The Evolution of SWRO Energy-Recovery Systems

John P. MacHarg,
Energy Recovery Inc, USA

Editor's note

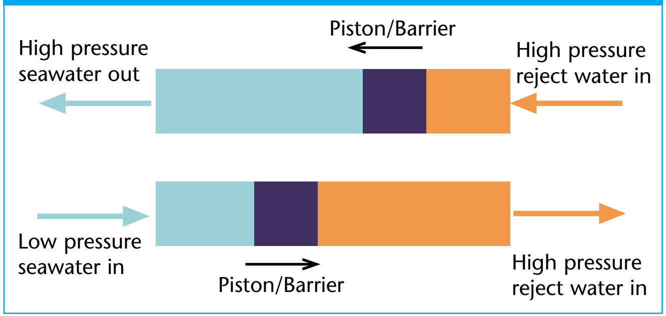
The recovery of energy from reverse-osmosis systems has been a major factor in the reduction of the cost of desalinated seawater to a point where it is beginning to offer a challenge to conventional sources. This article looks at the history of energy recovery, compares the different systems and observes that, now power consumption figures of less than 2kWh/m^3 are possible, the next leap forward may be in the power consumed by membranes.

Since the 1970s seawater reverse osmosis has been an energy intensive process largely because of the low (25 to 35%) conversion rates used in early pioneering plants to desalt seawater using membrane processes. These low conversion rates coupled with fairly high (800-1200 psi) operating pressures result in a large amount of energy left behind in the waste stream of SWRO systems.

Consequently the industry sought after a mechanical device that could recycle the energy found in the waste stream and transfer it back to the feed stream. Early efforts in energy recovery led to the successful commercial application of centrifugal devices, but now there are some commercially effective systems in the marketplace built around more efficient positive displacement devices.

Making a detailed comparison of efficiency and energy consumption between these two approaches is a critical step in reaching an understanding of which technology is right for today's SWRO systems.

Figure 1: Simple Schematic of Class I Energy Recovery Device



The Energy Recovery Approach

Class I energy recovery technologies use the principle of positive displacement and are commonly referred to as pressure exchangers. Commercial examples of such systems are Energy Recovery, Inc.'s Pressure Exchanger (PX), Desalco's Work Exchanger Energy Recovery (DWEER) system, Siemag's system and RO Kinetic's System. These technologies transfer the energy in the reject stream directly to a new seawater stream that combines with the total feed stream to the RO membranes. An energy saving is achieved by reducing the volumetric output required by the main high-pressure pump.

The efficiencies of all these devices can be quantified as the hydraulic energy out divided by the hydraulic energy in. Most of the positive displacement devices achieve relatively similar net energy transfer efficiencies between 91-96% over

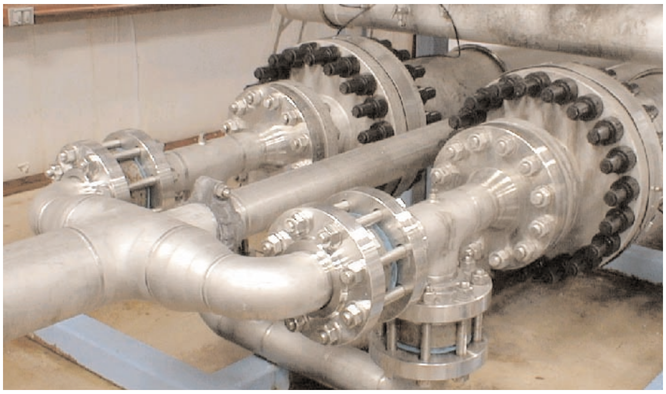
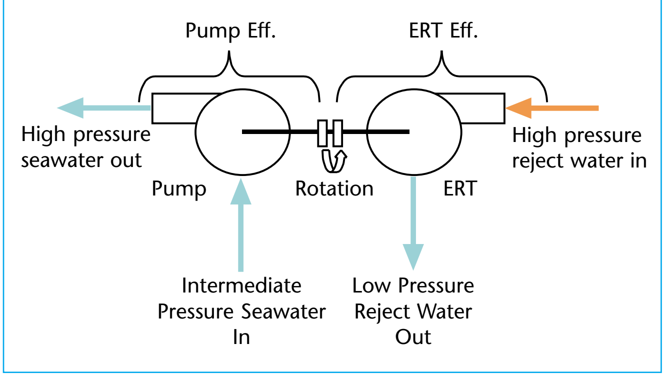


Figure 2: Simple Schematic of Class II Energy Recovery Device



the entire flow range of the systems considered in this article.

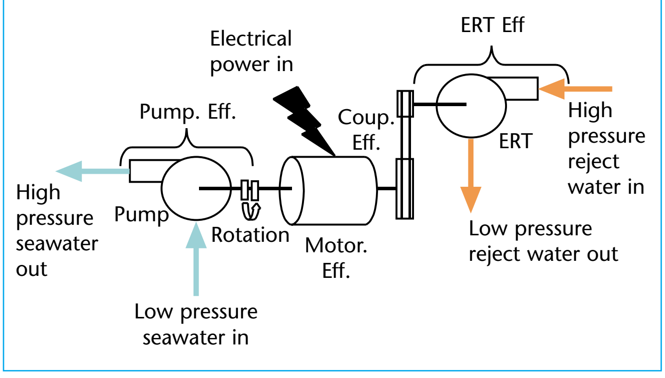
Class II energy recovery technologies are centrifugal in nature and are commonly referred to as turbo chargers. Commercial examples of such systems are Pump Engineering's TURBO and FEDCO's Hydraulic Pressure Booster. An energy saving is achieved because the main high-pressure pump's required discharge pressure is reduced.

These devices are typically supplied as a single stand-alone unit. The efficiency of these devices can then be quantified as the hydraulic energy out divided by the hydraulic energy in. Most of these devices achieve relatively similar net energy transfer efficiencies between 50-70% over the flow range of the turbo-type systems considered in this article.

Class III energy recovery devices are similar to class II devices in that they use the centrifugal approach and convert the hydraulic energy found in the reject stream into rotational energy, which is delivered in the form of mechanical shaft power. Instead of being applied within a stand-alone package however, they are typically applied as an add-on package in the form of a shaft assist mechanism.

In an SWRO system, the recovered rotational mechanical energy must be transferred back to the seawater feed stream

Figure 3: Simple Schematic of Class III Energy Recovery Device




Pelton wheel

through the main high-pressure pump. Commercial examples of these devices include Pelton Wheels and Francis Turbines.

The efficiencies of these devices can be quantified as the hydraulic energy out minus the motor shaft power in all divided by the hydraulic energy in. However, some manufacturers short circuit this definition by making claims for the efficiency of their class III devices as the rotational/mechanical energy out of their device alone divided by the hydraulic energy in. This definition of efficiency leads one to believe that these systems can reach efficiencies between 80-88%.

Although it is true that Pelton wheels can be 80-88% efficient in converting hydraulic energy into rotational mechanical power, that rotational power must be converted back to hydraulic energy to be useful. Therefore, the real net energy transfer efficiency equation must account for the efficiency losses of the pump and couplings to which the class III device is connected. This results in real net energy transfer efficiencies between 63-76% over the flow range of Pelton-type systems considered in this article.

Hydraulic Energy Transfer Efficiency (HETE)

In order to make a fair and practical efficiency comparison between the Class I, Class II and Class III energy recovery devices available today, we must define an equation that extends to the useful hydraulic energy produced by the system. This would be the energy transferred to a new seawater stream minus any motor shaft power in, all divided by the energy available in the reject stream.

Table 1 Base line systems characteristics, efficiencies, flows and parameters

Train Permeate Capacity (m^3/d)	500	1000	4000	6000	10000
Conversion Rate, %	40	40	45	45	45
System seawater feed flow rate (m^3/hr)	52.1	104.2	370.4	555.6	925.9
Feed Pressure (bar)	65.5	65.5	65.5	65.5	65.5
Membrane Differential Pressure (bar)	2	2	2	2	2
Class I HP Pump flow rate (m^3/hr) (1)	21.4	41.6	169.9	254.9	424.8
Class I HP pump Efficiency, %	90	75	81	82	84
Class I booster pump Efficiency, % (2)	75	78	81	82	84
Class II and III HP Pump flow rate (m^3/hr)	52.1	104.2	370.4	555.6	925.9
Class II and III HP pump Efficiency, %	75	80	83	84	86
Motor Efficiency, %	94	95	95.5	96	96
Class I HETE, % (3)	96	94	93	93	93
Class II HETE, %	55	62	66	67	69
Class III Device Specific Efficiency, % (4)	84	85.5	87.5	88	89

(1) When using Class I devices the high-pressure pump flow approximately equals permeate water flow.

(2) Class I devices require a booster/header pump to bring their outlet pressure up to full feed pressure. Assume 92% eff. motor.

(3) When the class I booster pump is included into the simple schematic of figure 1 the result lowers the HETE by 1-2%.

(4) Multiplying the specific efficiency by the HP pump efficiency will yield the HETE for Class III devices.

(5) 1.7 bar seawater inlet pressure is assumed for all systems.

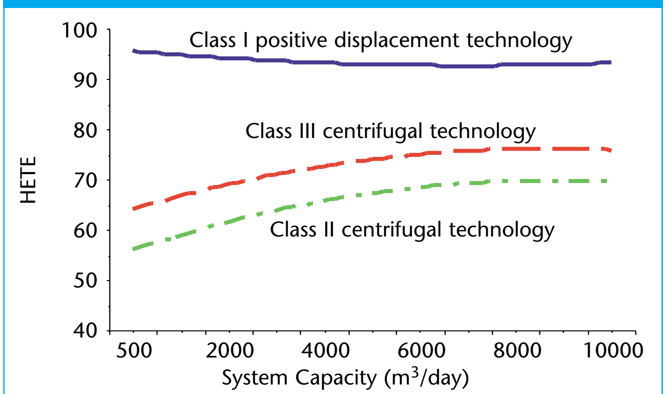
(6) Piping losses and coupling efficiencies have been neglected.

$$\text{Hydraulic Energy Transfer Eff.} = \frac{\text{Energy transferred new seawater stream} - \text{Mtr shaft Power In}}{\text{Energy available in the reject stream}}$$

The energy transferred to a new seawater stream can be defined as:

Energy transferred to a new water stream= seawater outlet flow x (outlet pressure-inlet pressure)

Figure 4: HETE Vs Systems Capacity



The energy available in the reject stream can be defined as:

Energy available in the reject stream = reject flow x (reject inlet pressure –reject outlet pressure)

When comparing one device to another in real world applications it is important to establish a minimum number of system characteristics such as those listed in Table 1 below.

Figure 4 above shows how the Hydraulic Energy Transfer Efficiency is affected by system capacity for the three classes of energy recovery technology available today. The results are what one might expect.

When looking at the class I positive displacement technologies their efficiencies are not significantly affected by the system flow rate, which is similar to positive displacement pump performance. Likewise, the class II and III centrifugal devices gain efficiency as their specific flow rates increase, which is similar to centrifugal pumps.

Knowing the efficiencies of each technology is an easy tool to compare the specific performance of one device to another, but the real test of today's energy recovery technologies is how they affect the overall energy consumption of an operating RO system.

The Ultimate Efficiency Test

The Hydraulic Energy Transfer Efficiency as defined above takes an objective look at the efficiency of each energy recovery system. However, in order to make a practical comparison of energy recovery technologies, one should look to the overall energy consumption of the entire process portion of the RO system being considered. Such an analysis fairly compares each technology's strengths and weaknesses and yields the bottom line energy consumption figure for the plant. This comparison accounts for all of the subtle design, applications and operating differences among the various systems and normalizes the analysis to overall power consumption.

The figure below is a simple schematic that defines the process limits for an SWRO system.

Using the data found in table 1 and standard hydraulic energy equations, we have developed the graph in figure 6 that compares each technology's overall specific power consumption versus the product water being produced.

In each case above, all of the major power consuming components within the system limits defined in figure 5 have been included such as the main high pressure pump, and, in the case of the class I devices, the header booster pump. This graph has been prepared by evaluating all technologies at the same 65.5 bar (950 psi) pressure cycle, which is commonplace in SWRO plants today.

As we have shown in a separate article published in a previous issue of this magazine (1), much lower power consumption figures are possible when designing the SWRO plant to work at a lower pressure cycle using advanced membranes.

It is significant to note that the when applying the class I devices the main high-pressure pump flow approximately equals the permeate flow of the system and not the full seawater feed flow. This allows the more efficient positive displacement high-pressure pumps to reach systems with higher permeate flows and thus the reason for the overlapping Class I curves in figure 6 above.

Figure 5. Energy Consumption Vs Product Water Production Process Limits

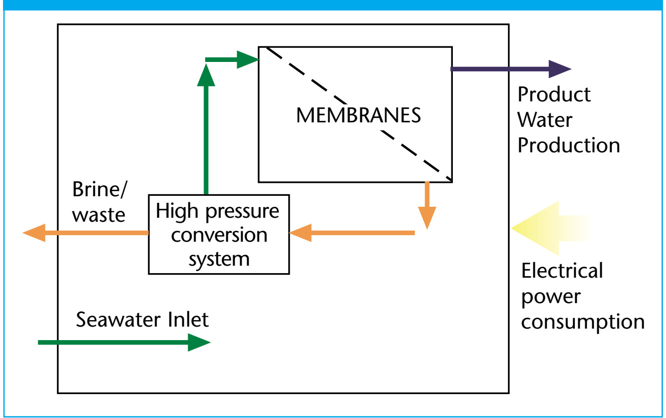
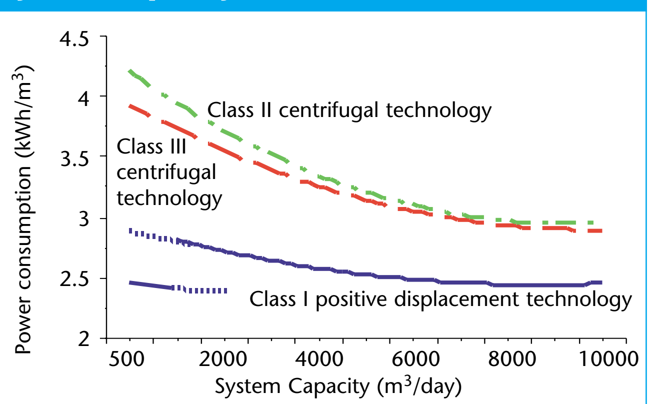


Figure 6: Specific power consumption vs system capacity



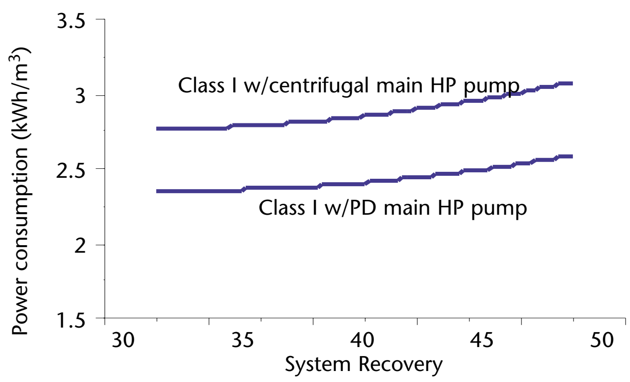
The Market Leader

From figures 4 and 6 above, we can see that the Class I devices are more efficient and yield significantly lower SWRO systems power consumption figures, but there are several other benefits to this technology as well.

One is that high recovery operation is no longer essential to lower the energy consumption of an SWRO system. Looking at figure 7, at constant flux, we can see that, for the Class I devices, the energy consumption at 30% recovery is actually lower than at 45% recovery (1). This is important in locations with high salinity and/or warm seawater where low recovery operation is desirable to obtain good permeate quality.

Another important point is that Class I devices do not penalise the smaller plants with lower efficiencies. In fact when used in conjunction with a positive displacement high-pressure pump these plants can yield extremely low power consumption figures below 2.0 kWh/m^3 (1).

Figure 7: Specific power consumption vs recovery at constant GFD



equals the permeate flow for Class I devices, these very efficient systems can now be designed for larger trains of up to 2000 m^3/day and beyond.

Conclusion

After more than 20 years of effort, the commercial application of energy recovery has evolved from the Francis turbines and early Pelton wheels, through the turbos and more advanced Pelton wheels, and has finally made the quantum leap to the positive displacement technologies. For the first time ever it is possible to desalinate seawater for less than 2.0 kWh/m^3 (7.57 kWh/1000 gal).

This is a remarkable milestone, and it is already being suggested that in some cases the widespread use of desalinated seawater for general agricultural irrigation is even economically feasible (2). Now that we finally have energy recovery technologies which are better than 90% efficient the industry will have to look elsewhere, perhaps to lower pressure membranes, to make the next major leap in reducing the power consumption of tomorrow's SWRO systems. ■

[1] *International Desalination and Water Reuse Quarterly* Volume 11/1.

[2] *Water Desalination Report*, Volume 37, No. 26, June 28, 2001.

About the Author

JOHN P. MACHARG is currently Vice President of Energy Recovery Inc. Previously he was a Vice President at Village Marine Technology where he spent 9 years involved in the design, manufacture and sales of packaged seawater desalination equipment. He majored in Manufacturing Engineering at Boston University. He can be reached at Energy Recovery, Inc.,
1908 Doolittle Dr., San Leandro, CA 94577, Phone: 510-483-737, Fax: 510-483-737,
E-mail: jmacharg@energy-recovery.com.