ERI-SIM™ Workshop

ERI-SIM

SWRO Process Simulator [Version 1.3]

An instructional computer program that simulates the pressures, flows and salinities of a SWRO process equipped with ERI®'s PX Pressure Exchanger® (PX®) energy recovery device. ERI-SIM integrates PX device performance, typical pump and valve characteristics and projected membrane responses into an interactive, dynamic training model.

WORKBOOK

for

ERI SIM™ – The SWRO Process Simulator

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Although most system designers understand the performance of individual pumps, membranes, valves and energy recovery devices, the performance of complete SWRO systems can be complex and counter-intuitive. A change in the output of one system component changes the input to other components, and the feedback can alter the outputs of all the components until a new equilibrium condition is reached. This is especially the case in SWRO systems equipped with isobaric energy recovery devices.

The ERI SIM program was developed by Energy Recovery, Inc. as an instructional tool for SWRO system designers and operators. It integrates PX Pressure Exchanger® device performance, typical pump and valve characteristics and projected membrane responses into an interactive, dynamic model. Although it is not a design tool, the ERI SIM program can assist with the design process by demonstrating how a modern SWRO process responds to changes in process settings and operating conditions.

ERI SIM simulates the pressures, flows and salinities of an SWRO process equipped with PX® technology. ERI SIM is intended for use by engineers and operators to provide a qualitative sense of SWRO process dynamics. The data presented in this spreadsheet does not represent guaranteed performance. In no event shall Energy Recovery, Inc. be responsible or held liable for damage, losses or adverse consequences associated with the use of ERI SIM.

SECTION 1

BASIC OPERATIONS

Getting Started

Microsoft Excel 2003 or more recent is required. ERI SIM may be run from a CD or from a computer hard drive.

ERI SIM utilizes macros. Therefore, macros must be enabled before program is opened. It may be necessary to adjust Excel security settings. The following steps should be followed.

1. Insert ERI SIM CD.
2. Open “Start Here” directory.
3. Open ERI SIM.
4. Set Marco Security setting to Medium.
    a. Tools
    b. Macro
    c. Security
    d. Security Level
    e. Medium
    f. Ok
5. Close Excel.
6. Open ERI SIM.
7. Enable Macros.

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Startup

Reverse osmosis system startup follows a specific sequence of operator actions. Systems must be charged with water and purged of air before the high-pressure pump is started. SWRO process startup and shutdown can be easily automated in practice, but ERI SIM requires that these operations be done manually for training purposes.

1. Open ERI SIM.
2. Select "ERI SWRO Process Simulator" tab.
3. Reset ERI SIM by clicking the **RESET** button.
4. Start the Supply Pump.
    a. Click the Supply Pump icon. It will change from **red** to **green**.
    b. Wait for the system to equilibrate.
5. Open vent valve to release air and allow high-pressure loop to fill.
6. Start the Booster Pump.
    a. Click the Booster Pump icon. It will change from **red** to **green**.
    b. Wait for the system to equilibrate.
7. Close the vent valve to seal the high-pressure loop.
8. Start the High Pressure Pump.
    a. Click the High Pressure Pump icon. It will change from **red** to **green**.
    b. Wait for the system to equilibrate.
9. Balance the flows to the PX devices. See attached Figure 1.
    a. Adjust the low-pressure control valve using the arrow buttons ▲ ▲▲.
    b. Set the low-pressure flow rate to approximately equal the high-pressure flow rate.

The high-pressure and low-pressure flow rates through the PX array are independent. Setting these flows equal is called "balancing flows."

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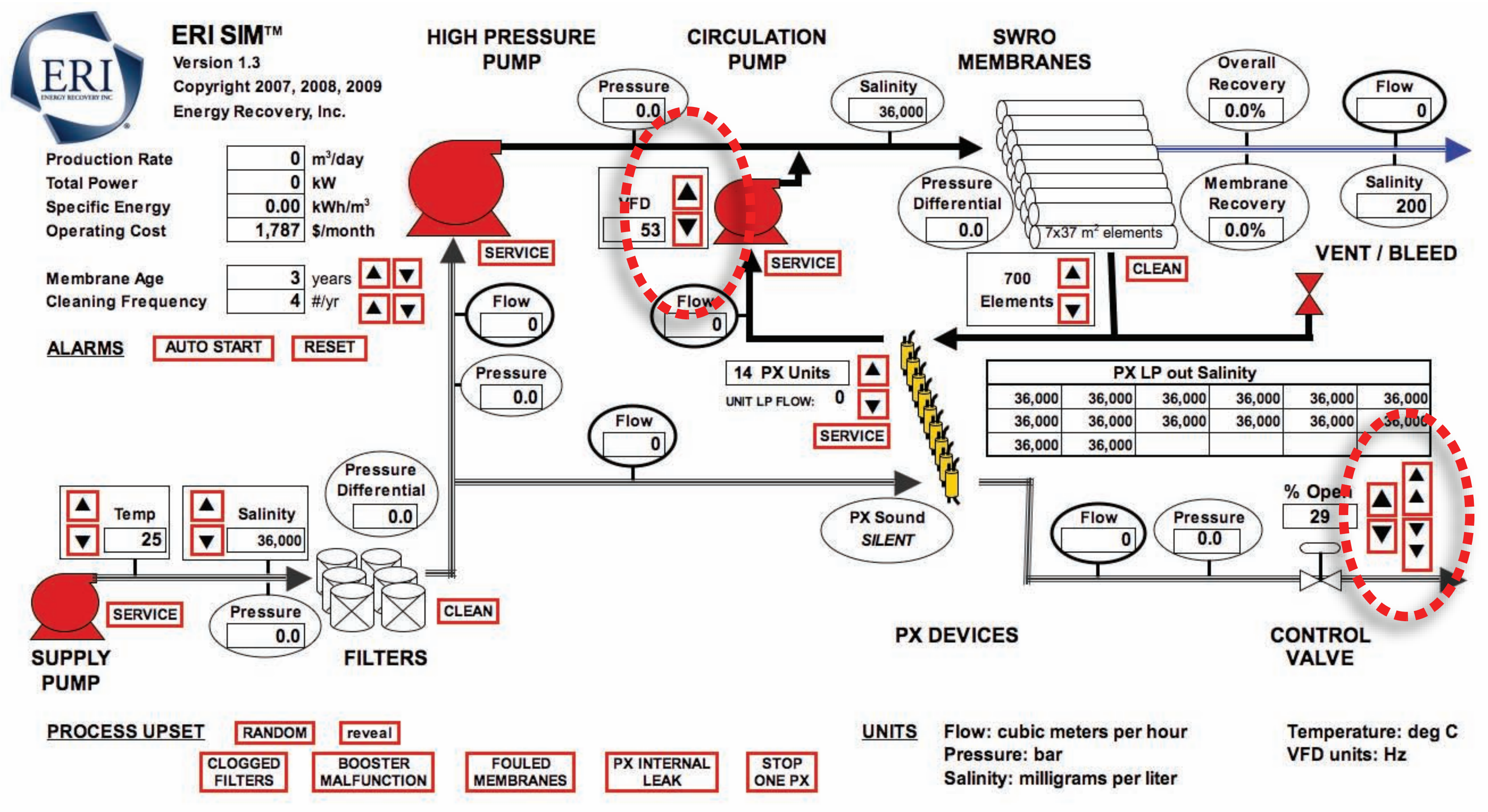
Figure 1 – Balance Flows

Adjust control valve to change the flow rate of low-pressure water through the PX array. Adjust the booster pump VFD to change the high-pressure flow rate through the PX array. Set these flow rates equal to "balance" flows.



Shutdown

The shutdown procedure is similar to the startup procedure in reverse. The low-pressure flow rate to the PX devices must be reduced before the high-pressure pump is stopped to prevent overflow of the PX devices. The system is vented to release suckback pressure. SWRO process shutdown can be automated, but these operations will be done manually for training purposes.

1. Reduce flow to the PX array.
   a. Partially close the low-pressure control valve using the down-arrow buttons ▼ ▼ next to the valve.
   b. Adjust the valve to the 29% open position.
   c. Record the low-pressure flow rate: ___________.
2. Stop the high-pressure pump. Click the pump icon. It will change from **green** to **red**.
3. Note the low-pressure flow rate.

   When the high-pressure pump stops, flow diverts to the PX array.
4. Check the PX unit flow to verify that PX devices are not being overflowed.

   Flow to or from a PX-220 should never exceed 50 m^3/hr per device.
5. Stop the booster pump. Click the pump icon. It will change from **green** to **red**.
6. Stop the supply pump. Click the pump icon. It will change from **green** to **red**.
7. Bleed the system pressure down to atmospheric pressure. Open the vent/bleed valve by clicking the valve.
8. Close the vent/bleed valve by clicking on the valve.

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Unbalancing Flow

The flow rate of high-pressure water to the PX devices can be adjusted independently of the flow rate of low-pressure water. The ratio of the flow rates affects the mixing characteristics of the PX devices. Mixing increases the salinity of the membrane feed. All isobaric energy recovery devices cause some degree of mixing. This can be adjusted by changing the flow ratio.

1. Conduct a Startup.
2. Balance the flow rates to the PX devices.
    a. Gradually adjust the low-pressure control valve using the up- and down-arrow buttons next to the valve.
    b. Set the low-pressure flow rate to approximately equal the high-pressure flow rate.
3. Check for alarms.
4. Record the following:

    Membrane feed pressure: __________

    Membrane feed salinity: __________

    High-pressure (booster pump) flow rate: __________
5. Increase the low-pressure flow rate to the PX devices by opening the low-pressure control valve to 44%.
6. Note the change in membrane feed salinity and pressure.

    Membrane feed salinity and pressure decrease slightly if the PX devices are flushed with extra feedwater.
7. Note that the high-pressure flow rate has not changed.

    Changing the low-pressure flow rate to the PX array does not change the high-pressure flow rate from the array. These flows are completely independent.
8. Reduce the low-pressure flow rate to the PX devices by closing the low-pressure control valve to 38%. The low-pressure flow rate should be less than the high-pressure flow rate.
9. Note the change in membrane feed salinity and pressure.

    Membrane feed salinity and pressure increase slightly if the PX devices are not fed sufficient feedwater.
10. Set the low-pressure control valve to 41% open.

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Changing Recovery

The membrane recovery rate – the ratio of the permeate flow rate to the membrane feed flow rate, also known as the conversion rate – can be adjusted by changing the booster pump flow rate. The flow rate of low-pressure water fed to the PX devices must also be adjusted to maintain balanced flow. Reducing recovery reduces membrane feed pressure and energy consumption.

1. With ERI SIM running, record the following:

   Permeate flow rate: ___________

   Membrane feed pressure: ___________

   Membrane feed salinity: ___________

   Recovery rate: ___________

   PX LP outlet salinities: ___________

   PX LP outlet salinity is approximately equal to the salinity of the concentrate reject from the SWRO membranes.

2. Increase the high-pressure flow rate from the PX array by increasing the Hertz setting of the Booster Pump VFD from 53 to 55 Hz. Note the change in the recovery percentage.

3. Re-balance the flows to the PX array. Adjust the low-pressure flow rate with the control valve.

4. Note that the membrane salinity has changed very little but the PX LP out salinities have decreased substantially. Also note the change in membrane feed pressure.

   Reducing the recovery rate decreases the salinity within the membrane elements. The result is a decrease in operating pressure.

5. Note the change in the permeate flow rate.

   Reducing the recovery rate increases system productivity. Reduced recovery rate also helps prevent scaling and can increase membrane life.

6. Set the booster pump VFD to 53 Hz.

7. Re-balance flows by setting the low-pressure control valve to 41% open.

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Feedwater Fluctuations

ERI SIM incorporates membrane projection data for a range of feedwater properties. If feedwater properties change, constant permeate flow and membrane flux can be maintained by adjusting membrane recovery rate.

1. With the ERI SIM process running, record the following:

   Permeate flow rate __________

   Permeate salinity __________

   Membrane feed pressure __________

   Specific energy consumption __________

2. Decrease the feedwater temperature by 5 degrees Centigrade. Note the increase in membrane feed pressure and the decrease in permeate flow.

   Productivity decreases as the feedwater temperature decreases if the SWRO system recovery is not adjusted.

3. Note the change in specific energy consumption.

   More energy is consumed at lower feedwater temperatures.

4. Adjust the recovery rate to reestablish the original permeate flow rate. Balance flows.

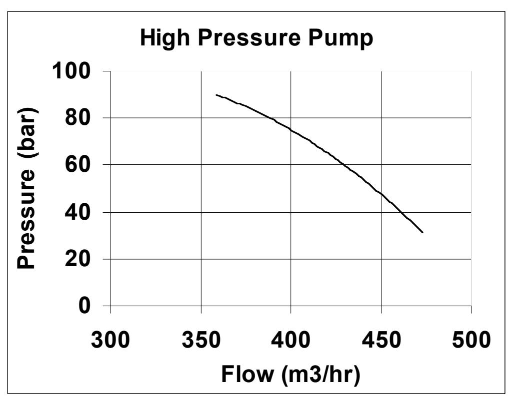
   Lowering the recovery rate increases permeate production.

5. Note the change in permeate salinity.

   Permeate quality is higher at lower feedwater temperatures.

6. Increase salinity by 1000 ppm. Note the change in membrane feed pressure and permeate flow rate.

   Higher salinity feedwater has a higher osmotic pressure, resulting in a higher feed pressure. Permeate flow rate changes as the duty point of the high-pressure pump moves along its curve.



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Membrane Flux, Cleaning and Age

ERI SIM incorporates membrane projection data for a range of membrane operating conditions.

1. Reset ERI SIM.

2. Conduct a Startup. Balance flows. Respond to any alarms.

3. Record the following:

   Membrane feed pressure: __________

   Permeate flow rate: __________

   Number of membrane elements: __________

4. Compute the flux in liters per square meter per hour assuming each membrane element has a surface area of 37 m^2: __________

   Flux is the flow rate divided by the area.
   468 m^3/hr ÷ (700 elements × 37 m^2/element) × 1000 liters/m^3 = 18.1 liters/m^2/hr

5. Increase the number of membrane elements by 10% to 770 elements. Rebalance PX flows.

6. Compute the flux: __________.

   472 m^3/hr ÷ (770 × 37 m^2) × 1000 liters/m^3 = 16.4 lmh

7. Note the membrane feed pressure and specific energy consumption.

   Less energy is consumed at lower membrane flux.

8. Decrease the cleaning frequency to 3 times per year. Note the change in membrane feed pressure. **Reducing the cleaning frequency increases the role of membrane fouling.**

9. Increase the membrane age to 4 years. Note the change in permeate flow rate and energy consumption. **Older membranes require more pressure.**

10. Adjust recovery rate to achieve the original permeate flow rate. Balance flows.

    Productivity can be maintained despite membrane age and fouling by reducing the recovery rate.

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PX Lubrication Flow and Pressure Drop

A small fraction of the high-pressure concentrate flows through the PX's hydrodynamic bearing. This flow is necessary to lubricate the PX rotor, but is also a volumetric loss. Excess lubrication flow is an indication of a leak in the system. The lubrication flow rate can be monitored with SWRO process flow readings.

1. Reset ERI SIM.
2. Conduct a Startup. Balance flows. Respond to any alarms.
3. Record the following:

   High-pressure pump flow rate: __________.

   Permeate flow rate in m^3/hr: __________.

4. Calculate the difference between the high-pressure pump flow rate and the permeate flow rate: __________.

The high-pressure pump supplies the permeate flow and the PX lubrication flow.

5. Record the following:

   PX array low-pressure inlet flow rate: __________.

   PX array low-pressure outlet flow rate: __________.

6. Calculate the difference between the low-pressure flow rates: __________.

   Lubrication flow rate calculated in these two ways is always equal. Also, the difference between the high-pressure inlet and outlet flows to the PX array equals the lubrication flow rate.

   Lubrication flows from high to low pressure and ends up in the PX low-pressure outlet.

7. Record the PX unit low-pressure flow rate: __________.
8. Set the low-pressure control valve to 29% open.
9. Stop the high-pressure pump.
10. Calculate the lubrication flow: __________.

    Lubrication flow is driven by pressure. Lubrication flow decreases when system pressure decreases and is zero when the membrane reject

<u>pressure equals the PX reject pressure. Lubrication flow can be driven by osmotic pressure even when the high-pressure pump is off.</u>

11. Restart the high-pressure pump. Balance flows.
12. Record the PX high-pressure flow rate: __________.
13. Record the PX low-pressure flow rate: __________.
14. Increase the number of PX units.
15. Balance flows.
16. Note the PX unit high- and low-pressure flow rates.

<u>Increasing the number of PX devices decreases the PX unitary flow rate. As the flow rate through the PX devices decreases, viscous friction also decreases.</u>

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SECTION 2

SYSTEM UPSETS

SWRO Process Upsets

ERI SIM can simulate three SWRO process upsets specified by the user. Restoring the system to normal operations may require that the process be shut down and service performed.

1. Reset ERI SIM.
2. Start the process by clicking the AUTO START button
3. Record the differential pressure across the filters: __________.
4. Click the "CLOGGED FILTERS" button. Note the change in differential pressure and the affect on the low-pressure flow rate.
5. Clean the filters by clicking the CLEAN button adjacent to the filters.
6. Note the following:

   Differential pressure across the membranes: __________

   Membrane feed pressure: __________

   Specific energy: __________

   Permeate production rate: __________
7. Click the "FOULED MEMBRANES" button. Note the membrane differential pressure.

   Membrane fouling has little affect on membrane differential pressure.
8. Note the change in membrane feed pressure, specific energy and permeate flow rate.

   Membrane fouling significantly increases membrane feed pressure and energy consumption. Permeate flow rate decreases as the duty point of the high-pressure pump moves up the curve.
9. Conduct a Shutdown. Clean membranes by clicking the CLEAN button adjacent to the membranes.
10. Conduct a Startup. Balance flows. Respond to any alarms.
11. Click the "BOOSTER MALFUNCTION" button. Note the change in the high-pressure flow rate.
12. Conduct a Shutdown.
13. Service the booster pump by clicking the SERVICE button adjacent to the pump.
14. Restart the ERI SIM process to confirm that the booster pump has been fixed.

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PX Device Upsets

ERI SIM can simulate two PX device upset conditions selected by the user: a stopped rotor or an internal leak. PX device upsets can be detected as changes in SWRO process flows or salinities. Restoring the system to normal operation requires that the process be shut down for service.

1. Reset and restart ERI SIM.
2. Record the following:

    Membrane feed pressure: __________

    Membrane feed salinity: __________

    High pressure pump flow rate: __________

    Permeate flow rate: __________

3. Calculate the PX lubrication flow rate: __________
4. Click the “STOP ONE PX” button. Examine the PX low-pressure outlet salinity readings to find the stopped rotor.
5. Note the change in membrane feed salinity and pressure.

    A stopped PX rotor allows a portion of the SWRO concentrate to mix into the membrane feed. The salinity increase results in higher membrane feed pressure.

6. Note that the permeate production rate changes less than 1%.

    If one PX rotor in an array of more than 5 PX devices stops for any reason, the SWRO train can continue to run with minimum loss of productivity.

7. Recalculate the PX lubrication flow rate: __________.

    A stopped PX rotor does not change lubrication flow. The PX devices seal the SWRO high-pressure loop even if the rotors are not spinning.

8. Stop the process by conducting a Shutdown.
9. Service the PX devices by clicking the **SERVICE** button adjacent to the PX array.
10. Set the low-pressure control valve to 29% open. Conduct a Startup.
11. Click the “PX Internal Leak” button.
12. Calculate the PX lubrication flow rate: __________.

    A PX internal leak can be detected as an increase in the PX lubrication flow rate.

13. Note the membrane feed salinity and the PX low-pressure outlet salinity readings.

    A PX internal leak does not significantly affect membrane feed salinity.

    A PX internal leak cannot be detected with PX LP outlet salinity readings.

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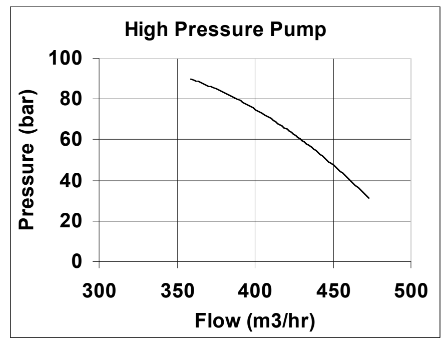
Operational Errors

SWRO processes must be started and shutdown in the established sequence to prevent overflow and overpressure situations. ERI SIM allows the user to study the consequences of operational errors.

1. Reset and restart ERI SIM.

2. Stop the booster pump. Note the alarms and process conditions.

   Without circulation in the high-pressure loop, the salinity in the membranes quickly increases. The duty point of the high-pressure pump is pushed up the curve as the membrane pressure increases resulting in an overpressure situation.



3. Stop the high-pressure pump, restart the booster pump, then restart the high-pressure pump.

4. Stop the supply pump. Note the alarms and process conditions.

   Without supply water, the high-pressure pump runs dry.

5. Restart the supply pump. Note any alarms.

   The system must be purged before it is pressurized to release trapped air and prevent destructive water hammer. Air will not pass through the membranes.

6. Stop the high-pressure pump. Note any alarms.

   The feedwater supply flow rate must be reduced before the high-pressure pump is shut down to prevent overflow of the PX devices.

   NOTE: SWRO systems of this size typically have control systems that allow the operator to automate startup and shutdown sequences, thereby avoiding overflow conditions.

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Random Process Upsets

ERI SIM is programmed with 16 random process upsets, including the 5 upsets described above. The user initiates a random upset, then must diagnose the problem based upon the available instrument readings. Appropriate corrective action restores the process to startup conditions.

1. Reset and restart ERI SIM.
2. Record the following process data:

   Feedwater salinity: ___________

   Feedwater temperature: ___________

   Filter differential pressure: ___________

   Membrane feed pressure: ___________

   Membrane feed salinity: ___________

   Permeate flow rate: ___________

   Permeate salinity: ___________

   PX lubrication flow rate: ___________

   PX low-pressure flow rate: ___________

   PX high-pressure flow rate: ___________

3. Click the **RANDOM** button. Note any change in process data. Note any alarms.
4. Diagnose the process upset. Take appropriate corrective action.
5. Re-establish startup conditions to confirm that corrective action restored process operations.
6. If unsuccessful diagnosing process upset, click the **reveal** button. The process upset will be displayed.
7. Review process data and note any changes.
8. Take appropriate corrective action.
9. Re-establish startup conditions to confirm that corrective action restored process operations.
10. Continue to generate, diagnose and rectify random process upsets.

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SECTION 3

PROCESS OPTIMIZATION

Optimizing System Operation

The pumps, membranes and PX devices incorporated into ERI SIM cannot be changed by the user. However, many of the operating conditions can be changed to reduce energy consumption and operating costs.

1. Reset ERI SIM. Conduct a Startup. Balance flows. Respond to any alarms.

2. Record the following:

   Specific energy: __________

   Operating cost: __________

3. Manipulate system variables to minimize specific energy consumption and operating cost.

   The lowest "scores" achieved by the author, with a feedwater temperature of 25 degrees Centigrade, a feedwater salinity of 36,000 ppm and no alarms, was:

   Specific energy: 2.43 kWh/m^3

   Operating cost: $4,058/month

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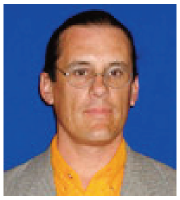
About ERI® and PX® Technology

Energy Recovery Inc (NASDAQ: ERII), a global leader in the development and manufacture of energy recovery devices, is helping to make desalination affordable. Our PX Pressure Exchanger® (PX®) energy recovery technology can reduce the amount of energy required to desalinate seawater by up to 60%, resulting in more economical production of drinking water and a reduced carbon footprint. Over 6,000 PX devices have been shipped to more than 80 OEMs worldwide to support the production of drinking water for about 17 million people. Some of the world's largest seawater desalination plants are reducing their environmental impact by using PX technology. These devices are saving an estimated 550 MW of energy, and reducing carbon dioxide production by about 1.6 million tons per year.

ERI is headquartered in the San Francisco Bay Area and has offices on every continent.

About the author and developer of ERI-SIM



Richard Stover, Ph.D., ERI Chief Technical Officer has 20 years of research, development and manufacturing engineering experience with 3M, IBM and ERI. His technical expertise includes fluid mechanics, hydraulic systems and process design. His hands-on approach to product development - from fundamental research through prototyping, scale-up, operation, and troubleshooting - have led to a number of successful commercial products including the PX-180/220. He was a co-recipient of the European Desalination Society's Sidney Loeb award for innovation for his work on the PX device. Dr. Stover earned his Ph.D. in Chemical Engineering at the University of California at Berkeley.

SYSTEM REQUIREMENTS:
Microsoft Office Excel 2003 or greater

Making Desalination Affordable®

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