Developing Sustainable Solutions to Address Global Water Scarcity

Jeremy Martin and William Anderson
Energy Recovery Inc,1717 Doolittle Drive, San Leandro, CA, USA, jmartin@energyrecvoery.com

ABSTRACT

Global water scarcity has reached crisis levels, as more than 880 million people worldwide do not have access to clean, fresh water.

Seawater reverse osmosis (SWRO) desalination—the process of removing salt from seawater through a semi-permeable membrane—has historically not been a viable solution because of the energy-intensive nature of the process. However, technological advances such as the isobaric energy recovery device have dramatically improved energy efficiency and reduced cost.

This paper describes the SWRO process and reviews the role of energy recovery devices in making desalination a cost-effective and environmentally friendly solution to alleviate global water scarcity.

Keywords: *water, desalination, energy, efficient, ERI*

1 INTRODUCTION

Global water shortages have reached crisis levels—as many as one in eight people lack access to safe water supplies. While many of those suffering from water insufficiencies reside in developing countries, a number of industrialized nations (including the U.S.) also face serious droughts and are up against major decisions about how to address a looming—and inevitable—global water deficiency.

Water scarcity can be addressed, in part, through conservation and recycling as well as through better use of conventional resources. While conservation efforts are not enough to sustain the growing demand, however, modern seawater desalination technology is a sustainable new option for obtaining fresh water, and should be a component of any program designed to address long-term water supply needs.

2 SEAWATER REVERSE OSMOSIS

Seawater reverse osmosis (SWRO) is a water desalination process that produces drinking water by forcing seawater through a semi-permeable membrane, producing pure water on one side and concentrated brine on the other. Reverse osmosis is widely used around the world; indeed, reverse osmosis processes accounted for 59 percent of contracted desalination capacity as of September 2008, having grown at a rate of 17 percent per year since 1990.

The SWRO process, however, can be energy-intensive because of the high pressures that must be attained for it to work effectively. In SWRO systems, an operating pressure of 870 to 1015 psi is required. Even at these pressures a maximum of approximately 50 percent of the available pure water can be extracted before the osmotic pressure becomes so high that additional extraction is not economically viable. The rejected concentrate leaves the process at nearly the membrane-feed pressure. The combination of the necessary membrane-feed pressure and the high-volume reject stream has historically limited the deployment of large-scale SWRO only to regions where power is inexpensive and abundant.

2.1 Turbine Energy Recovery Devices

A number of devices have been developed to recover pressure energy from the membrane reject stream and return it to the feed of the RO process. Turbine-based, centrifugal energy recovery devices (ERDs), such as Pelton turbines, have been employed since the 1980s. A typical RO process with a Pelton wheel is illustrated in Figure 1.

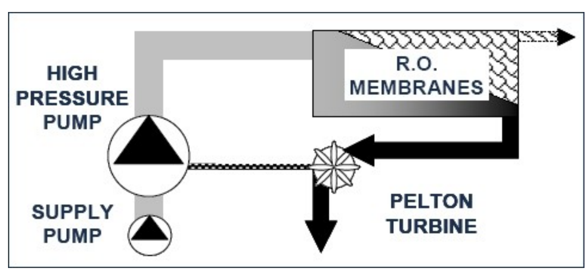

Figure 1: Reverse osmosis with a Turbine ERD

The membrane concentrate is ejected at high velocity through one or more nozzles onto a turbine wheel. The turbine, coupled to the high-pressure pump shaft, assists the motor in driving the pump that pressurizes the RO system. Energy is lost in a turbine ERD because it is transformed twice, once by the turbine and once by the pump impeller. The water-to-water transfer efficiency of a turbine ERD system is the product of the turbine and impeller efficiencies. The component efficiencies range from 70 percent to a maximum of 90 percent. The overall efficiency of a turbine ERD, therefore, is typically 50 to 75 percent.

2.2 Isobaric Energy Recovery Devices

Engineers developed isobaric ERDs to avoid the inefficiencies associated with the energy-transformation inherent in turbine ERDs. They place the RO concentrate reject and the seawater feed in contact inside pressure-equalizing, or isobaric, chambers. These innovative devices were introduced to large desalination plants in 2002 and have been deployed widely since.

A simplified flow diagram of an SWRO process with isobaric ERDs is shown in Figure 2. Concentrate rejected by the membranes flows to the ERD(s) driven by a circulation pump. The ERDs replace the concentrate with seawater. The pressurized seawater merges with the discharge of the high-pressure pump to feed the membranes. Water leaves the process as fresh water permeate from the membranes or as spent low-pressure concentrate from the ERDs. An energy recovery efficiency of 98 percent can be achieved with state-of-the-art isobaric ERDs, making the overall desalination process approximately 60 percent more energy efficient.

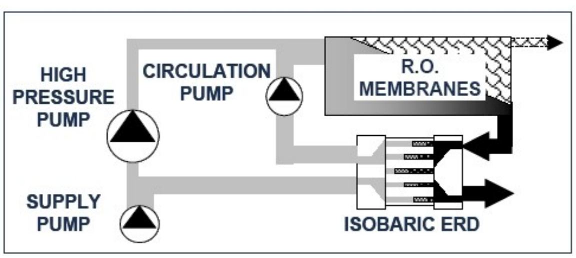

Figure 2: Simplified Diagram of an SWRO Process with Isobaric ERDs

Another benefit of isobaric ERDs is that they can provide high constant energy transfer efficiency over a wide range of flows and pressures. As a result, the membrane water recovery rate can be varied without increasing the energy required to produce a unit of permeate. This flexibility allows a process operator to optimize membrane performance as seasonal variations in the seawater occur or as the membrane elements age by adjusting the speed of the booster pump. Numerous best-efficiency operating points can be found, which is a tremendous advantage for low-cost SWRO operation.

Flexibility of recovery rates is optimal in providing solutions for different processes and goals of desalination. For example, a high recovery rate means a high process yield. High-recovery operation reduces supply-pumping and pretreatment expenses and can keep an SWRO process running at design production levels if there are pretreatment system problems.

Reducing recovery reduces membrane pressure and the load on the high-pressure-pump motor. Low recovery operation is beneficial if heavy fouling conditions occur because membrane cross-flow is increased and contaminant deposition and biological growth on membrane surfaces is reduced. Such adjustments can significantly change membrane performance but have negligible effects on isobaric ERD performance which provides high efficiency regardless of flow rate or pressure. In this way, an operator can manipulate and optimize SWRO system performance to achieve low energy consumption throughout the year.

As ERDs deliver high efficiency despite pressure and speed/flow rate variations., most SWRO plants being designed and built today utilize isobaric ERDs, and many plants built with legacy ERDs have been retrofitted. Isobaric ERDs have changed the economics of desalination by reducing energy consumption and increasing production capacity. Through the reduction of energy required in the desalination process, facilities experience dramatic cuts in energy expenditures, yielding higher results at a lower cost. Furthermore, minimizing energy usage also greatly reduces a facility's adverse environmental impact by cutting carbon dioxide emissions, making desalination a more environmentally conducive process.

2.3 SWRO Energy Consumption

Energy is consumed throughout the SWRO process for conveying and pressurizing water. A breakdown of energy use in a large state-of-the-art plant is shown in Figure 3. These data indicate that 68 percent of the power consumed in a SWRO process goes to the high-pressure pumps that feed the RO membranes, even in modern plants using low-energy membranes and high-efficiency pumps.

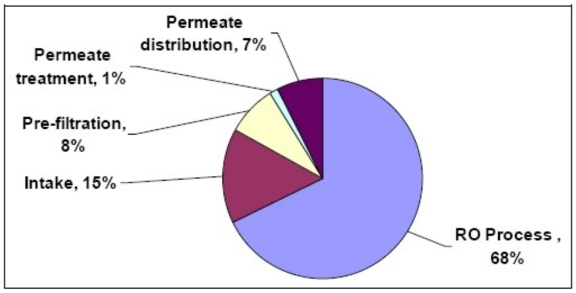

Figure 3: Estimated power consumption in a 50 million gal/day SWRO plant

The energy requirements for modern SWRO were compared to those of conventional sources of water supply in Southern California by the Affordable Desalination Collaboration. Energy consumption for a small SWRO plant was measured as 3.1 kWh/m^3 (12 kWh/kgal) compared to the power required to convey surface water to Los Angeles: about 2.9 kWh/m^3 (11 kWh/kgal).

However, regardless of the energy required, additional surface water capacity to meet increased demand in Southern California is simply not available. Therefore, the cost of seawater desalination was compared to the cost of alternative means of new supply. Specifically, the cost of a plant producing 50 million gallon of permeate per day with conveyance piping was compared to the cost of a comparable recycled water facility. The SWRO cost range was $2.38-2.80/kgal compared to $3.07/kgal for recycled water.

In addition to the cost advantage of SWRO, other factors make it preferable to large-scale recycling including the unlimited availability of seawater, legal limits on use of recycled effluent and the challenge of overcoming the public's aversion to "toilet-to-tap" reclaimed water.

2.4 Other Environmental Factors

Concern has also been raised about the potential environmental impact of concentrate discharges from desalination facilities. However, the majority of the known impacts are from thermal (distillation) facilities from which copper and other metals leached from the process are discharged. Membrane desalination facilities, which use significantly less metal and operate at much lower temperatures, do not cause such impacts. Nevertheless, some desalination plants assure zero environmental impact by discharging the seawater concentrate far out to sea in open currents.

Less concern has been raised about the environmental impacts of seawater intakes. Intake systems are designed to minimize the entrainment of solids and marine life that must be removed by the pretreatment system before the water flows to the SWRO process. Open intakes are ideally placed in flowing currents to assure uniform, clean feedwater and intake velocities are minimized to prevent entrainment. Beach wells and ocean-floor subsurface intakes offer a lower impact and are also widely employed.

3 ENERGY RECOVERY AND OTHER APPLICATIONS

PX Pressure Exchanger™ technology is employed in hundreds of desalination plants around the world. Single devices are used in relatively small RO trains, while multiple isobaric ERDs are connected by manifolds to run in parallel to serve large trains. Although it was developed specifically for membrane desalination applications, isobaric ERD technology can potentially be applied to any hydraulic pressure-recovery application. One such application is water elevation, such as is necessary in mining applications. The head pressure of a down-flowing stream is used to pressurize an up-flowing stream with just the energy required to drive a small booster pump to overcome friction losses.

Another potential application is in high-pressure liquid-liquid heat transfer. An isobaric ERD depressurizes a process stream prior to heat transfer and then re-pressurizes the stream. This would reduce the pressure requirement and associated cost of the heat exchanger.

Yet another application that was recently developed is osmotic power technology. Osmotic power consists of exposing a fresh water stream to a salt water stream across a semi-permeable membrane. The osmotic pressure that results is used to drive a turbine and generate electricity. The diluted pressurized salt water waste and fresh seawater are run through the isobaric ERD to recover the pressure energy. As in desalination application, the isobaric ERD serves as a seal for the high-pressure portion of the process. An osmotic power demonstration plant is currently in operation in Tofte, Norway.

4 CONCLUSIONS

The global demand for fresh water continues to grow while supplies dwindle. Desalination of seawater with reverse osmosis membranes and energy recovery devices has become an affordable means of water supply.

Many desalination plants being designed and built today save energy by utilizing isobaric energy recovery devices, such as the PX Pressure Exchanger device. Isobaric ERDs save energy by reducing the water that must be pressurized by the high-pressure pump. Seawater RO systems equipped with isobaric ERDs consume 15-30 percent less energy than comparable systems equipped with turbine ERDs such as Pelton wheels. Although it was developed specifically for membrane desalination applications, PX technology can potentially be applied to any hydraulic pressure-recovery application.