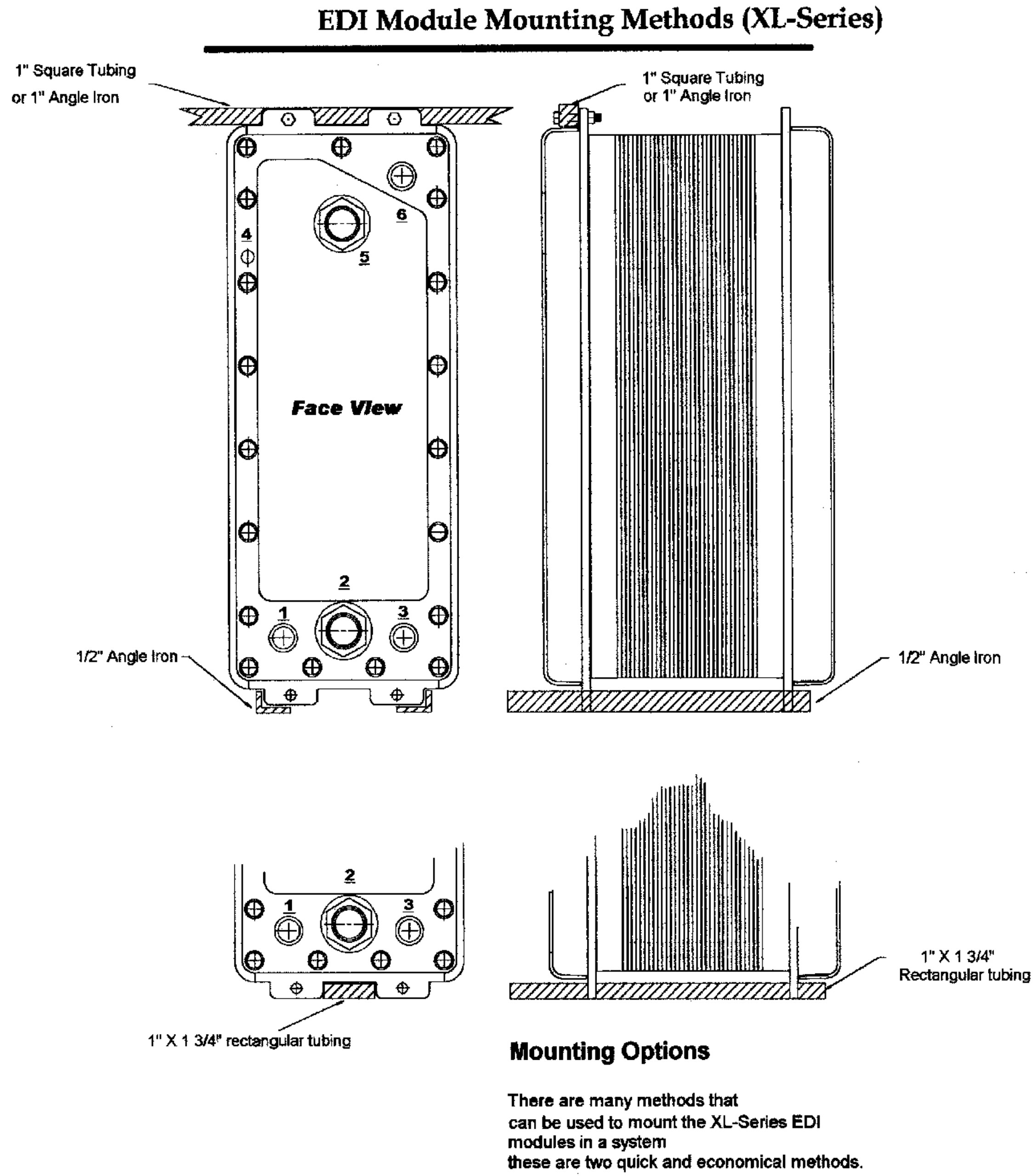
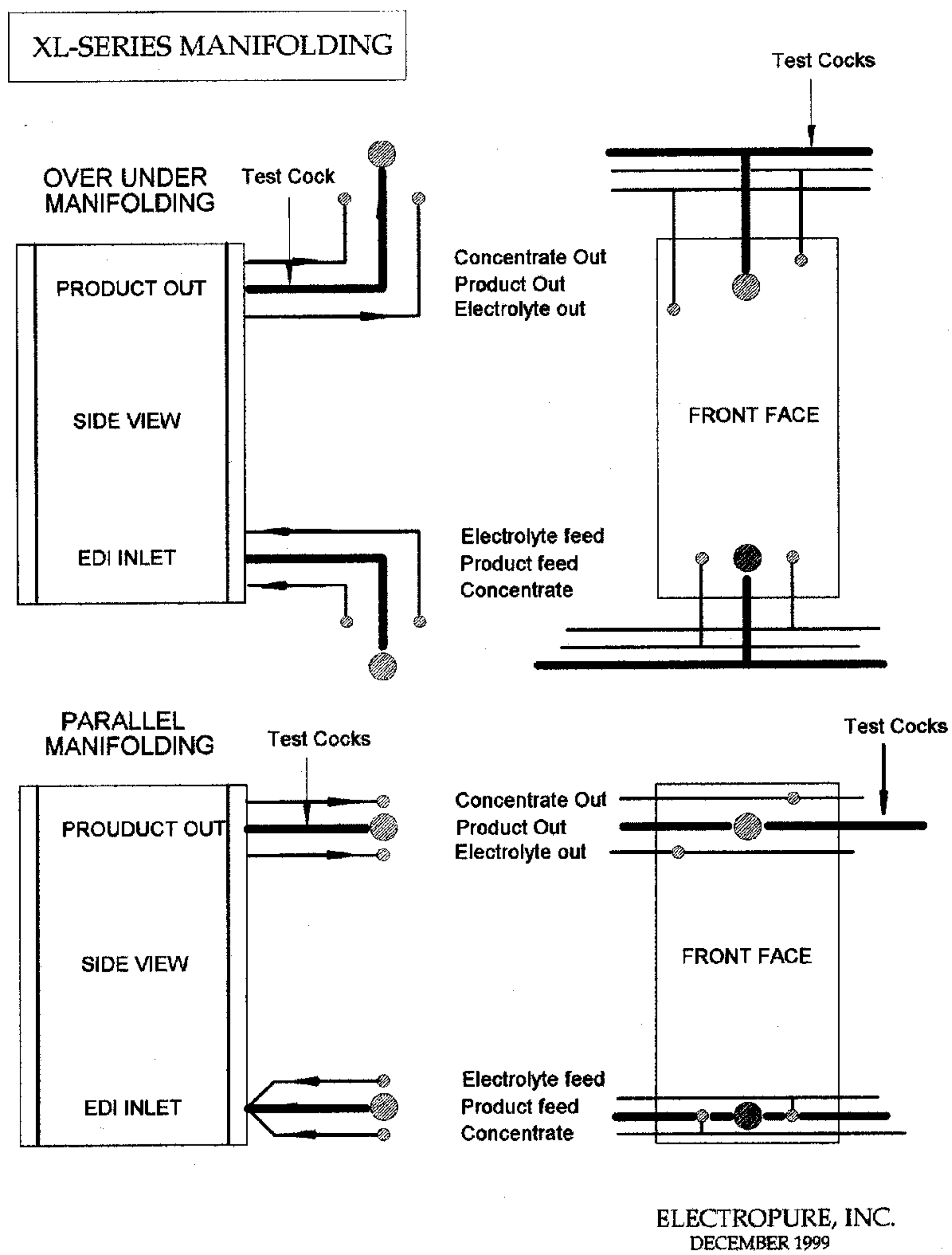


Figure 7: Manifolding Options



Chapter 11: SnowPure LLC Limited Warranty

SNOWPURE LIMITED WARRANTY

SnowPure warrants the EDI modules manufactured by it against defects in materials and workmanship when used in accordance with applicable instructions and within the operating conditions specified for the modules for a period of one (1) year from the earlier of: (a) the date of installation, or (b) the 60th day following the date of shipment (the "LIMITED WARRANTY PERIOD"). SNOWPURE MAKES NO OTHER WARRANTY, EXPRESSED OR IMPLIED. Any implied warranty of merchantability or fitness for a particular purpose applicable to the EDI module is limited in duration to the duration of this written warranty. Module replacement or performance of repairs are the exclusive remedies under this written warranty. SnowPure shall not be liable for incidental or consequential damages arising from personal injury, property damage or for any economic loss (such as, but not limited to, loss of module use, inconvenience or storage) resulting from breach of this written warranty. SnowPure does not authorize any person to create for it any other obligation or liability in connection with the EDI module.

Only modules purchased directly from SnowPure LLC, or its authorized distributor, are covered by this warranty. This warranty is invalid on any module sold to OEM customers who have not been expressly Qualified by SnowPure. (see Terms and Conditions).

The warranty provided herein and the data, specifications and descriptions of the EDI module appearing in SnowPure's published product literature, may not be altered except by express written agreement signed by an authorized officer of SnowPure, LLC. Representations, oral or written, which are inconsistent with this warranty, or such publications that are not so authorized, should not be relied upon.

In the event of a breach of the foregoing warranty, SnowPure's sole obligation shall be to repair or replace, at its option, any product or part thereof that proves to be defective in materials or workmanship within the warranty period; provided the EDI module is returned to SnowPure promptly with all appropriate operational logs. The cost of shop labor for the above warranty period is included in the warranty. Freight and field labor costs shall be at the customer's expense. The exclusive remedy provided herein shall not be deemed to have failed of its essential purpose so long as SnowPure is willing and able to repair or replace any non-conforming module or component part thereof.

In the interest of customer satisfaction, SnowPure may offer exchange service on some EDI components. This service is intended to reduce the amount of time your module is not available for use due to repairs. Components used in exchange are service replacement parts which may be new, remanufactured, reconditioned or repaired, depending on the component involved. All exchange components will be covered by the warranty SnowPure then gives on such new components.

Products or components manufactured by companies other than SnowPure or its affiliates ("Non-SnowPure Products") are covered by the warranty, if any, extended by the Product Manufacturer. SnowPure hereby assigns to the purchaser any such warranty.

If, for a period of two (2) years following the expiration of the Limited Warranty Period, any EDI module covered by this warranty becomes unusable for any reason within the manufacturer's control, upon prompt return of such EDI module along with all appropriate operational logs, SnowPure shall repair or replace, at its option, such EDI module on the basis set forth below under *Replacement Price*. Some examples of causes or conditions normally *beyond* the manufacturer's control are:

- Intentional alteration or modification of either the appearance or the physical characteristics of the EDI module;
- Damage caused by improper integration into a system, or conditions resulting from tampering, abuse or neglect;
- Fire, theft, freezing, vandalism, explosion or objects striking the EDI module;
- Failure to follow the specifications and recommendations contained in SnowPure's published product literature and OEM manual, and failure to observe safety and maintenance precautions contained therein for the EDI module and components specified therefore.

REPLACEMENT PRICE

After expiration of the Limited Warranty Period, the replacement price is determined by multiplying the customer's then current buying price by a fraction, the denominator of which shall be 36 months and the numerator of which shall be the number of full months elapsed since the failed module was placed in service. Taxes and freight will be added to the adjustment replacement price. If you receive an EDI module under this warranty, it will be covered by the warranty SnowPure then gives on that module.

Chapter 12: SnowPure LLC Terms and Conditions

TERMS AND CONDITIONS

The following Terms and Conditions apply to products purchased through SnowPure LLC, its parent, subsidiaries, divisions, and their affiliates, ("SnowPure") and are subject to the condition that the Customer has been expressly Qualified by SnowPure in the design, installation, use, and service of the products. The Terms and Conditions contained herein may be modified only by express, written consent of SnowPure.

1. SNOWPURE'S COMMITMENTS TO ITS CUSTOMER:

   A. The products when shipped will meet SnowPure's quality and performance specifications, and
   B. The products will be fit for the ordinary uses explicitly identified in SnowPure's current product literature.

2. CUSTOMER'S COMMITMENTS TO SNOWPURE:

   A. The Customer acknowledges that it is responsible for the safe selection, handling, storage, system design, installation, and use of SnowPure's products. Customer warrants that it will:

      i. familiarize itself with, and follow, recommendations contained in product information supplied by SnowPure at any time;
      ii. follow safe handling, use, storage, system design, installation, and use practices and ensure that all employees, contractors, agents, and customers follow these practices;
      iii. indemnify SnowPure against any claim, loss, liability and expense (including reasonable attorneys' fees) on account of any damage to property or injury or death of persons (including Customer's employees) arising out of Customer's handling, storage, design, installation, or use of the products or the failure of Customer to comply with any of the obligations set forth in this Section (2A);
      iv. in any action against SnowPure for personal injury or death of Customer's employees, expressly waive, as to SnowPure, the exclusive defense under any Workers Compensation Act if Customer failed to comply with any of the obligations set forth in this Section (2A);
      v. comply with all federal, state, and local laws, rules and regulations concerning the export, system design, installation, and use of SnowPure's products.

   B. Customer warrants that it has received, and is familiar with, product information published by SnowPure, that it has used its own independent skill and expertise in connection with the selection and use of the products, and that it possesses skill and expertise in the selection, handling, storage, system design, installation, and use of SnowPure's products.

   C. Customer warrants that it has received, reviewed, and understands the SnowPure Limited Warranty provided with its EDI products and has had an opportunity to ask questions of, and receive answers from, SnowPure concerning the Terms and Conditions of such Limited Warranty or any other matters relevant to the proper safe handling, system design, installation, and use of SnowPure's products.

   D. If Customer requests the use of any design, trademark, tradename, or copyright published by SnowPure, or if SnowPure makes special products for Customer, Customer agrees to indemnify SnowPure against any claim, loss, liability and expense (including reasonable attorneys' fees) on account of the infringement or alleged infringement of any design, trademark, tradename, copyright or patent.

   E. Customer agrees to not resell SnowPure's products except as part of a complete system built by Customer for the end-user. Resale of products to unqualified OEM customers will result in retraction of Customer's Qualified status and will void all warranties on such products.

   F. Customer agrees that if exported, these commodities will be exported from the United States in accordance with U.S. Export Administration Regulations. Diversion contrary to U.S. law is prohibited.

   G. Customer will pay for the products on the terms described on the invoice. SnowPure, or its assignee, may charge the maximum interest allowed by law on all overdue amounts. If payments are not paid on time, or if SnowPure has reason to believe that Customers financial responsibility is unsatisfactory, SnowPure may defer shipments, accelerate due dates on all amounts owed, and/or require cash or other security. Customer agrees to pay all of SnowPure's collection costs (including reasonable attorneys' fees). SnowPure retains title to, ownership of, and to the extent permitted by law, the right to repossess its goods, until payment in full is made for such goods.

Chapter 13: Safety

Electrical Safety

EDI works by applying a DC voltage across a set of aqueous, conductive streams. Further, EDI systems are typically installed in wet areas. Because of this, electrical safety in the design of a system is critical to prevent accidents. Note that the customer is responsible for the safe design and installation of the system, and for the training of the operators. SnowPure does not claim that the information below alone will ensure electrical safety.

Key system design reminders:

- Electrical installation should be done by qualified, trained electricians. Installation should be to local code.

- Proper grounding of the power supply and module is important. Ground fault interruption (GFI) circuits may be used, but can be unreliable with DC power supplies.

- Grounding should be tested on-site after installation, during operation, to be sure no voltage is present at any metal surface.

- Feed and concentrate streams contain ions, are conductive, and will carry current. These need to be grounded via the installation of a conductive material directly in the stream, grounded typically through a “tee” fitting.

- Proper training and proper hazard warnings should be posted at the installation, and on all finished equipment.

Chemical Safety

The electrochemical reactions at the anode and cathode will produce gases under normal conditions. The oxidation at the anode produces acid, O_2 (gas), and Cl_2, and generates electrons. The reduction at the cathode produces hydroxyls and H_2 (gas), and uses electrons. The chlorine is totally soluble in the water, and the H_2 and O_2 form gas bubbles.

Primary Anode Reaction: $OH^- = \frac{1}{4} O_2(g) + \frac{1}{2} H_2O + e^-$
Minor Anode Reaction: $Cl^- = \frac{1}{2} Cl_2(dis) + e^-$

Primary Cathode Reaction: $H^+ + e^- = \frac{1}{2} H_2(g)$

Gas bubbles will be present in the electrode waste stream. Venting of this stream is required to safely dispose of these gases according to local code. There will be up to 11 ml/minute of gas (H_2+O_2) evolved per Ampere based on Faraday’s Law.

The lower explosion limit (LEL) of H_2 is 4%(v/v). For safe operation, the electrode gases should be vented to dilute the gases to less than 25% of the LEL, or less than 1%(v/v). This is the responsibility of the OEM and the installation team.

Chapter 14: Appendices

Appendix #1: Acid Cleaning Procedure / Scale in the Concentrate Stream

Electropure™ EDI has a unique acidic concentrate feature which minimizes the potential for carbonate scale. However, we still *recommend* that you minimize the feed hard ions and the total $CO_2 + HCO_3^-$ to minimize potential scaling in the EDI concentrate stream. Note that the injection of acid or antiscalant before the RO will increase hardness and CO_2 in the RO permeate. These will pass to the downstream EDI. A pre-RO softener has the additional advantage of removing Iron (Fe) from the RO feed, which lengthens its life and prevents Iron fouling of the RO and the EDI.

Equipment and Supplies needed for module service:

- Acid-capable pump: 100 lph (0.5 gpm) at 2 bar (30 psi)
- 2 plastic containers 20-50 liter (5-10 gallon), plastic fittings, tubing

Formula 1 (recommended):
This formula is a simple, safe, commercial formula that makes a 2% pH-adjusted solution of organic acid and chelating agents. This makes a pH solution between 2.5 and 3.5:

- ► 5 liter deionized water
- ► 100 ml RoClean™ L403 solution, from Avista Technologies[9]. Technical spec sheet and MSDS are available at www.snowpure.com/downloads.htm.

Formula 2 (next best formula):
This formula is a simple formula using only organic acid. This makes a 5% weak-acid solution at a pH of about 3:

- ► 5 liter deionized water
- ► 250 gm citric acid

Formula 3 (only for extreme problems):
This formula makes a 2.5% strong-acid solution, to aid in the removal of extreme scale levels. This is the most drastic of the three formulas:

- ► 5 liter deionized water
- ► 350 ml 37% Reagent Grade hydrochloric acid (HCl)[10]

***Safety tip*: mixing of acids: remember to add acid to water—never add water to acids.**

[9] www.avistatech.com, MSDS and technical sheets available on Avista and SnowPure websites.
[10] must be low in iron (Fe)

Acid Cleaning Procedure:

- ✓ Before cleaning, measure and record the flow and pressure drop through the electrode and concentrate streams.
- ✓ Close (seal) the Feed and Product ports to keep acid from contaminating the ion exchange resins.
- ✓ Connect the discharge side of the acid-capable pump to (***elec in*** and ***conc in***) inlet ports. Do not feed acid to the dilute/purifying chambers or the resins will require a very long regeneration time. If the acid is fed to the product chambers, rinse time will be 6-8 hours, and it may take 16 hours to reach equilibrium quality.
- ✓ Connect the suction side of the pump to a 20-50 liter (5-10 gallon) plastic tank filled with one of the above acid cleaning solutions.
- ✓ Direct (***elec out*** and ***conc out***) outlet ports to a waste recovery tank suitable for acid solutions, or to the chemical feed tank.
- ✓ Pump the acid slowly through the EDI module until acid and waste products come out the outlet, then turn off the pump and allow the cleaner to soak in the module for 5 minutes or longer. Dense scale deposits may require longer soaks or stronger acid.
- ✓ Reactivate the pump periodically until the scale is dissolved. *Avoid pumping air into module.*
- ✓ Fill the tank with deionized (DI) water and pump it through the module to rinse out the cleaner, with the outlets going to drain. Continue to add rinse water until the effluent measures no greater than 5 ppm in TDS, and the pH is within normal operating range.
- ✓ Disconnect the lines from the ports, and connect the ports to their original plumbing. Measure the pressure drop, flow, pH, and TDS, and record. The pressure drop should have decreased into the normal range.
- ✓ Run the EDI in regeneration mode until an ion material balance is achieved. Run the EDI in standard mode until water quality is re-established. If the purifying chambers are contaminated with acid, it will require a rinseout time of at least 6 hours, and ultimate product quality will be reached after about 16 hours of operation.

Appendix #2: Resin Cleaning Procedure / Organics in the Feed/Product Stream

The organic cleaner may either be an approved **non-ionic** surfactant solution, such as Triton X-100tm, or an approved caustic-based solution, such as Avista RoCleantm L211.

Recommendation: Minimize the organic fouling of the resins in the EDI system by minimizing TOC (Total Organic Carbon) via the RO and its pretreatment system.

Suggestion: Use 3-way valves in the design of a CIP system to eliminate the need to manually disconnect the plumbing when servicing the EDI module.

Surfactant Solution:

- 10 liters deionized water
- 10 ml of pure Triton X-100tm (or 100 ml of 10% solution), available from Sigma[11], or chemical equivalent. Makes a 0.1% solution. This should cost approximately US$16 for 100 ml, or US$26 for 1 liter. Technical specification sheet and MSDS are available at www.snowpure.com/downloads.htm.

Caustic Cleaning Solution Formula 1 (best, contains approved buffers and sequestering agents):

- 9.8 liters deionized water
- 200 ml RoCleantm L211 solution (100 ml for mild fouling), available from Avista Technologies. Technical specification sheet and MSDS are available at www.snowpure.com/downloads.htm. The pH will be 10.5 or so.
- The solution should be heated to 35-40°C for aggressive cleaning.

Caustic Cleaning Solution Formula 2:

- 9.8 liters deionized water
- Sodium Hydroxide (pure NaOH) to make a 0.1-0.5% solution. Target pH 12-13. Technical specification sheet and MSDS are available at www.snowpure.com/downloads.htm.
- The solution should be heated to 35-40°C for aggressive cleaning.

Procedure:

- Do not “brine” the resins or the EDI product quality will never recover.
- Plug the concentrate and electrode inlet and outlet ports. Isolate the *Feed* and *Product* ports from the RO and the product plumbing.
- The cleaning of the resins is DOWNWARD FLOW.
- Connect the chemical transfer pump to the *PRODUCT* port.

[11] Triton X-100tm: CAS 9002-93-1, is also known as t-octylphenoxypolyethoxyethanol, or Octoxynol-9.

- Connect the *FEED* port to a waste recovery tank, or for circulation connect it to the chemical feed tank.

- Connect the inlet of the pump to a 20 liter (5 gallon) tank filled with either the nonionic surfactant or caustic cleaner warmed to 35-40°C (100°F).

- Pump the cleaner DOWNWARD through the EDI module until the cleaner has come out of the module, then turn off the pump and allow the cleaner to soak for 5 minutes or longer.

- Reactivate the pump periodically until all of the cleaner is consumed, or until the resins have been adequately cleaned. A typical time is 15-30 minutes.

- If cleaning solution is circulated, be sure to use a filter to prevent debris from entering the module(s).

- Fill the tank with 35-40°C (100°F) deionized water and pump all of it through the module to flush out the cleaner.

- Circulate at least 100 more liters of room temperature deionized water through the module. Repeat as necessary until the TOC level is below the system requirement, and the pH is near neutral.

- Connect the *Feed* and *Product* ports to their original plumbing.

- Run the system for up to 4 hours to rinse out all of the cleaner. Check the outlet for TOC if this is a critical parameter. TOC may take 16 hours to reach ppb levels.

Appendix #3: Resetting Bolt Torques-XL Series

Torque is critical for EDI XL series. It is important for maintaining internal pressure to achieve water quality, and for preventing internal and external leakage. The torque should be set at the following times:

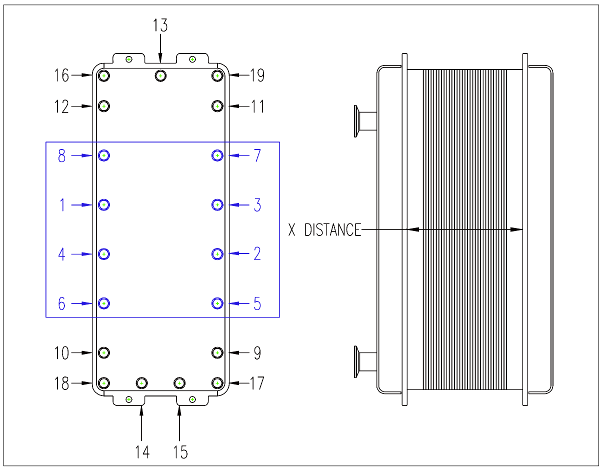
1) After it has been mounted to the skid
2) Before operation at the customers' site
3) After water pressure has been applied
4) Periodically (weekly) for the first month until all of the internal plastic parts have fully compressed, and
5) Whenever the product quality declines a little.

Refer to the illustration below for resetting the torque of the bolts. Both final torque and torque sequence/pattern is important. Following the torque pattern ensures that the module is torqued evenly, and that local stresses are eliminated. There are 19 bolts. Bolts require a 9/16-inch (") hex socket. Tighten the bolts in the sequence numbered, with the center 8 bolts torqued first. Then tighten the upper and lower bolts without causing the plates to deform or bend. The distance "X" should be the same from top to bottom (parallel plates).

Recommended Torque Settings:

Module	Target Torque
XL (all)	**20 ft-lbs (27 N-m)**
XL-HTS (all)	**10 ft-lbs (13 N-m)**

Figure 8: Torque Sequence



Appendix #4: Module Sanitization Procedure

The simplest and best technique for sanitizing traditional DI beds is to separate and regenerate the resins. The conditions presented by the strong acid and base kill and eliminate bacterial colonies.

EDI modules under applied voltage are constantly splitting water and generate locally very high and very low pH. These pH extremes are believed to create a biostatic environment within the EDI module, especially on the product side where it is critical.

A good study of this topic was published by Millipore in 1990. They found that a weekly-sanitized RO-EDI system maintained low bacterial and endotoxin counts, and that the EDI effluent was similar in counts to its influent. When the sanitization regimen was stopped for three months, the concentrate stream did rise in counts, yet the product stream did not. Their conclusion was that the critical product side of the EDI module did indeed act as a biostat.

The best sanitization method, according to SnowPure, is to keep the unit operational. In this mode, bacterial colonies should not grow, especially on the product side.

EDI Module Sanitization:

There is no ideal sanitization regime for EDI. Sanitizers consist of oxidizers, ions, and/or organics. Organic sanitizers require long rinsing times to reduce TOC to acceptable levels. Ionic sanitizers require a post-sanitization regeneration procedure. Oxidizers can reduce the lifetime of the module via oxidation of resins and membranes.

Periodic sanitization can be one of several methods. We recommend:

1. Use of “hydrogen peroxide-stabilized peracetic acid” as used in current RO systems, such as the use of Minncare® Cold Sterilant by Minntech[12]. Use the low concentration of 0.1% Minncare® for 1 hour, ideally in recirculation, or

2. If any bacteria are pernicious or persistent, *carefully* use 1% Minncare® for 1 hour (repeated use will oxidize EDI resins), or

3. Use of Avista Technologies RoCide™ DB-20[13,14] at 100 ppm (20%) for 1 hour, or

4. Use of 200 ppm RoCide DB-20 for 6 hours if any bacteria are pernicious or persistent.

Other Sanitization Notes:

We know which chemicals prevent growth and should not harm DI systems. However, all have some side effects and cautions.

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[12] See www.minntech.com
[13] Note: DB-20 is not approved for USP water.
[14] Note: MSDS and technical brochure available at www.snowpure.com or www.avistatech.com

- ✓ 0.1% Minncare® Cold Sterilant peroxide/peracetic acid works well. Check approval for use in USP Purified Water systems.

- ✓ A 20% propylene glycol + 1% Triton X-100tm surfactant will prevent growth, but the effects of long-term storage are not well known, and takes a long time to rinse out the TOC.

- ✓ Organic biocides, such as Avista Technologies' DB-20 work well but are generally not approved for use in USP Purified Water systems.

- ✓ Formaldehyde works well for disinfecting resin beds, but is a carcinogen.

- ✓ Avoid oxidizing agents, which damage the module.

- ✓ Avoid hot water sanitization (65-80°C), which damages the base-form (OH^-) anionic resin and membrane, unless the module is an HTS design.

Appendix #5: Module Regeneration Procedure

A module needs regeneration whenever it has been operated so as to exhaust the internal resins with ions. This may happen during cleaning, extended shutdown, or if module is run with the power too low or off. The regeneration process is designed to drive the excess ions out and enable the module to operate under steady state.

The regeneration procedure forces excess ions out of the module by significantly changing the operating parameters for a short time—the feed ions are reduced and the electrical driving force is increased. The excess ions are driven from the purifying chamber into the concentrate chamber where the ion concentrate significantly increases.

Module	Regeneration Product Flow gpm (m^3/hr)	Regeneration Concentrate Flow gpm (lph)	Regeneration Recovery (90% normal)	Regeneration Voltage (VDC)
XL-100-R	0.25 (0.05)	0.05 (10)	80%	60
XL-200-R	0.50 (0.11)	0.10 (25)	80%	120
XL-300-R	1.5 (0.35)	0.30 (70)	80%	200
XL-400-R	3.0 (0.7)	0.50 (120)	85%	250-300
XL-500-R	6.0 (1.3)	1.0 (220)	85%	350-400
EXL-600	10 (2.3)	1.5 (340)	85%	350-400
EXL-700	15 (3.5)	2.5 (560)	85%	550-600

1. Set main product flow to setting above (which is the lower limit for each model). Set the concentrate flow to above setting (15-20% of feed flow). This gives a recovery of 80-85%. Leave the electrode flow at normal 10 lph (0.05 gpm). Raise voltage to the setting above. Alternatively, set the power supply on “current control” and set the current at 150%-200% of normal operating current. Run module—TDS in concentrate will be very high.

2. When concentrate TDS drops to approximately 100 ppm (200 µS/cm) or lower, decrease concentrate flowrate to ½ of above setting. The other settings remain the same. This should cause the concentrate TDS to double.

3. When concentrate TDS lowers down to 80 ppm (160 µS/cm) or so, increase the main feed to nominal flow. All other settings remain the same. Run unit for one (1) hour.

4. After one hour of runtime, set power supply to “voltage control” and return voltage to normal operating value (very important). Set concentrate outlet to normal flow rate (10% of product). Electrode flow has remained the same throughout the procedure.

5. Run the unit at these settings; module should be fully regenerated and the quality of the product should be normal. Note: the above is an approximate guide. You may need to vary the parameters to achieve regeneration.

Appendix #6: Data Form for Electropure™ EDI Module

Electropure™ Standard XL EDI Module Testing
"Quality Testing under Standard Conditions"

	This Module	Voltage Final	Product Outlet	Conc Outlet	Elec Feed
XL-060-______	□	48 VDC	0.25 gpm 60 lph	0.025 gpm 6 lph	0.05 gpm 11 lph
XL-100-______	□	48	0.5 gpm 110 lph	0.05 gpm 11 lph	0.05 gpm 11 lph
XL-200-______	□	100	1.0 gpm 220 lph	0.1 gpm 22 lph	0.05 gpm 11 lph
XL-300-______	□	150	2.0 gpm 0.5 m3/h	0.2 gpm 50 lph	0.05 gpm 11 lph
XL-400-______	□	200	5.0 gpm 1.1 m3/h	0.5 gpm 110 lph	0.05 gpm 11 lph
XL-500-______	□	300	7.5 gpm 1.7 m3/h	0.75 gpm 170 lph	0.05 gpm 11 lph

SnowPure LLC
"makers of Electropure EDI products"
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San Clemente, CA 92672 USA
+1.949.240.2188

Module Serial Number	
Assembly Date	/ /2014
Test Station ID	
Test Date	/ /2014
Person	
Torque	ft-lbs
pH Meter Calibrated	/ /2014
Cond Meter Calibrated	/ /2014

Time	Voltage	Current (Amps)	Product Resistivity (MOhm.cm)	Concentrate In/Out (gpm)	Feed Temperature (C)	Feed TDS (mg/l)	Feed pH	Concentrate Outlet TDS (mg/l)	Electrolyte Outlet TDS (mg/l)	Concentrate Outlet pH	Electrolyte Outlet pH	Notes

Note: Feed Conductivity (uS/cm) = 2.10 * Feed TDS (mg/l).

Note: 30 minutes to drain, then product and concentrate water are recirculated; data is taken after each hour of run time.

Form: January 2014

Temp (C)	PCF	Temp (C)	PCF
18.0-18.9	0.86	26.0-26.9	1.03
19.0-19.9	0.88	27.0-27.9	1.06
20.0-20.9	0.90	28.0-28.9	1.08
21.0-21.9	0.92	29.0-29.9	1.10
22.0-22.9	0.94	30.0-30.9	1.13
23.0-23.9	0.97	31.0-31.9	1.15
24.0-24.9	0.99	32.0-32.9	1.18
25.0-25.9	1.01	33.0-33.9	1.20
26.0-26.9	1.03	34.0-34.9	1.23

	Pressure, PSI		Difference @ Test Temp	Temp (C): ______	Difference @ 25 (C)
	Inlet	Outlet		PCF: ________	
Feed/Product				x PCF =	
Concentrate				x PCF =	
Electrolyte				x PCF =	

	Feed
CO_2, ppm	
Cl_2, ppm or ND	
SiO_2, ppm	
FCE, uS/cm	

REVISED 10/31/12

FCE (uS/cm) = 2.22*TDS(mg/l) + 2.79*CO_2 + 1.94*SiO_2

Appendix #7: EDI Power Consumption and Electrical Cost

The operating cost of an EDI system includes the cost of the electrical power supplied to the EDI system. However, at all times, it can be shown that the total operating cost is dominated by the power usage of the RO equipment. Here is a sample energy cost calculation for an XL-500-R module:

1. **Power** used by each module is a product of the DC voltage and DC current.

DC Power (Watts) = Voltage (VDC) * Amperage (ADC)
(e.g., XL-500-R) 600 W = 300 VDC * 2.0 Amps

2. There is some **power loss** at the power supply during the conversion from AC to DC. Power supply efficiency is typically over 85% (15% losses).

AC Power = DC Power / 90%
0.7 kW = 600 W / 0.90 / 1000

3. **Energy** used is the product of Power and Time.

Energy (kWh) = AC Power (kWatts) /1000 * Hours
6 kWh = 0.7 kW * 8 hrs

4. **Energy Cost** depends on the local utility rate (e.g., $0.12 per kW-hr). Cost = Energy * Rate. A typical XL-500-R module the energy costs under $1 per 8-hour period.

Cost (8-hour period)	Energy	Rate
$ 0.72	6 kW-hr	$ 0.12 /kW-hr
€ 0.84	6 kW-hr	€ 0.14 /kW-hr

5. **Cost of energy used to produce a unit volume** of pure water:

Cost	**Volume**	Energy	Rate
$ 0.15	**1000 gallons**	1.2 kW-hr	$ 0.12 /kW-hr
€ 0.05	**1 m^3**	0.3 kW-hr	€ 0.14 /kW-hr

Appendix #8-A: Silica Removal by RO and Electrodeionization

Silica is one of the more important minerals to remove from water for Power generation and Semiconductor applications. It is also one of the most difficult. Silica chemistry is complex. On the most basic level, silica is found in both colloidal/polymerized and reactive/molecular forms. Silica level in feedwater depends on the geology of the region and whether the source is surface- or well-water. Silica in raw water will range from under 2 ppm to over 100 ppm.

Physical membrane processes such as ultrafiltration and reverse osmosis effectively remove colloidal silica, and much of the reactive silica.

The removal of reactive silica by RO or EDI depends on its charge. Silica has little charge at neutral pH near 7.0 since the pK_1 of silicic acid is 9.8. The lack of charge makes it difficult to exchange with ion exchange resin, or to remove with RO or EDI. Raising the pH to above 9.8 helps with the driving force.

Silica scaling is also an issue. The solubility of silica at pH 6-8 is only 120 ppm at 25^{o}C. This means that a 30 ppm RO feedstream with 75% recovery will begin to scale. There are two prevention techniques for silica scaling. One is the use of silica antiscalant in the RO process, which mechanism is to delay the formation of solid silica. The other is raising the pH, which increases the solubility limit of silica. At pH 10.0, silica is soluble up to 310 ppm. Of course, high pH will cause hardness scaling if the feed is not softened.*

Commercial RO modules will pass silica at about twice the passage as chloride ion**. Most spiral RO module manufacturers claim 99.7% rejection for individual (200 psi) high quality elements. 99.0%-99.5% is a reasonable silica rejection rate for a well-designed RO system with quality elements. Note: Nitto Denko CPA5-LD are reputed to have the best silica rejection of all brackish water RO membranes.

With a 20-ppm silica feed, with 75% recovery, and 99.0% rejection elements, the RO permeate (and EDI feed) can be maintained at 0.5 ppm.

For higher levels of silica in the feed, the RO system should be designed with higher quality RO elements or lower recovery. Using 99.7% rejection elements and 65% recovery, the RO feed can be up to almost 90 ppm.

It is important to maintain the silica in the EDI feed under 0.5 ppm in order to:

- Avoid scaling in the EDI concentrate, and
- Minimize silica levels in the high-quality EDI product water.

Strategies for effective silica removal in the EDI:

1. High quality RO system (for removal of feed silica)
   a. High quality RO modules
   b. RO feed pH raised
   c. HERO™ process
2. CO_2 removal (CO_2 competes with silica in the EDI)
   a. CO_2 removal pre-RO using Calcite+Corosex® media
   b. CO_2 removal by RO using pH >= 8.3
   c. CO_2 removal interstage RO
   d. CO_2 removal post RO using Liqui-Cel™

3. EDI voltage
    a. EDI voltage too low may lead to fouling
    b. EDI voltage too low may lead to low silica removal
    c. EDI voltage needs to be splitting water effectively in the polishing section.

* see US Patent 5,925,255 for HERO[tm] process.

** e.g., Hydranautics CPA5, or Koch Fluid Systems TFC-XR.

Appendix #8-B: Silica Fouling and Cleaning in Electropure™ EDI

Silica can foul an EDI system in 2 cases.

1. When the feed silica level is too high
2. When the operating voltage is too low

Best practice is to avoid silica precipitation.

1. In areas with high silica in the raw water, use the best quality RO membranes, and use RO membranes that are designed to reject silica. SnowPure recommends *Nitto Denko CPA5-LD*, available from Hydranautics.
2. Operate your Electropure™ EDI at 10% higher than standard voltage. The higher voltage encourages more water splitting in the polishing section of the EDI module, generating larger amounts of OH-, keeping the silica in soluble form, and enhancing the transport into the concentrate.
3. Minimize the CO_2 in the feed, it competes with the removal of SiO_2.
4. Once formed, polymerized silica is very difficult to remove.

Mechanisms of silica precipitation:

1. At the pH of high purity water (7.0) silica is uncharged ($pK_1 = 9.8$) so will not diffuse into the concentrate if it is in the water phase. When adsorbed on a virgin anion resin (pH = 14 surface) it becomes charged ($H_3SiO_4^-$)
2. If the $H_3SiO_4^-$ ions are not removed from the resin, they may accumulate and polymerize to form $(SiO_2)_n$ The solubility of silica is about 6 ppm according to R. Sheikholeslami and S. Tan (1999), hence our practical EDI feed limit of 0.5 ppm.
3. Silica precipitation is enhanced in RO situations with cations such as Ca^{+2}, but this should not be an issue in EDI in the polishing section.

Symptoms of silica fouling:

1. EDI quality decreases (polishing section is hindered)
2. EDI current decreases (less water splitting)
3. No SiO_2 mass balance, more silica enters the EDI feed than is removed in the concentrate, this indicates a buildup.

Cleaning procedure for silica precipitation:

The primary way to remove polymerized silica precipitation/fouling from the resins is via a high-pH treatment. For RO cleaning, NaOH + EDTA + SDS at high temperature is recommended. NaOH increases the pH which makes silica more soluble. pH should be greater than 11 for best results. EDTA may sequester cations if present but is not likely to help in EDI. SDS (surfactant) helps to remove colloids, and may be useful in EDI.

Two silica cleaning solutions are recommended for Electropure™ EDI:

1. NaOH in DI water at pH 12-13, temperature 40-50°C.
2. Avista RoClean™ high-pH cleaner at 2%, temperature 50°C. Powder form is RoClean™ P111. Liquid form is RoClean™ L211.

Procedure outline:

1. Isolate the resins by closing the concentrate and electrolyte ports and valves. High pH cleaners will attack the concentrate screens and damage them.
2. Slowly circulate the high pH cleaning solution through the EDI purifying chambers. Ideal is to circulate the solution downward to keep the resin bed packed (introduce the solution in the product port, collect it at the feed port).
3. Monitor the pH of the solution, and reformulate if the pH drops below 10.5
4. Treat for at least 60 minutes.
5. Neutralize and dispose of cleaning solution according to local waste treatment regulations.
6. Rinse the module with DI water, downward if possible, until the effluent is below pH 9. This may take some time since the NaOH has permeated the resins and the membranes.
7. The anion resins and membranes will be fully in the OH- form.
8. The cation resins and membranes will be fully in the Na+ form.
9. Operate the module under "regeneration" conditions with product and concentrate and electrode flow all flowing to drain. This may take 8-16 hours to fully remove the excess Na^+ ions. Monitor the pH and conductivity of the concentrate to watch the progress. The pH of the concentrate should be acidic, and lower than the pH of the EDI feed.
10. It is expected that the quality of the EDI product will decline with each cleaning. This is why it is better to avoid fouling/cleaning by using the best pretreatment possible.

Suggestion: Use 3-way valves in the design of a CIP system to eliminate the need to manually disconnect the plumbing when servicing the EDI module.

Caustic Cleaning Solution Formula 1:

- 9.8 liters deionized water
- 200 ml RoClean^tm L211 solution (100 ml for mild fouling), available from Avista Technologies. Technical specification sheet and MSDS are available at www.snowpure.com/downloads.htm. The pH will be 10.5-11.0 or so.
- The solution should be heated to 45-50°C for aggressive cleaning.

Caustic Cleaning Solution Formula 2:

- 9.8 liters deionized water
- Sodium Hydroxide (pure NaOH) to make a 0.1-0.5% solution. Target pH 12-13. Technical specification sheet and MSDS are available at www.snowpure.com/downloads.htm.
- The solution should be heated to 40-50°C for aggressive cleaning.

Procedure:

- Do not "brine" the resins with NaCl salt or the EDI product quality will never recover.

- Plug the concentrate and electrode inlet and outlet ports. Isolate the *Feed* and *Product* ports from the RO and the product plumbing.

- The cleaning of the resins is DOWNWARD FLOW.

- Connect the chemical transfer pump to the *PRODUCT* port.

- Connect the *FEED* port to a waste recovery tank, or for circulation connect it to the chemical feed tank.

- Connect the inlet of the pump to a 20 liter (5 gallon) tank filled with either the nonionic surfactant or caustic cleaner warmed to 35-40°C (100°F).

- Pump the cleaner DOWNWARD through the EDI module until the cleaner has come out of the module, then turn off the pump and allow the cleaner to soak for 5 minutes or longer.

- Reactivate the pump periodically until all of the cleaner is consumed, or until the resins have been adequately cleaned. A typical time is 60-120 minutes.

- If cleaning solution is circulated, be sure to use a filter to prevent debris from entering the module(s).

- Fill the tank with 50°C (120°F) deionized water and pump all of it through the module to flush out the cleaner.

- Circulate at least 100 more liters of room temperature deionized water through the module. Repeat as necessary until the TOC level is below the system requirement, and the pH is near neutral.

- Connect the *Feed* and *Product* ports to their original plumbing.

- Run the system for up to 4 hours to rinse out all of the cleaner. Check the outlet for TOC if this is a critical parameter. TOC may take 16 hours to reach ppb levels.

Appendix #9: Procedure to Prevent Freezing of EDI Modules

This is SnowPure's recommendation for the prevention of freezing of Electropure™ EDI modules. Freezing may take place either during shipment (by air or by land), or in storage. Electropure™ EDI modules are shipped sealed, bacteria-free, and drained of free water but still wet. No antifreeze or brine solution is added to the modules before shipment. There are disadvantages to all added solutions, which will be outlined below.

SnowPure's Recommendation: Avoid Freezing.

As with pure water resin bead systems, the primary recommendation is to maintain the temperature of the modules or packages above 2°C at all times. Brief exposure of the packaged modules to freezing temperatures (for example in the cargo hold of an airplane or the bed of a truck) may be tolerated since the packaging provides insulation and the mass of the module provides thermal inertia. Avoid cyclical freezing as this causes more damage than a single freeze.

Alternate Recommendation: Use USP Organic Antifreeze.

Certain non-ionic organic chemicals may be used as "antifreeze solutions" to prevent freezing of EDI modules. The problem with introducing organic chemicals into the modules is the long time it takes to rinse them out. A 15% solution (by weight) of any of these will provide about -5°C freeze protection (to 23°F). There are three acceptable organic compounds that may be used:

1. USP grade Glycerol [CAS 56-81-5]
2. USP grade Propylene Glycol [CAS 57-55-6]
3. USP grade Glutaraldehyde [CAS 111-30-8]

The easiest of the three is Glycerol, since it will rinse out the fastest. The most widely used of the three is Propylene Glycol. Glutaraldehyde provides bacteriological protection in addition to antifreeze protection.

<u>Procedure</u>:

a) Prepare a 15% solution by weight of one of the above.
b) Circulate the solution by pump into all three streams (feed, concentrate, and electrode).
c) Drain excess solution from the module/system.
d) Seal the module/system.
e) If the module/system freezes, be sure to let it thaw slowly.
f) To restore the system, first re-torque the bolts then flush the modules to drain using RO or DI water for 15 minutes. Flush for an additional 4-24 hours with the system operating (DC power applied). Test for organic (TOC) in the product and flush to drain until levels are acceptable to customer. Flushing with warm water will accelerate the rinseout.
g) Sanitize the module/system if necessary.

Appendix #10: EDI Module Storage and EDI System Shutdown

SnowPure's recommendations for module storage and for EDI system shutdown and startup are based on our experience and our customers' experience. The primary criterion for how to store modules and shutting down systems is the prevention of bacterial growth.

The actions suggested below depend on "ambient" temperature and length of planned shutdown. When an EDI is in operation, its bacteriostatic properties usually prevent bacterial colonies from propagating and growing. Bacteria will propagate rapidly in ultrapure water[15] from 25-35˚C. If the system is under 15-18˚C, bacterial growth is much slower.

Summary Matrix (suggested actions):

	Less than 1 day	**1 to 7 days**	**8 to 31 days**	**> 1 month**
Power Generation	• Normal shutdown • Normal startup	• Normal shutdown • Startup with Regen*	• Sanitize on shutdown • Startup with Regen*	• Sanitize on shutdown • Drain and seal system • Sanitize on startup
General Industrial	• Normal shutdown • Normal startup	• Normal shutdown • Startup with Regen*	• Sanitize on shutdown • Startup with Regen*	• Sanitize on shutdown • Drain and seal system • Sanitize on startup
Semiconductor (bacterial sensitive)	• Normal shutdown • Startup with Regen*	• Sanitize on shutdown • Startup with Regen*	• Sanitize on shutdown • Drain and seal system • Sanitize on startup	• Sanitize on shutdown • Drain and seal system • Sanitize on startup
Pharmaceutical (highly bacteria sensitive)	• Normal shutdown • Check for bacteria on startup • Sanitize if necessary or according to policy	• Sanitize on shutdown • Drain and seal system • Sanitize on startup	• Sanitize on shutdown • Drain and seal system • Sanitize on startup	• Sanitize on shutdown • Drain and seal system • Sanitize on startup

* "Startup with Regen": in order to minimize any bacterial colonies present, a startup sequence may include a 1-hour to 4-hour period of operation in regeneration mode. This specifically includes operation at regeneration voltage (see Appendix 5).

[15] from Ultraclean Technology Handbook, by Tadahiro Ohmi, 1993

Appendix #11: FDA Compliance of Materials in Electropure™ EDI Modules

SnowPure, LLC manufactures electrodeionization modules which are suitable for use in a variety of applications. All of the wetted materials within the modules have been identified by the United States FDA in Title 21 of the Code of Federal Regulations (CFR 21) as safe to use in contact with food.

SnowPure, LLC maintains files from its suppliers as to their CFR 21 compliance. SnowPure, LLC does no independent testing of component materials and solely relies on its suppliers to be in compliance with FDA requirements.

If necessary for validation, SnowPure can provide to its customers, under a non-disclosure agreement, a list of the wetted materials in its modules and their specific CFR 21 compliance letters.

Appendix #12: Continuous Control of CO_2 as RO pretreatment

Clack Corosex® II (MgO) can be mixed with Clack Calcite ($CaCO_3$) media to treat acidic, low pH waters to remove free carbon dioxide (CO_2). For freebed filters, upflow is recommended with occasional backflushing, to help prevent cementing. A minimum of 50% Calcite is also recommended to prevent cementing.

By neutralizing the free carbon dioxide in water, Corosex® II and Calcite can correct low pH water conditions and render the water non-corrosive and more conducive for CO_2 removal by the RO system. Since this media is passive, it often eliminates the need for caustic injection on acidic waters.

Corosex® II, being a highly reactive magnesium oxide, is used most effectively where pH correction is substantial or high flow conditions are in use. Corosex® II, being soluble to acidity, will have to be replenished periodically. However, under certain low flow conditions MgO may overcorrect and create a basic condition.

It is important to combine Calcite with Corosex® II to mitigate the rapid neutralization properties of Corosex with the slower reacting properties of Calcite, effectively reducing potentially basic (high pH) properties due to overcorrection.

SnowPure recommends a mixture of between 10% and 20% Clack Corosex® II with Clack Calcite media, depending on the pH and CO_2 content of the feedwater. Corosex® II is recommended over plain Corosex® because it is higher in purity and slower reacting.

Since Corosex and Calcite will add some hardness to the water, antiscalant levels may need adjusting or the system may require a softener before the RO.