Energy Recovery in Desalination: Returning Alternative Water Supplies to Consideration

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Desalination has been used by many countries around the world and it is often considered the most expensive water supply option available. The idea that desalination is expensive has contributed to a public perception that it is not a viable option for areas other than the Middle East, where energy costs are highly subsidized. When a community is in the middle of a water supply crisis, however, the water industry is posed with the question, "Where are we going to get our water?" The lack of education by the public about desalination makes it a technology that seems untouchable to the communities of Florida and the Unites States.

Reports of diminishing aquifer levels are often in the news, while scientific models tend to vary about the severity of the issue. Across the U.S., various water agencies have imposed regulations on existing groundwater supplies and they are forcing local municipalities to find alternative water sources. Typically, alternative water sources include surface water sources such as fresh water and seawater, or brackish water aquifers. The idea that these water sources exist are often overlooked in public discussion and are generally dismissed as too costly.

Given climate change and its effect on water supplies around the world, any water utility has to consider the longevity of water supply, as well as treatment options. Fresh surface water may not be available during drought, or in the cases of contamination recently making headlines, or because of restrictions from regulatory agencies. If these concerns could be addressed through a reliable source of supply, would a utility pursue desalination, or be repelled by the public's pricey perception? This could be the decision that plagues a utility or boosts it into a prominent future.

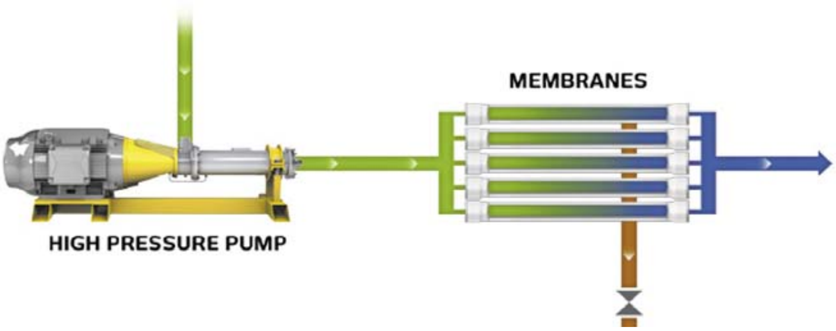

Figure 1. Reverse Osmosis Process Without Energy Recovery Devices

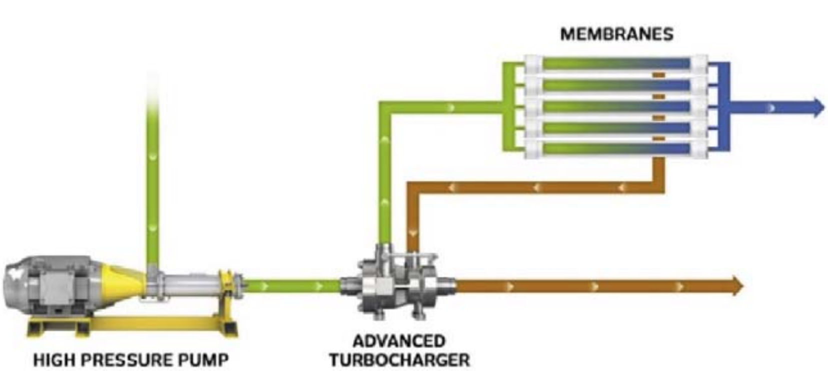

Figure 2. Hydraulic Turbocharger Device Schematic

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Where is Desalination Today?

The science supporting desalination has been advancing at a significant rate over the past decade. With regard to the membrane market, the industry has seen noticeable changes in production, performance, and reliability. One manufacturer is infusing the membrane's polyamide layer with nanoparticles to promote a negative charge, as well as including hydrophilic particles. In turn, the negative charge on the membrane surface assists in higher rejection rates, while the hydrophilic nature of the nanoparticles promotes higher flux rates through the membrane surface.

Other advances include membrane elements being developed to perform with higher rejection rates than previous elements at less driving pressure. Membranes are being manufactured specifically to reject ion-specific contaminants that were poorly rejected in past models. Ultimately, these improvements open up the market for further membrane consideration.

In addition to advances in membrane technology, chemical treatment capabilities can enhance membrane performance. With the introduction of the scanning electron microscope analysis of membrane elements, there is now a more accurate understanding of the foulants that plague membrane installations. Accordingly, chemical suppliers have focused on preparing chemicals that promote improved performance of membrane applications in water and wastewater. Antiscalents and dispersants are focused on operation without acid pretreatment for pH control, while inhibiting iron and other contaminants at the higher pH ranges. Traditional hampering of membrane performance included iron, calcium phosphate, calcium carbonate, and silica. Chemical manufacturers are now producing pretreatment chemicals to not only address these problem-specific items, but eliminate acid at the same time.

Lastly, there is popular pressure to use "green" chemicals in the process of producing potable water. Chemical suppliers are now generating cleaning chemicals with reduced or eliminated Ethylenediaminetetraacetic acid, or EDTA, while performing similar cleaning effectiveness. All together, the chemical advances of recent years have allowed membranes to be operated more efficiently and at reduced cleaning frequency, all while improving recovery rates where problematic foulants limited production in the past.

Perhaps the most significant cost-effective measures, and the focus of this article, include the energy recovery of the hydraulic energy potential captured in the desalination process. In general, desalination uses a lot of energy to overcome osmotic pressure from saline solutions. Reaching high pressures with the entire feed flow, a large portion of this pressure (hydraulic energy) has traditionally been lost or burned by throttling the waste stream (concentrate). Effectively, the hydraulic energy created for 20 to 60 percent of the raw feed flow has been lost, which contributes to the excessive energy costs of desalination. Energy recovery has been a large focus of membrane applications and brings a significant opportunity to reduce the energy costs of seawater and brackish water desalination plants. The following sections identify the various energy recovery devices available on the market today, as well as case studies where these applications have been considered and/or implemented.

Energy Recovery Devices

Currently, energy recovery devices are limited to recouping the concentrate pressure by transferring hydraulic energy to power generation, hydraulic-to-mechanical-to-hydraulic energy transfer, or hydraulic-to-hydraulic energy transfer. The typical brackish and seawater water applications focus on generating a driving pressure to exceed the osmotic pressure of the source water. A simple schematic is shown in Figure 1.

This traditional approach leaves the concentrate control valve responsible for bleeding the pressure from the system, and ultimately, the utility's wallet.

To make this process more energy friendly, the transfer of hydraulic energy remaining in the concentrate stream must be converted into a useful means of energy, whether it is electrical energy pushed back into the power grid or hydraulic energy transferred to the raw water stream. The bulk of energy recovery devices has been focused on the latter option since it can be very efficient and has a direct effect on the equipment procured for the membrane facility. As such, the key equipment elements in this process improvement include energy recovery devices (ERD) and high-pressure pumps. Linking these two elements together to work in unison has recovered 10 to 50 percent of the overall pumping energy required for the desalination process in multiple facilities.

First, ERDs are machines designed to recover the hydraulic energy of a pressurized water flow, and in this case, it is the concentrate stream. The process to recover the energy will vary, depending on the type of energy transfer technology utilized.The remainder of this section will explain the most widely used ERD technologies in the market today: centrifugal and isobaric devices.

Centrifugal Energy Recovery Devices

Centrifugal ERDs use the hydraulic energy of the membrane concentrate stream to help drive a high-pressure pump or coupled Pelton Wheel to boost the pressure of a contacted stream. These elements use a turbine to convert the hydraulic energy of the concentrate stream into the mechanical energy of a spinning shaft, which is then transferred to hydraulic energy through the use of a pump impeller or another Pelton Wheel (Figures 2 and 3). These are the two most employed centrifugal ERDs in desalination.

The hydraulic turbocharger device utilizes the mechanical energy of the Pelton Wheel shaft to turn a similar Pelton Wheel on the opposite end of the mechanical shaft. The coupling of both the hydraulic turbocharger and the high-pressure pump reduces the total displaced head of the pump and ultimately reduces the overall power consumption of the system. The efficiency of the hydraulic turbocharger in transferring the concentrate energy to the feed stream is nearly 81 percent.

The Pelton Turbine unit utilized the mechanical energy of the turbine shaft to augment the energy supplied by the high-pressure pump motor in pressurizing the raw water. Through this application of adding power to the motor, the efficiency of the energy transfer, or the percent of the hydraulic energy recovered, is nearly 78 percent.

Isobaric Energy Recovery Devices

Understanding the transfer efficiency limitations of the centrifugal systems, the next gen-

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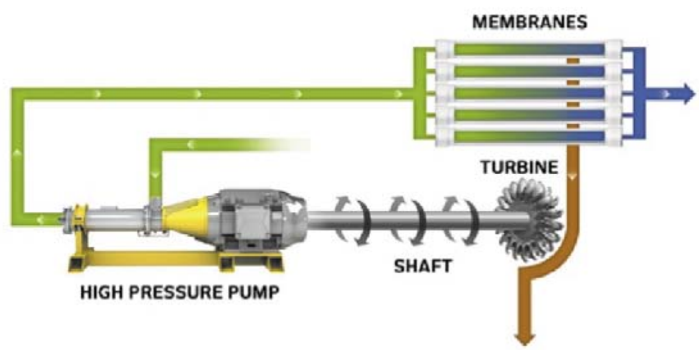

Figure 3. Pelton Turbine Schematic

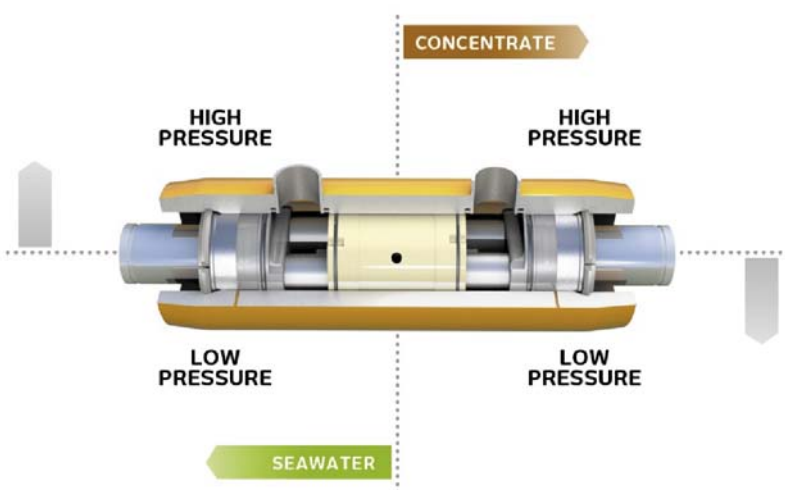

Figure 4. Isobaric ERD Showing High- and Low-Pressure Flows

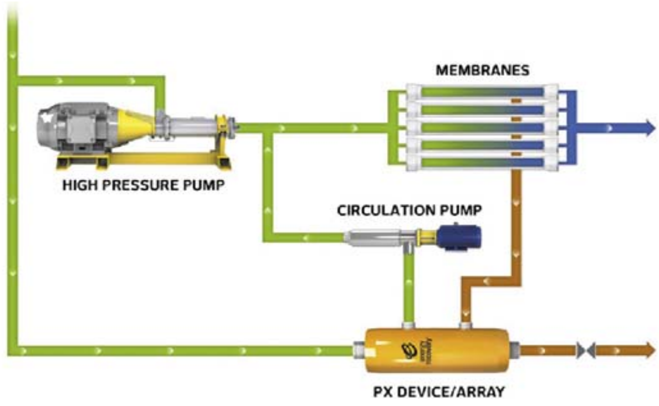

Figure 5. Isobaric Device Schematica

Table 1. Energy Recovery Devices: Technology Considerations

Description	Isobaric	Isobaric	Centrifugal	Centrifugal
	PX™ devices	Piston	Turbocharger	Pelton Wheel
Efficiency	98%	98%	81%	78%
Efficiency Curve	Flat	Flat	Curved	Curved
Mixing	2-3%	1%	0%	0%
HP Pump Size	Sized for Partial Membrane Feed Flow, Full Membrane Feed Pressure	Sized for Partial Membrane Feed Flow, Full Membrane Feed Pressure	Sized for Partial Membrane Feed Pressure, Full Membrane Feed Flow	Sized for Partial Membrane Feed Pressure, Full Membrane Feed Flow
Footprint Requirement	Relatively Small Compared to Overall SWRO Equipment	Relatively Small Compared to Overall SWRO Equipment	Relatively Small Compared to Overall SWRO Equipment	Relatively Small Compared to Overall SWRO Equipment
Extra Motor per RO Train	One Motor per RO Train - Standard Configuration	One Motor per RO Train - Standard Configuration	NO	NO
Periodic Maintenance	NO	YES	NO	YES
Modularity	YES	YES	NO	NO

Table 2. Energy Recovery Devices: Typical Applications

	Applications			
Description	**Isobaric**	**Isobaric**	**Centrifugal**	**Centrifugal**
	PX™ devices	Piston	Turbocharger	Pelton Wheel
Seawater - one or multiple stages	YES	YES	YES	YES
Brackish - one stage	YES	YES	Membrane Recovery Rate Below 60%	YES
Brackish - multiple stages	YES	YES	As Interstage Boost	NO
Interstage boost	ERD Booster Pump as Interstage Pump + ERD Feeding the First Stage	ERD Booster Pump as Interstage Pump + ERD Feeding the First Stage	YES	NO

Continued from page 41

eration of devices addresses a more direct transfer of energy, which eliminates the majority of the efficiency losses through transfer. These devices are isobaric in function, which means they equalize pressure. Simply, this system works with a ceramic piston or static water piston that separates two flow streams in a constantly oscillating chamber. Using the concentrate to pressurize one side of the chamber, it drives the piston down the chamber, imparting the same pressure on the opposite end of the chamber, the raw water stream. Because this application is a more direct transfer of energy from the concentrate stream to the raw water stream, the isobaric devices generally operate at higher overall hydraulic efficiencies. In a reverse osmosis (RO) system equipped with isobaric ERDs, the high-pressure pump (HPP) is only required to pressurize the amount of water that leaves the system as permeate, rather than the whole feed stream.

Rotary Isobaric Devices

Rotary isobaric devices recover the hydraulic energy from the concentrate stream by utilizing a small rotor. This rotor has ducts that alternately fill with high-pressure brine and low-pressure feed water. As the rotor spins, it exposes these ducts alternately to high- and low-pressure zones, effectively replacing the high-pressure brine with seawater in a 1-to-1 ratio (Figure 4). In this unit, the water exchange is timed such that the chamber is not completely exhausted, effectively creating a static water piston that minimizes mixing of the two streams.

Piston-Based Isobaric Devices

Piston-based isobaric devices, sometimes called work exchangers, use a pair of large pistons to alternately pump seawater into the membrane feed stream (using the brine reject pressure) and pump the brine reject out of the plant using the seawater feed pressure. The operation and timing of the pistons is controlled by a series of check valves, actuated hydraulic valves, and a dedicated electronic control system. As in the case of the rotary isobaric, a small circulation pump facilitates the process by circulating the water in the high-pressure loop through a slight boost of pressure (Figure 5).

The various ERDs are appropriate for different applications. As shown, ERDs focus on similar goals of reducing the HPP energy requirement and ultimately the energy consumption of the desalination process. When considering these ERDs for new and existing desalination plants, each technology must be reviewed to maximize the advantages and minimize the overall energy consumption of the

Continud on page 44

Continued from page 42
facility. Typical advantages and disadvantages are summarized in Table 1.

Accordingly, each device can be utilized for both seawater and brackish water. Table 2 shows the general conditions of employing each technology within the traditional desalination application.

As shown in Table 2, each technology can be implemented within brackish and seawater environments. Until recently, energy recovery has traditionally been focused on seawater applications, while less frequent ERDs have been installed on low total dissolved solids (TDS) brackish applications. This is due primarily to the lower feed pressures in brackish applications, as well as the low flow rate of the concentrate stream.

Now that the seawater market has begun to be saturated with ERDs and they are being implemented on the majority of new applications, ERD manufacturers are turning their focus to the brackish water applications, where significant energy savings can be realized both in retrofitted and new facilities. In seawater, ERDs provide simple energy transfer from the wasted stream to the feed stream; however, brackish ERDs bring energy recovery, as well as flux balancing for multistage systems. Flux balancing has numerous advantages:

- Spreads the rate of fouling deposition over the greatest membrane area
- Improves final-system permeate quality when the flux is increased in the last stages
- Reduces recovery in the first stage and increases it in the second stage
- Can reduce fouling potential in the first stage

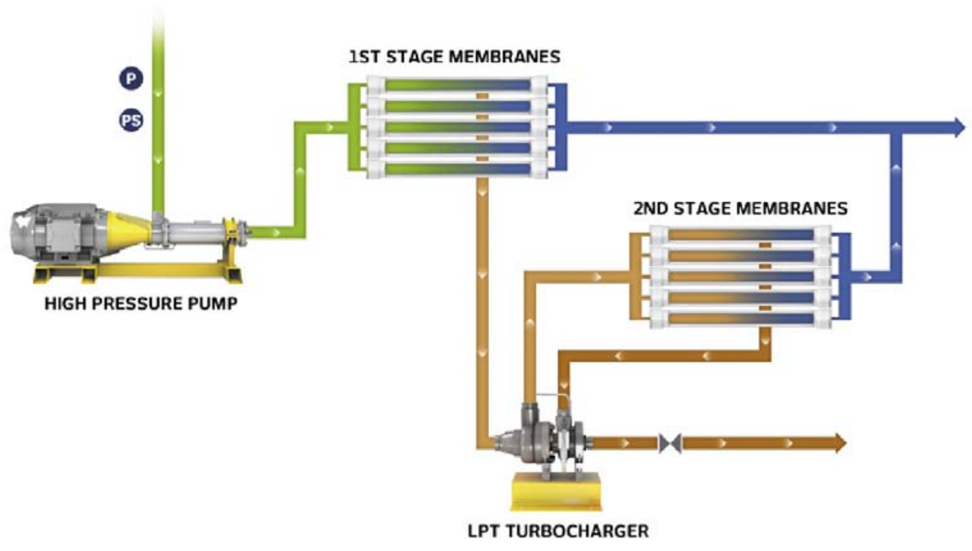

Figure 6. Low-Pressure Turbocharger Schematic With Flux Balancing

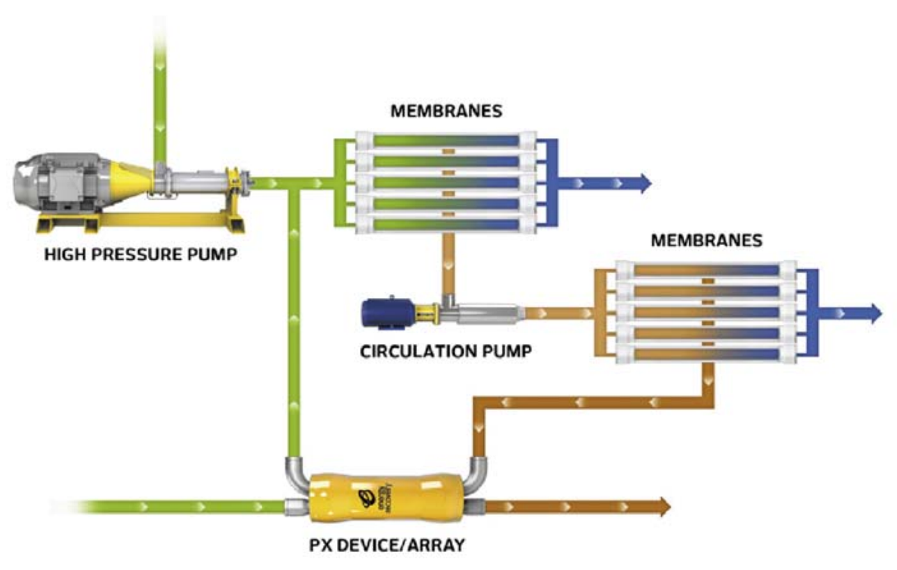

Figure 7. Pressure Exchanger Schematic With Flux Balancing

One of the major RO membrane manufacturers described the advantage of flux balancing as follows:

"By applying a balanced flux through the membranes, it can extend the lifetime of the system, which ultimately increases uptime. Fouling, scaling, and replacement rates also decrease. What's more, it leads to less maintenance, and this will be reflected in operational expense savings."

Flux balance configurations result in a number of advantages for multistage membrane treatment plants. Figures 6 and 7 identify the flow schematics for both a turbocharger and the pressure exchanger devices, respectively. Furthermore, several advantages are listed that detail the benefits of flux balancing among multistage treatment systems:

- *Two-Stage Membrane Flux Results.* In typical two-stage brackish water reverse osmosis (BWRO) systems without an interstage pump, the flux of the first stage is much higher than the flux of the second stage. By using an interstage boost, it is possible to increase the feed pressure of the second stage, therefore, increasing its flux. With this, it is likely to reduce the flux of the first stage, and the interstage boost will allow increasing flux and production rate of the second stage.
- *Increase Operational Life of the Membranes.* If the membranes operate at a lower flux rate, their operational life typically extends due to less repetitive fouling and subsequent cleaning. When retrofitting a current system, it is possible to increase permeate flow from the second stage without affecting the production rate of the first stage.
- *Increase of Production Flow.* When retrofitting a current multistage system, it is possible to increase permeate flow from the second stage without affecting the production rate of the first stage.
- *Reduction of Operational Expense.* Through implementing an interstage boost device, the hydraulic energy remaining in the concentrate stream is harnessed and used to boost the feed pressure to the second stage of membrane elements. As a result, the increased pressure between stages reduces the overall feed pressure of the membrane train, in turn, reducing the operational expense.

Facility Evaluations/Installations

ERD Application #1: The first facility evaluation is a 1.2-mil-gal-per-day (mgd) brackish water RO treatment plant located in Hawaii. The facility includes four existing brackish water RO trains with a permeate production rate just over 300,000 gal per day (gpd) or 220 gal per minute (gpm). Each train is a single-stage RO train with independent feed pumps. The brackish raw water source wells vary slightly in TDS and can be contained within the range of 7,500 to 10,000 TDS.

Following treatment by RO, a filtered raw water blends with RO permeate to supply irrigation to be used primarily for a golf course. The finished water storage lake has a capacity of 1 mil gal (MG) of storage. Water is then pumped from the lake for irrigation. The system was placed into service in June 2008 operating at 320 pounds per square inch (psi) feed pressure with 65 percent recovery.

For this application, the interest in energy recovery revolved around the high power costs from the electrical utility. At $0.42/kWh, any decreases in power consumption result in a significant operational savings for this facility. As such, the focus of the evaluation was geared toward achieving minimum energy consumption.

Through a quick evaluation utilizing Energy Recovery Inc. (ERI) software, the Pelton Wheel Turbine and turbocharger were eliminated from consideration based on the energy consumption of the system and lower transfer efficiencies with each device. For this application, the pressure exchanger system was selected to maximize the energy savings of this facility.

Given the current single-stage configuration (Figures 8 and 9), a significant amount of energy is being burned across the concentrate control valve. Utilizing the ERI energy projection software, the estimated energy savings is nearly 2,150 kWh daily ($900 per day), which accounts for nearly $330,000 per year in operational expense savings for the utility. With a capital cost for the pressure exchanger units of this size and other modifications at approximately $150,000, the payback for the pressure exchanger installation is less than six months of operation. Furthermore, the estimated CO_2 emission reduction is nearly 600 tons per year at this facility.

ERD Application #2: The second facility evaluation includes a two-stage brackish water RO plant in South America. The facility is composed of one brackish water RO train with two-stage membrane configuration. The train produces a total permeate flow rate of over 2.5 mgd (1,780 gpm / 9,720 m³/day). The project facility was designed for a feed pressure of 220 psi at 75 percent recovery.

Through a quick evaluation utilizing ERI software, the Pelton Wheel Turbine was eliminated because it cannot offer additional flux balancing for the system. For this application, the turbocharger and pressure exchanger device were feasible options for consideration. Following a brief review of the software, the turbocharger was selected due to the multitude of advantages it offered for this project. The solution was chosen due to the minimal footprint needed for installation and ease in operation for the utility. It also offered the least amount of ancillary equipment and a relatively short payback period.

With the two-stage configuration (Figures 10 and 11), a focus on flux balancing was paramount for this installation. The existing flux rates are heavily weighted toward the first stage of membrane elements; nearly a 50 percent increase in flux rate was observed in the second stage. The pre-ERD and post-ERD flux rates are shown in Table 3.

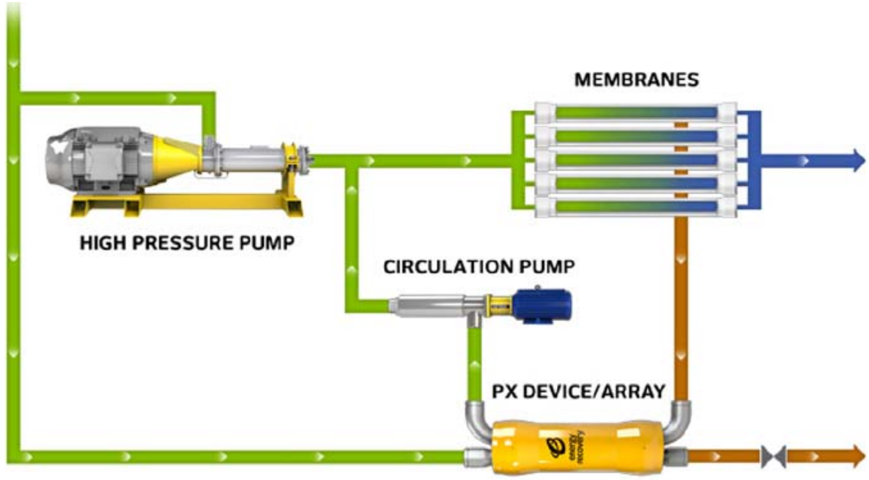

Figure 8. Brackish PX Installation Schematic

Figure 9. Brackish PX Installation

Utilizing the ERI energy projection software, the estimated energy savings is nearly 1,500 kWh daily ($180 per day-$0.12/kWh), which accounts for nearly $65,000 per year in operational expense savings for the utility. With a capital cost for the turbocharger unit and other modifications at approximately $80,000, the payback for the turbocharger installation is less than 15 months of operation. Furthermore, the estimated CO_2 emission reduction is nearly 284 tons per year at this facility.

ERD Application #3: The City of Port St. Lucie has two brackish water treatment facilities that currently treat brackish RO water. The focal point of this evaluation is the Prineville Water Treatment Plant, which consists of 10-mgd total production capacity from five RO trains. Each train produces just under 2 mgd and is combined with a blended stream to make up the total capacity of 10 mgd. For this case study, the viable options included both the centrifugal and isobaric devices.

Through a quick evaluation utilizing ERI

Continud on page 46

Continued from page 45
software, the Pelton Wheel Turbine and the pressure exchanger ERDs were eliminated from consideration based on the high-pressure pumps discharging into a common feed manifold and the pumps distance from the RO trains. The turbocharger device was compared using the ERI software to identify the operational savings and any major deficiencies prohibiting the installation.

After running the evaluation software, the turbocharger device was selected for further consideration based on the physical configuration of the existing RO trains and high pressure pumps. The preliminary evaluation for the turbocharger device indicated a return of 354 kWh per day of operation.

Capital expenses for this retrofit application include pipe modifications, control system modifications, and the ERD capital expense. Table 4 identifies the capital expenses, as well as the estimated energy savings for this application.

Given the extended payback period for the capital expense of the project, the utility did not pursue installing ERDs at this facility. As is the case with most existing facilities, implementing an energy recovery device after commissioning is much more invasive and results in significant capital expense outside of the ERD equipment. Provided consideration is given in the design phases of the facility, ERDs offer a much less expansive capital-intensive installation.

Each facility application described had individual goals and objectives for entertaining ERD evaluations. From power consumption to CO_2 reduction to operational cost minimization, the ERD components are viable options for cost-effective operation. Each facility's mechanical and process configuration must be considered individually as the energy returns/savings vary significantly for each application. From seawater to low TDS brackish water applications, ERDs provide an opportunity to reduce the operational costs for RO treatment facilities.

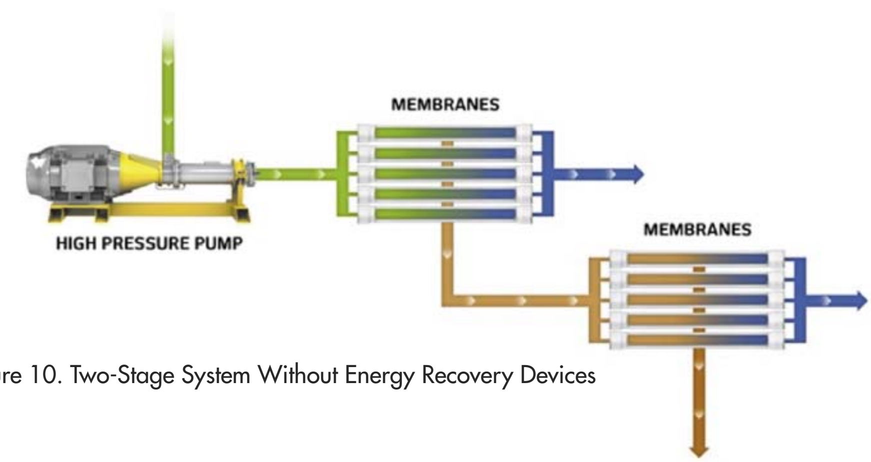

Figure 10. Two-Stage System Without Energy Recovery Devices

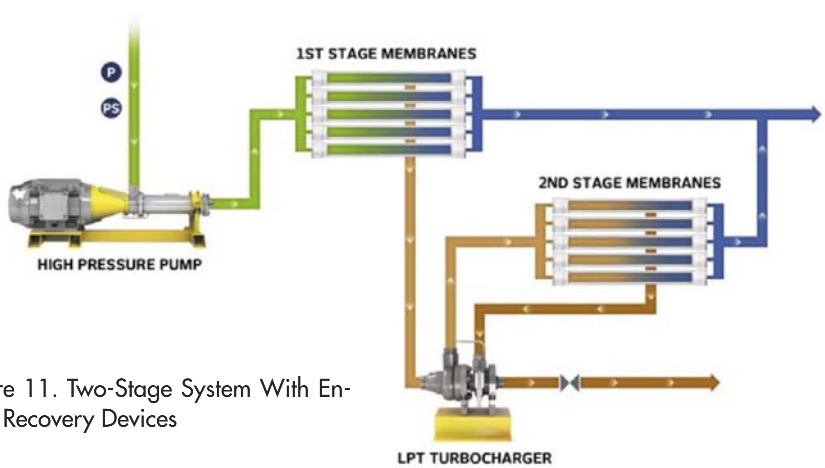

Figure 11. Two-Stage System With Energy Recovery Devices

Conclusions

As demonstrated through the evaluations and installations for these treatment facilities, energy recovery devices are producing significant operational expense reductions. In coupling these ERDs and the other technical advances, desalination is becoming a more affordable method of treatment for brackish and seawater alternative water supplies.

Utilities facing saltwater intrusion and increasing treatment regulations are starting to reconsider RO as an option to maintain reasonable utility rates for potable water, while evaluating alternative water supply and treatment options. By utilizing ERDs to reduce power consumption, the resulting operational expenses become more palatable for utilities.

When considering ERDs, all technologies must be considered to ensure that the appropriate unit can be applied for the respective application. The ERD efficiencies range from 78 to 99 percent, with isobaric being the most efficient and Pelton Wheel Turbines having the lowest efficiencies. Since no one-size-fits-all approach works for ERD consideration, each application must be analyzed specifically to determine the appropriate capital improvements necessary, cost implications, and feasibility to complete the retrofit of existing facilities.

Table 3. Pre- and Post-Energy Recover Device Flux Rates

	No ERD	Turbocharger
Flux - 1 Stage ($l/m^2/h$)	27.73	23.4
Flux - 2 Stage ($l/m^2/h$)	14.33	22.98
Membrane Feed Pressure (psi)	253	217

Table 4. Capital and Operational Expense

Financial Analysis		
Total Capital Expense	$100,000	USD
Piping	$30,000	USD
Control System Upgrades	$10,000	USD
ERD Unit	$60,000	USD
Energy Savings	354	kWh/day
Energy Costs	0.10	$/kWh
Operational Expense Reduction	$35	$/day
Payback Period	8.0	years