Comparison of
FEDCO HPB Pressure Booster and
ERI Pressure Exchanger

Prepared by
Fluid Equipment Development Company
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What to Look for in a Energy Recovery Device (ERD)

Life Cycle Cost – minimizes the cost permeate over the life of the plant;

Low Capital Cost – equally important to Life Cycle Cost, the equipment must be affordable to encourage customers to use desalination as a solution to water scarcity and system builders to win proposals with competitive bids;

Reliability – provide years of continuous service with zero maintenance;

Safety – inherently safe for personnel and equipment;

Ease of operation and maintenance – For a system to work for years, it must be easy to operate and maintained regardless of the level of training or experience;

Long Term Support – supplier financial strength and independence.
The FEDCO HPB turbocharger manufactured by Fluid Equipment Development Company (FEDCO) is compared with the Pressure Exchanger (PX) manufactured by Energy Recovery, Inc. (ERI).

All data used in this comparison were obtained from the following sources:
1. Published data from Fluid Equipment Development Company (FEDCO);
2. Published data from Energy Recovery, Inc. (ERI)
   - Primarily “Installation, Operation & Maintenance Manuals” for “65 Series Pressure Exchanger™” (ERI Doc number 80019-01-02) referred to as “PX Manual” in this document
3. Reasonable engineering estimates

All calculations and data are fully transparent. Details are available from FEDCO upon request.

If there are any errors in the data or analysis, please contact us immediately and we will correct accordingly.

Any new information regarding the data in this presentation will be greatly appreciated.
Equipment Evaluated

FEDCO Hydraulic Pressure Booster (HPB)
Nominal ratings:
• Feed flow = 10 to 2800 m³/hr (44 – 12,300 gpm)

FEDCO HP-HEMI
Nominal ratings:
• Feed flow = 300 to 2800 m³/hr

ERI PX-220
Nominal ratings:
• Feed flow = 50 m³/hr (220 gpm)
(PX units require substantial additional equipment to achieve functionality which will be included in the evaluation)
FEDCO Hydraulic Pressure Booster (HPB)

The HPB produces up to 50% of the membrane pressure requirement, thereby, reducing the energy input and size of the HP feed pump, motor and motor starter/VFD. Typical installation and operation are indicated below.

**Key Concepts**
- Works just like an automotive turbocharger
- Automatically boosts feed pressure
- Fully powered by brine pressure
- Absolutely no other equipment required
Features

- One moving part
- No shaft seal – zero leakage to atmosphere
- Water lubricated bearings
- Integral brine control valve
- All-duplex or Super Duplex Construction
- Quiet and smooth operation
- Most compact size of all ERDs
HPB - Installation

The HPB can be installed in any orientation - sideways, vertical, etc. Connect the 4 pipes and the installation is complete.

Features
- no high pressure booster pumps
- no special instrumentation
- no isolation valves
- brine disposal at any pressure
HPB Operation

Operation
• Start the low pressure feed pump, vent air from system
• Start high pressure feed pump
• Walk away – system is running

To increase brine pressure:
• Close the valve

To decrease brine pressure:
• Open the valve

manual or automatic valve actuator

Features
• Easy training of operating staffs, replacement staff intuitively learns operation
• Operator error can not damage the HPB or feed pump
• Simplicity demanded by military users, off-shore operators, hotels and resorts
• Reduces complexity in large systems thereby reducing system control costs.
Overhaul Requirements

• 15 - 60 minutes
• No skilled labor
• No special tools
• No measurements
• Same procedure for every HPB model
Hydraulic Energy Management Integration (HEMI)

The HP-HEMI is an HPB with a motor attached to the low pressure (brine outlet) end of the rotor. The motor helps adjust the rotor speed to provide the desired feed pressure. The HEMI motor is typically 10-15% of size of HP feed pump motor and uses a standard (low voltage) VFD. The HEMI:
• Regulates feed flow and pressure for desired membrane performance;
• Eliminates need for VFD or control valve on the HP feed pump;
• Regulates brine flow and pressure as required for desired membrane performance;
• Can provide total feed and brine regulation via PLC control (provided by FEDCO).

HP-HEMI-1000
HP-HEMI models cover flow ranges from 300 to 2000+ m³/hr
Feed Pressure Control

The HP-HEMI can produce the exact amount of feed boost needed to meet membrane requirements. The HP pump runs at constant speed and without a throttle valve to regulate feed pressure. The HEMI modulates feed and brine pressure exactly as needed to achieve desired membrane pressure from a constant pressure feed supply.

The PX system, in comparison, has absolutely no ability to regulate feed pressure. Therefore, costly and energy wasting feed throttle valves or Variable Frequency Drives on the HP pump are required. That is one reason why the HEMI can deliver a lower energy consumption than the PX system in realistic field operation.

The chart (below) presents a typical annual pressure variation. The HEMI smoothly adjusts its operation to deliver the required membrane pressure without any throttling. Note that the HP pump operates at fixed pressure thus eliminating the need for a feed control valve or variable frequency drive.
PX Principle of Operation

- HP feed pump
- Residual pressure relief valve
- Isolation valve (3)
- PX units (1 to 20+)
- Control valve
- High inlet pressure booster pump with VFD. Boosts pressure and used to control PX rotor rotation.
- HP flow meter
- Membrane

Qf = feed flow
Qb = brine flow
Qp = permeate flow

A simplified system diagram[1] – special flushing piping, safety interlocks, PX sample ports, etc. omitted for clarity. Indicated flows are approximate.

A given rotor channel is alternately filled with low pressure feed and then purged with high pressure brine with the fill purge cycle controlled by the rate of rotor rotation, brine discharge control valve and HP boost pump.

Rotor rotation rate must be closely matched to the fill/purge rate. However, the rotor speed and fill/purge cycle rate operate independently thereby requiring adjustment of the HP booster pump and brine control valve to maintain acceptable operation.

Changes in feed water conditions or pretreatment pressure may require ongoing adjustments to maintain the phase relationship between rotor rotation and fill/purge cycle times.
**PX – Rotor Blow Through**

**“BALANCED” OPERATION**
- Rotor rotation is driven by impingement of flow on end of rotor
- Lubrication flow (feed leaking into the brine stream (1-2% when units are new)
- Brine/feed interface – the interface location oscillates from one end of the channel to the other end several hundred times per minute. At normal operation, 4-5% of brine mixes with feed and enters the membrane

**“UNBALANCED” OPERATION – Rotor Blow Through**
- HP brine entering HP feed “Blow through”
- LP feed entering LP brine “Blow through”

**Blow Through**
Unbalance operation means that the rotor speed is wrong for channel fill rates resulting in the brine/feed interface moving outside the rotor channel resulting in “blow through[1]”. Brine blow through can reach very high levels thereby possible forcing a system shutdown. At the very least, feed pressure will rise and permeate quality will deteriorate due to excessive feed TDS.

Stuck PX Rotor Failure

There are two types of rotor failure. One failure involves destruction of the rotor and/or bearing surfaces. This discussion will focus on a stalled or stuck rotor.

A stuck rotor creates a brine flow into HP feed stream approximately equal to normal unit rating. For example, a stalled PX-220 may inject from 45 to 55 m³/hr of brine into the feed stream[1]. This is the most extreme form of “blow through”.

Factors that can stall the rotor include:
• bio-fouling [2]
• debris in the feed or brine streams [3]
• precipitates such as various salts [4]
• Several anti-scalants and various water treatment chemical [5]
• damaged rotor, bearing or end plates caused by:
  • air bubbles [6]
  • operation outside the specified flow range [7]
  • pressure spikes damaging the rotor and/or bearing surfaces [8]
  • cavitation [9]

Why the PX rotor sticks and the HPB does not
• Torque exerted by feed or brine impinging on the PX rotor is low;
• The PX bearing surfaces are very large (i.e. The entire rotor);
• The combination of low torque, large bearing surfaces and small clearances create sensitivity to bio-fouling and other foulants.

In contrast, the HPB has high torque and small bearing surfaces making rotor sticking virtually impossible.

Un-sticking the PX rotor
• System is shutdown;
• PX array isolated and drained;
• Failed unit physically removed to work area;
• Disassembled, cleaned and re-assembled (49+ steps).

Please refer to page 10 to compare with the internal inspection of the HPB.

1 - private communications with PX users
2 - page 13, PX Manual
3 - page 27, PX Manual
4 – Private communications
5 - page 12, PX Manual
6 - page 8, PX Manual
7 - page 11, PX Manual
8 - page 8, PX Manual
9 - page 11, PX Manual
Potential PX Rotor Destruction

Operating beyond flow limits

“Failure to do so [maintaining flow limits] can result in damage or destruction to the PX unit and/or other equipment.” [1]

Cavitation

” ...[sufficient back pressure required to] prevent destructive cavitation”[2]

Air Bubbles

“Large bubbles can damage the PX device”[3]

Pressure spikes

“Pressure/flow spikes require particular consideration in systems with multiple SWRO trains as trains go on- and off-line. An automatic flow control system is typically not responsive enough to provide constant flow during sudden pressure changes. Emergency shutdown sequences should include shutting down the seawater supply pump(s) to avoid overflow.”[4]

The PX rotor is described as being very tough based on its ceramic construction. However, the factors that can destroy the rotor can occur in virtually any seawater RO system.

The cost of repairing a PX unit with worn-out or destroyed rotor is apparently quite close to the cost of an entirely new unit[5]. In contrast, if an HPB rotor needs replacement (for example due to massive ingestion of debris), the cost of a new rotor and bearing set is about 40% of the new unit cost. Moreover, the rotor can often be refurbished to an “as new” condition by FEDCO for a fraction of the cost of an overhaul kit.
Multiple PX Units and System Reliability

“...with a conservative design, a plant with multiple PX's in designs of five or more can typically operate indefinitely with one or more PX's removed from service...” - from ERI published statements

The above statement means that a single failed PX unit in an array of 1-4 units can force system shutdown. Here’s why:

• a failed unit allows brine flow into the feed equal to or exceeding the rated capacity;
• for example, a PX-220 may allow 50 m³/hr of brine contamination of the feed stream[1];
• High levels of brine contamination greatly degrades system performance to the point of preventing system operation;
• Therefore potential for system failure is increased by 400% compared to a single unit of similar reliability in a PX system with four (4) units.

Mean Time Between Failures (MTBF) is the average time between failures of a given item. Two operating units with the same MTBF will experience a failure in one of the units at 50% of the single unit MTBF[2]. Extending this concept to a system that allows 1 failure per 5 operating units results in the adjacent chart. Here the MTBF applies to RO system failure relative to the MTBF of a single PX device.

Thus, multiple PX units create a shorter system MTBF.

1 - private communications with various PX users
2 - “Reliability and MTBF Overview” by Scott Speaks, Vicor Reliability Engineering
PX Auxiliary Equipment

A – Residual pressure remains on the feed side of the system after shutdown. This valve relieves pressure to reduce potential for accidents during system maintenance.

B – A flow meter rated for membrane pressure is needed to help achieve “flow balance” of the PX units.

C – This pump regulates PX feed rate and must be adjusted in combination with valve F to achieve “flow balance”. Must be rated for membrane pressure operation.

D – Each PX unit generates sound levels up to 92 dB. An array of 10 units may emit a total dB of 102 dB making acoustical enclosures highly desirable if not mandatory.

E – To reduce pipe strain, a spool piece is required for each PX connection with 2 Victaulic™ joints per spool piece. A PX array of 20 units require 80 spool pieces and 160 Victaulic™ joints.

F – Regulates brine flow to help achieve “flow balance”.

G – Needed to help achieve “flow balance”.

H – Isolates units from cleaning chemicals.

I – Used to detect excessive brine mixing indicating a failed unit.

J – Four (4) manifolds

Not shown:
- special flushing pipes and valves
- safety interlocks
- cleaning bypass lines
- special pressure control valves and emergency shutdown for multi-train operation.
A routine pump trip on the HP pump or LP feed pump supply will cause a momentary change in feed supply pressure. The consequences can result in severe damage to the PX ERD[1].

For example, a trip of Pump B (diagram at right) can cause PX units in trains A and C to suffer destruction from a momentary pressure/flow spike.

Special fast acting control valves, emergency shutdowns and other special means are needed to reduce the potential for destruction of the PX units[2].

Or, the PX trains can be supplied by a separate pretreated water supply system with separate feed pumps and supply piping[3]. Substantial added costs and complexities are incurred.

HPB and HEMI units are immune from effects of flow surges and pressure spikes.
Operating Range

- HPB hydraulic characteristics match membrane performance.
- HPB is not subject to severe damage or destruction if flow reaches hydraulic limits.

For PX, the LP brine pressure must be at least 1 bar less than LP feed pressure to allow purging of brine from the PX rotor channels.

This linkage between feed pretreatment pressure and brine discharge pressure complicates the need to discharge brine at higher pressures.

HPB has no restriction of LP brine pressure relative to feed pressure.
Safety

The PX has a variety of stringent operating requirements that, if not closely adhered, can result in serious equipment damage and possible injury to personnel. Examples include:

1. Very strict flow limits otherwise PX units may be destroyed[1];
2. Retaining ring can fail with “catastrophic” results if exposed to moisture[2];
3. High pressure remain in system after shutdown exposing maintenance personnel to risk[3];

The PX requires additional equipment which involve:

1. Booster pump and VFD with associated electrical components, wiring, conduits, etc each with their own hazards and safety requirements;
2. Additional lockout – tag out safety procedures;
3. Highly trained maintenance personnel required for motor, VFD, PLC controls and interlocks, high accuracy flow meters sampling of feed and brine at each PX unit, etc.;
4. Hundreds of additional Victaulic™ high pressure pipe joints in large PX arrays;
5. Stoppage of PX rotor during system operation is equivalent to a sudden blockage of the brine flow. Feed pressure may rise abruptly. If safety equipment fails to respond, serious damage can occur through the system;
6. Noise levels that can greatly exceed 90 dB. 90 dB is considered harmful to unprotected operating staff [4].

2 – p. 11, PX Manual  4 – Occupational Safety and Health Administration (OSHA) – Regulation 1910.5(a)
Illustrated in the adjacent figure, efficiencies of well-design centrifugal HP pumps increase from about 57% to nearly 90% over flow ranges typical of RO systems.

The PX reduces HP pump flow to that of the permeate flow thus reducing pump efficiency relative to a pump handling the entire feed flow.

For example, assume an SWRO system produces 450m$^3$/hr at 45% recovery. With the PX, the HP pump handles 450 m$^3$/hr but with an HPB or HEMI the feed pump handles 1,000 m$^3$/hr. The expected HP pump efficiencies are 80.7% and 84.2% respectively – over 4% reduction in HP pump efficiency for the PX.

Thus, the PX reduces feed pump efficiency for a given train capacity.
Economic Analysis

Major Assumptions
- Recovery = 45%
- Psuc = 2 bar
- Pm = 60-70 bar
- Pr = 58-68 bar
- Pex = 1 bar
- Feed throttle pressure control
- HPP efficiency from chart on page 21
- Period = 15 years
- Power = $0.09 kw-hr
- Interest = 7%
- Inflation = 3%
- Field rate = 950USD/day (maintenance)
- Cost = 1.50USD (lost revenue during downtime)
- All pump efficiencies are calculated without regard to type of ERD.

Overhaul:
- PX - 5 years
- HPB & HEMI - 6 years

Conclusions
- HPB SEC within 3-12% of PX
- HEMI beats the PX SEC in all cases
- HPB and HEMI matches or beats the PX in Life Cycle Cost

The HPB and HEMI provide a lower LCC and lower cost permeate
Bid Competitiveness

This chart illustrates the capital and installation costs for the following equipment:
- ERD
- high pressure pump
- control valve,
- contactor
- associated design and procurement costs.

The HPB and the HEMI packages have much lower total cost than with the PX package resulting in a substantial reduction of the total SWRO system.

With the HPB and HEMI, the OEM can offer lower bid prices with greater margins.
## Toughness - Ability to Handle the Unexpected

<table>
<thead>
<tr>
<th>Factor</th>
<th>HPB</th>
<th>PX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (Storage/operating)</td>
<td>70 C / 60 C</td>
<td>45 C / 45 C[1]</td>
</tr>
<tr>
<td>Particle size</td>
<td>20 micron</td>
<td>5 micron[2]</td>
</tr>
<tr>
<td>Bio-fouling</td>
<td>No potential damage</td>
<td>Can cause unit failure – warranty requires extensive precautions[3]</td>
</tr>
<tr>
<td>Anti-scalants and water treatment chemicals</td>
<td>No restrictions</td>
<td>Total prohibition on several types, very strict usage requirements on others. No water treatment chemicals of any kind[4].</td>
</tr>
<tr>
<td>Pressure spikes</td>
<td>No potential damage</td>
<td>Extensive system modifications, fast acting valves, emergency shutdowns prescribed[5].</td>
</tr>
<tr>
<td>Mis-operation</td>
<td>No potential for ERD damage from operating error</td>
<td>Complex operating requirement increases potential for operator error resulting in possible destruction of ERD and other system components</td>
</tr>
<tr>
<td>Brine intrusion into feed</td>
<td>Zero</td>
<td>“Normal” leakage is 5+% of brine flow and can be much higher if flows are “unbalanced”[6]</td>
</tr>
<tr>
<td>Startup</td>
<td>Turn off HP pump, LP pump</td>
<td>Follow multi-page procedures, verify safety interlocks are in place, perform “flow balance” to prevent “blow through”[7].</td>
</tr>
<tr>
<td>Shutdown</td>
<td>Turn of HP pump, LP pump</td>
<td>Following shutdown sequence, system remains dangerously pressurized for a period of time[8].</td>
</tr>
<tr>
<td>Membrane cleaning</td>
<td>No damage to unit</td>
<td>PX units must be physically removed from system or isolation vales employed[9].</td>
</tr>
<tr>
<td>Flow variation</td>
<td>No damage</td>
<td>Rotor can be destroyed by slight variations in flow rate beyond specified limits[10].</td>
</tr>
<tr>
<td>Air bubbles in feed or brine</td>
<td>No problems</td>
<td>Voids warranty, can destroy the unit[11]</td>
</tr>
</tbody>
</table>

With the HPB, there is one and only one warranty.

With the PX, many suppliers of critical equipment are involved each with their own warranty, length, terms and exceptions. Warranty management and administration can become major difficulties.

![Warranty Length Diagram]

1 – p. 29, PX Manual
Every disclaimer and exception in a warranty may represent multiple failures in the field for which the supplier has no answer and no solution.

A quality warranty has a minimum of exceptions, warnings and disclaimers. The PX warranty reflects a variety of operating issues for which ERI has addressed through warranty exceptions – i.e. the PX design restrictions are now the responsibility of the customer.

In comparison, the FEDCO warranty:
• keep debris from the unit
• maintain brine disposal pressure
• avoid excessive pipe strain.
## Summary of Comparison

<table>
<thead>
<tr>
<th>Feature</th>
<th>FEDCO HPB</th>
<th>ERI PX System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Cycle Cost – provides lowest cost of permeate</td>
<td>✗</td>
<td></td>
</tr>
<tr>
<td>Capital cost – lowest engineering, procurement and purchase cost</td>
<td>✗</td>
<td></td>
</tr>
<tr>
<td>Brine feed mixing – no contamination of feed with brine</td>
<td>✗</td>
<td></td>
</tr>
<tr>
<td>Reliability – fewest components, simplest construction</td>
<td>✗</td>
<td></td>
</tr>
<tr>
<td>Ease of operation – requires least amount of training, less potential for operator error</td>
<td>✗</td>
<td></td>
</tr>
<tr>
<td>Noise – which ERD is inherently quieter</td>
<td>✗</td>
<td></td>
</tr>
<tr>
<td>Safety – Least amount of HP equipment, piping, joints, no electrical components</td>
<td>✗</td>
<td></td>
</tr>
<tr>
<td>Maintenance – no auxiliaries, easier and lower cost overhauls</td>
<td>✗</td>
<td></td>
</tr>
<tr>
<td>Operating Range – broadest operating range, immune to mis-operation</td>
<td>✗</td>
<td></td>
</tr>
<tr>
<td>Toughness – ability to handle the unexpected</td>
<td>✗</td>
<td></td>
</tr>
<tr>
<td>Reliability and Warranty – longest and most generous warranty</td>
<td>✗</td>
<td></td>
</tr>
</tbody>
</table>
Comprehensive training on Selection, Installation
Commissioning and Maintenance of all FEDCO Products

With the most comprehensive produce lines from any RO equipment supplier, FEDCO offers the most comprehensive training on all aspects of:

- HPB and HP-HEMI
- MSS feed pumps
- SSD feed pumps
- LP (low pressure) ERDs and pumps
- RO system control for maximum energy efficiency

Class sizes range from 2 to 10. Contact FEDCO today for details.