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Saving Energy, Water, and Money with Efficient Water Treatment Technologies

New technologies for enhancing water purification processes

Introduction

Reverse osmosis (RO) is a method of purifying water for industrial processes and human consumption. RO can remove mineral salts and contaminants such as bacteria and pesticides. Advances in water treatment technologies have enhanced and complemented the conventional RO process, reducing energy and water consumption, lowering capital and operating costs, and producing purer water. This publication introduces RO, describes the benefits of High Efficiency Reverse Osmosis (HERO™), and compares HERO with conventional RO/electrodeionization (EDI) technology.

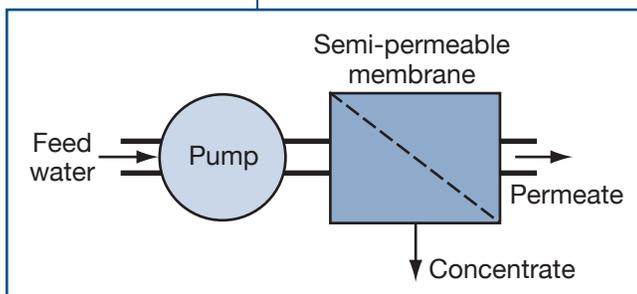


Figure 1. Schematic of an RO system.

Reverse Osmosis

Reverse osmosis is often used to treat saltwater or brackish water to create potable water. It is also used in a number of industrial processes to produce water with a high level of purity, reducing dissolved minerals and pollutants in the treated water. A stream of water, called the feed water, enters the RO system and is pressurized against a semi-permeable membrane (Figure 1).

Two streams exit the system, the concentrate and the permeate streams. The permeate is filtered, purified water. The concentrate is rejected water containing a high level of dissolved minerals. The concentrate is sent to drain, or a portion of it is recycled back to the feed stream to increase the system's overall water recovery. The recovery rate (i.e., the ratio of the volume of permeate to the volume of the feed water) is typically about 75% for a conventional RO system operating on a city water supply.

High Efficiency Reverse Osmosis

High Efficiency Reverse Osmosis is a proprietary system originally developed to provide ultrapure water to the microelectronics industry. HERO has several potential advantages over conventional RO: greater water recovery, higher quality permeate, higher operating flux (gallons per square foot of membrane per day), and generally lower costs. HERO systems are most advantageous for applications with challenging feed water (e.g., with a silica content greater than 20 ppm) or in areas with high water costs, limited available water, high water quality requirements, or zero liquid discharge requirements. HERO is





Aquatech International Corporation/PIX13171

Figure 2. HERO system installed in a power station.

typically used for industrial processes (Figure 2). It produces water that is higher in quality than necessary for potable use.

How It Works

The key to HERO is the chemical pretreatment that the feed water undergoes before undergoing RO. The pretreatment removes hardness from the feed water and raises its pH, which enables high efficiency RO. A schematic of the process is shown in Figure 3.

In the following discussion, the numbers in parentheses refer to the steps (circled numbers) in Figure 3. The number of steps in the process depends on the quality of the feed water; in some situations, some of the pretreatment steps might not be necessary.

Feed water entering the system (1) typically contains many dissolved and suspended impurities, including magnesium, calcium, silica, chlorine, and bacteria. Magnesium and calcium are the major constituents that make water “hard.” If left

untreated, hard water leads to scaling on the RO membrane (i.e., calcium and magnesium compounds precipitate onto the membrane) at the high pH and high recoveries used in the RO phase of the HERO process. Scaling on the RO membrane shortens membrane life and increases maintenance costs.

To remove hardness constituents such as calcium and magnesium, chemicals may be added to the feed water to raise the alkalinity to the same level as the hardness concentration. This hardness/alkalinity balance increases the efficiency of the subsequent weak acid cation (WAC) softening process (2). To produce soft water, hydrogen ions from the WAC resin are exchanged with hardness ions in the water. The addition of hydrogen ions (H+) reduces the pH of the feed water, which converts much of the feed alkalinity to carbonic acid and carbon dioxide. Additional acid may be added to this water to completely convert all the remaining alkalinity to free carbon dioxide gas, which then may be removed via degasification (3). This step improves the final water quality and reduces the amount of chemicals required to raise the pH in the next step. In the next step,

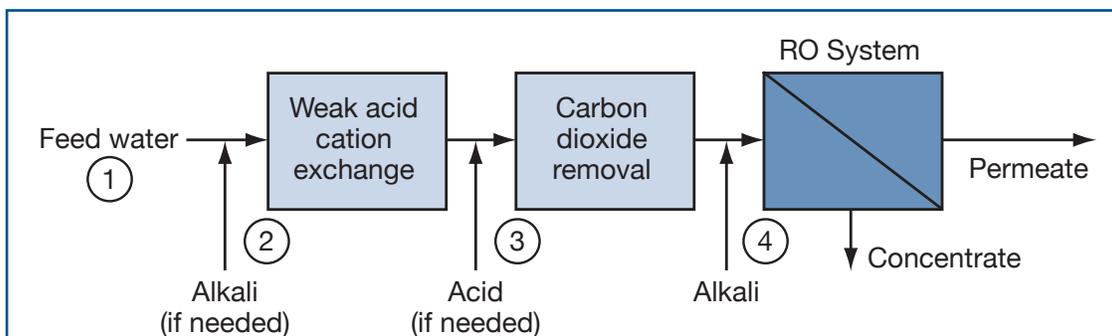


Figure 3: Schematic of a HERO system.

the pH of the feed water is raised to pH 10.5 to increase the solubility of the silica and destroy biological organisms in the feed water. The feed water then enters the RO system (4).

Benefits and Costs

The HERO system provides several benefits. For example, it reduces scaling of the RO membrane.

Dissolved silica is one of the major causes of membrane scaling. Increasing the pH of the water entering RO greatly increases the solubility of silica, thus eliminating its potential for scaling. Increasing the pH also destroys many bacteria and creates a slightly negative charge that repulses colloids; both reduce fouling of the membrane.

The typical water recovery of the HERO process is 95%–99% (depending on site-specific characteristics) in comparison to a typical recovery rate for conventional RO of approximately 75%. In addition,

HERO produces purer water than conventional RO processes do, and the operating flux for HERO is nearly double that of conventional RO.

Because the pretreatment process eliminates many of the causes of membrane fouling and scaling, HERO does not use antiscalant chemicals and requires less cleaning and maintenance than conventional RO does. HERO also has limited self-healing properties, so small problems tend not to cause major system disruptions. In addition, there are the environmental benefits of saving water and energy and the ability to use reject water from HERO (which is soft water at high pH) for acidic gas scrubber makeup or acid waste neutralization.

Capital costs for HERO are generally higher than those of conventional RO for small (25–50 gallons per minute [gpm]) systems because of the pretreatment requirements.

However, for systems larger than 50 gpm, capital costs for HERO are generally about 15% lower because of the higher flux rate, which allows fewer RO membranes to be used. Because of higher water recovery rates and reduced fouling and scaling of the RO membranes, HERO operating and energy costs are also typically less than those of conventional RO. Case studies suggest that, depending on the characteristics of the feed water and water costs, operating a HERO system costs about 20%–40% less than operating a conventional RO system.

Reverse Osmosis/ Electrodeionization

Reverse osmosis/EDI is another technique for purifying process water (Figure 4). Feed water is first treated by single- or double-pass RO. Then, the water undergoes EDI to deionize it.

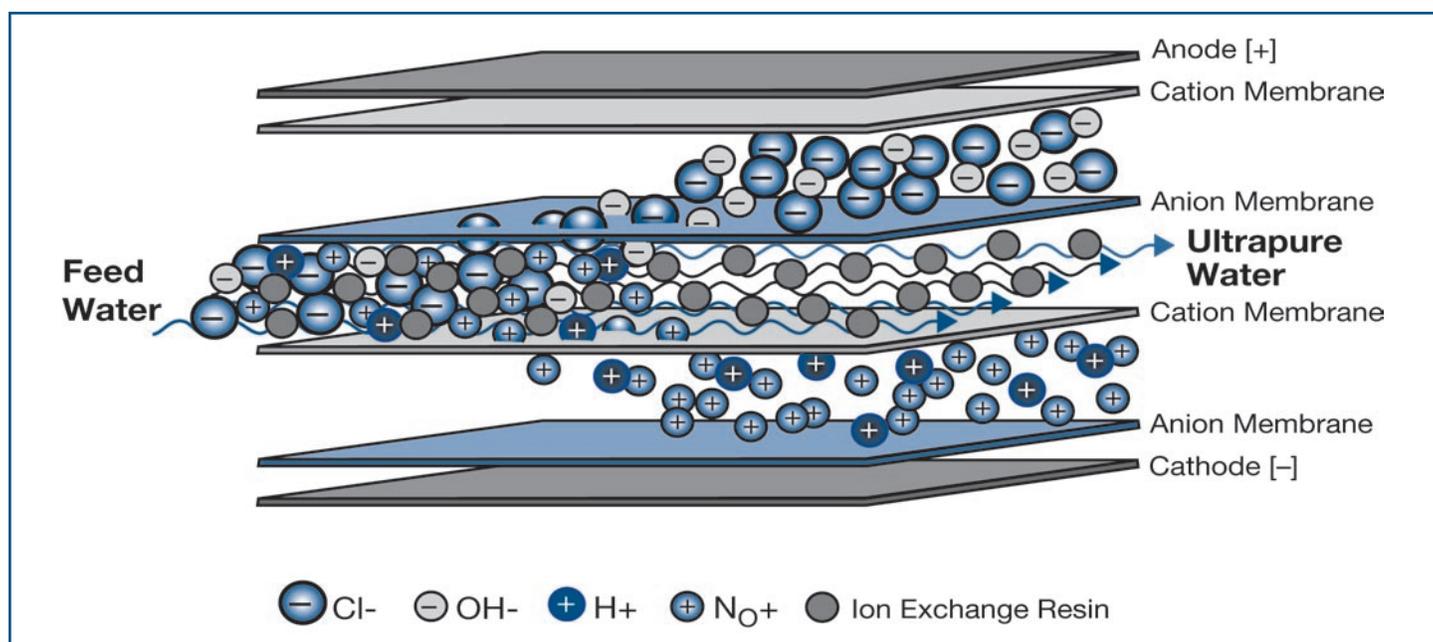


Figure 4. Schematic of EDI.

During EDI, the RO-treated feed water is sent through an EDI cell. Voltage is applied across the cell, which forces the migration of ions (e.g., dissolved salts) out of the feed water, through the cell membranes, and into a concentrated reject stream. The current is the motive force to transport the ions, but it also splits the water molecules into hydrogen (H+) and hydroxyl (OH-) ions for complete regeneration of the ion exchange resin at the end of the EDI cell.

The high power requirements of EDI can be mitigated by designing a system with a longer path (more membrane), which requires less current per gallon produced. The trade-off is between a lower initial capital cost and lower operating and maintenance costs. In other words, a longer path requires more membrane (added capital cost) but results in less membrane maintenance and lower power requirements.

Case Study: Sandia National Laboratories

Sandia National Laboratories in Albuquerque, New Mexico, recently decided to upgrade its water purification system. Ionics, a global separations technology company that can supply the HERO and RO/EDI systems, analyzed both for Sandia’s particular situation. The analysis suggested that HERO would consume less power and water and produce less wastewater than RO/EDI, whereas RO/EDI would consume fewer chemicals (Table 1).

Table 1. Comparison of RO/EDI and HERO*

Annual Statistics	RO/EDI	HERO
Power use (kWh)	2,838,667	1,849,760
Feed water use (1,000 gal)	160,421	116,817
Wastewater production (1,000 gal)	44,781	7,767
Chemicals (lb) (acid and caustic; does not include cleaning chemicals or scale inhibitors)	56,871	198,272

*Analysis based on hypothetical 250-gpm systems.

Table 2. Annual costs of RO/EDI and HERO*

Annual Costs	RO/EDI	HERO
Utility	\$404,113	\$251,918
Chemical	\$37,269	\$57,716
Other consumables	\$454,353	\$370,506
Total	\$895,735	\$680,139**

* Analysis based on hypothetical 250-gpm systems.
 ** Component costs do not equal the total because of rounding.

Comparison of HERO and RO/EDI

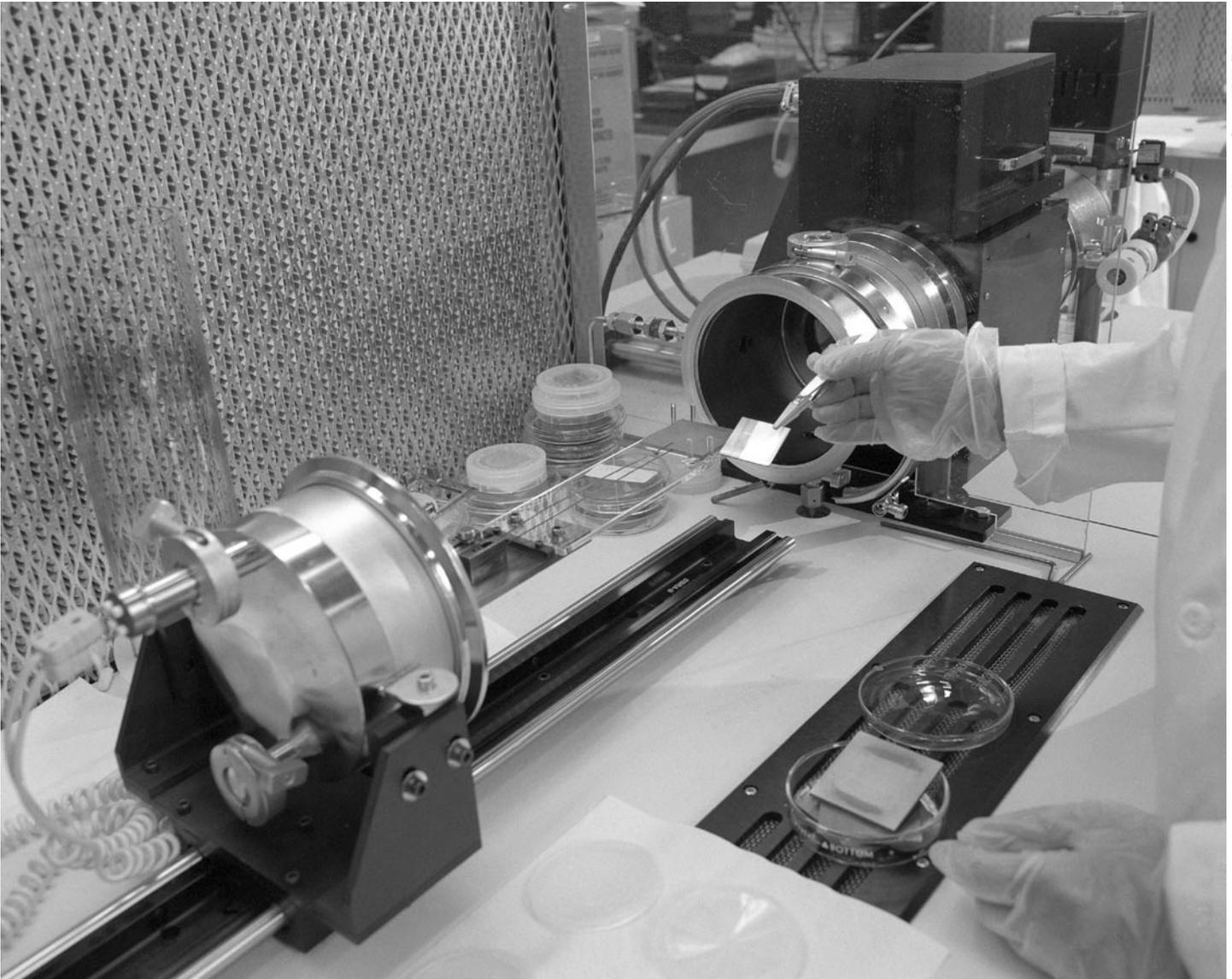
The annual cost for HERO was predicted to be 24% lower than for RO/EDI (Table 2). HERO was more cost-effective because of the high silica content (~60 ppm) of Sandia’s feed water. Sandia subsequently installed a HERO system with output of 160 gpm and a 93% recovery rate. The HERO-treated water is used to supply Sandia’s microelectronics development laboratory.

Lessons Learned

Sandia learned several lessons during the installation and initial use of its HERO system: consider the chemistry, pay attention to commissioning, and know the quality of the water supply.

Consider the chemistry.

Hydrochloric acid (HCl) has been proven for use with HERO systems. However, Sandia decided to use sulfuric acid (H₂SO₄) to eliminate the need for a large outdoor HCl tank (using H₂SO₄ allows the use of a smaller tank but increases the complexity of the WAC regeneration). The use of H₂SO₄ combined with unanticipated variations in feed water quality required several



Warren Gretz, NREL/PIX10119

Federal research laboratories use the ultrapure water produced by hyperfiltration technologies to develop advanced microelectronics like this thin-film solar cell.

rounds of chemistry and adjustments of controls to fully automate the system and ensure reliable operation. Users must evaluate the benefits and drawbacks of different chemistries to make an informed decision about which chemical to use.

Pay attention to commissioning.

A thorough commissioning plan is essential to the successful implementation of a HERO system. Every control point—such as valve

positions, pumps, and pressure set points—should be checked. Sandia's commissioning plan covered typical construction checks (e.g., leak tests) and thorough testing of the entire system. First, the quality of the HERO-treated output water was checked to verify that contaminants were removed satisfactorily. Next, a 2-week test was conducted to verify that the entire system functioned correctly. This test was performed with the water treatment company that built and

installed the system on site and was available for emergency support. Finally, a 30-day trial of the system was conducted without any outside support.

Know the quality of the water supply. Knowing the quality of the water that will supply a HERO system is important when designing and operating the system. Sandia's water supply was harder by 20%–30% than that used in the design of its system, and this resulted in

problems during commissioning. Sandia therefore recommends monitoring the water supply continuously for a period of time before the system is designed to provide an accurate characterization of water quality.

Conclusions

Both HERO and RO/EDI may offer benefits over conventional RO alone. HERO is best for challenging feed waters and when system water efficiency or product quality is important. Because of higher water efficiency, HERO typically has lower capital costs than RO/EDI. RO/EDI is best suited for environments in which a “chemical-free” system (i.e., minimal acid/caustic) is required. RO/EDI also may be more appropriate for situations in which the feed water cannot be efficiently softened (i.e., high hardness and low alkalinity) and it is not critically important to recover a high amount of water.

Water Treatment System Suppliers

For more information, these two companies currently supply HERO and RO/EDI systems:

Aquatech International Corporation

One Four Coins Dr.
Canonsburg, PA 15317
Tel: 724-746-5300
Fax: 724-746-5359
E-mail: aquatech@aquatech.com
Web site: www.aquatech.com

Ionics, Inc.

65 Grove St.
Watertown, MA 02472
Contact: Tom Chiara,
Phoenix Office
Tel: 602-437-1355
Fax: 602-437-9540
E-mail: tchiara@ionics.com
Web site: www.ionics.com

For information about additional manufacturers or suppliers of reverse osmosis or electrodeionizing treatment systems, please see the *Thomas Register* online: www.thomasregister.com

About FEMP's New Technology Demonstrations

The Energy Policy Act of 1992 and subsequent Executive Orders mandate that energy consumption in federal buildings be reduced by 35% from 1985 levels by the year 2010. To achieve this goal, the U.S. Department of Energy's Federal Energy Management Program (FEMP) sponsors a series of activities to reduce energy consumption at federal installations nationwide. FEMP uses new technology demonstrations to accelerate the introduction of energy-efficient and renewable technologies into the federal sector and to improve the rate of technology transfer.

As part of this effort, FEMP sponsors the following series of publications that are designed to disseminate information on new and emerging technologies:

Technology Focuses—brief information on new, energy-efficient, environmentally friendly technologies of potential interest to the federal sector.

Federal Technology Alerts—longer summary reports that provide details on energy-efficient, water-conserving, and renewable-energy technologies that have been selected for further study for possible implementation in the federal sector.

Technology Installation Reviews—concise reports describing a new technology and providing case study results, typically from another demonstration activity or pilot project.

Other Publications—we also issue other publications on energy-saving technologies with potential use in the federal sector.

Federal Energy Management Program

The federal government is the largest energy consumer in the nation. Annually, the total primary energy consumed by the federal government is 1.4 quadrillion British thermal units (quads), costing \$9.6 billion. This represents 1.4% of the primary energy consumption in the United States. The Federal Energy Management Program was established in 1974 to provide direction, guidance, and assistance to federal agencies in planning and implementing energy management programs that will improve the energy efficiency and fuel flexibility of the federal infrastructure.

Over the years, several federal laws and Executive Orders have shaped FEMP's mission. These include the Energy Policy and Conservation Act of 1975; the National Energy Conservation and Policy Act of 1978; the Federal Energy Management Improvement Act of 1988; the National Energy Policy Act of 1992; Executive Order 13123, signed in 1999; and, most recently, Executive Order 13221, signed in 2001, and the Presidential Directive of May 3, 2001.

FEMP is currently involved in a wide range of energy-assessment activities, including conducting new technology demonstrations, to hasten the penetration of energy-efficient technologies into the federal marketplace.

A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

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Produced for the U.S. Department of Energy, Energy Efficiency and Renewable Energy, by the National Renewable Energy Laboratory

DOE/EE-0294

June 2004