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# Production of High Purity Water From Seawater

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*The Diablo Canyon Power Plant at Avila Beach in California utilizes seawater for both cooling water and makeup water for steam generation. Ionics, Inc., Watertown, Mass., designed and built and now operates a complete water treatment system serving the high-purity water needs of this power plant. Over the past eight years, the seawater treatment section has demonstrated excellent long-term performance as a result of strong design, consistent maintenance and qualified operators.*

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This article mainly discusses operating experience of the seawater desalination section of the water treatment plant. However, there also is some discussion of the rest of the integrated membrane system for high-purity water production at Diablo Canyon Nuclear Station, operated by Pacific Gas and Electric.

This entire system has operated reliably since installation and start-up with very few technical problems. Remarkably, the seawater membranes never have required cleaning or replacement.

The following discussion and data will highlight the design and operation of this successful water treatment scheme.

## Plant Background

The Diablo Canyon water treatment plant was commissioned in March 1992. The main technical feature of this water treatment plant is that the bulk of the water destined for the power plant steam boiler comes from the Pacific Ocean.

Seawater is used at Diablo Canyon Power Plant (DCPP) to cool down the waste heat generated by the twin nuclear reactors. The large intake pumps draw millions of gallons of water per day, and a tiny fraction of this is sent to the biolab. (The biolab is a large facility that maintains samples of marine life to demonstrate their health and viability in the nuclear power plant environment.) Seawater overflow from the biolab feeds the seawater treatment system.

The seawater reverse osmosis (SWRO) facility generates a maximum product flow of 450 gpm from two parallel units. Permeate product from the seawater site is pumped to a set of twin man-made reservoirs, which have a combined capacity of six million gallons. Flow to these reservoirs is supplemented by seasonally available well and creek water that is pH adjusted and chlorinated. Water is drawn from these reservoirs into the makeup water treatment system (MWTS) where it is further processed for either power plant steam makeup or drinking and domestic water. Figure 1 illustrates the water treatment system.1

The makeup water treatment system combines ultrafiltration (UF), electrodialysis reversal (EDR), double-pass RO, vacuum degasifier and mixed-bed ion exchange to produce high-purity water. Blended water also is fed to another RO system that produces potable water for plant drinking and domestic water.

Normal demand is approximately 180 gpm, but the MWTS quickly can ramp up to 600 gpm to meet higher demand.

## Description of Seawater Treatment Plant

The seawater treatment system consists of the following train of unit operations (as shown in Figure 2).

- **Lift pumps.** Seawater feeds into a 6,000-gallon tank. A set of custom-made 8-inch stainless steel strainers feeds a set of three lift pumps—Worthington Model D-1012 50 hp pumps. These send the water to the primary filters.

- **Primary filters (dual media).** A set of five dual media (DM) filters each are 8 feet in diameter with 63 inches of media height. The layers are gravel, coarse sand, fine sand and anthracite. Polyelectrolyte and ferric sulfate are injected at this point for in-line coagulation. Flow is 4.0 gpm/sq. ft.

- **Secondary filters (multimedia).** A set of four multimedia (MM) filters also are 8 feet in diameter with 63 inches of media height. The layers are gravel, coarse sand, fine garnet, fine sand and anthracite. Both the dual and MM filters are monitored for pressure drop. Backwashing of the filter is initiated manually. For the MM filter, there is an additional criterion for the SDI15 to be less than 3.0. If the SDI15 is greater than 3.0, an additional backwash may be initiated. Flow is 4.5 gpm/sq. ft.

- **Ultraviolet (UV) lamps.** This set of three UV units operates at 254 nm. Dosage is 30,000 µw sec/sq. cm. Two of three are used at one time for full flow. Each has a flow capacity of 520 gpm.

- **Cartridge filters.** After Hypersperse AF200 antiscalant injection, the flow continues to a set of four cartridge filter units, each with a capacity of 440 gpm. Cartridge filter rating is 5 microns. Anti-scalant is added as a requirement of RO process design to prevent scaling inside the RO system. The criterion for cartridge filter replacement is pressure drop across the filters.

- **SWRO high pressure pumps.** A set of three pumps accepts and pressurizes the filtered water. Controlled by variable frequency drives (VFDs), these pumps are 450 hp, each with 500 gpm capacity. Typical operating feed pressure is 800 psi.

- **Energy recovery turbines.** Reverse-turning turbines accept the brine reject flow. This reduces the load on the feed pump thus reducing the power consumption of the SWRO system.

- **RO element array.** The array design is a 12-vessel first stage feeding a nine-vessel second stage. The first stage has three additional spare vessels, and the second stage has one additional spare vessel. However, the design has been maintained at the 12:9 staging with seven elements in each vessel. The RO elements are Filmtec SW30-8040HR. These are operated at 45 percent recovery with 99 percent or higher salt rejection.
- **Product tank and transfer pumps**. RO permeate goes to a 10,000-gallon tank. A set of three 40 hp product transfer pumps sends the water to the MWTS reservoirs.

- **RO reject.** RO waste reject flow is sent to a backwash tank. This backwash water is used for a high-salinity flush for the DM and MM filters. The high salinity helps to reduce bacteria viability by osmotic shock. The availability of this backwash water reduces the need for additional feed water pumping.

The number of units used depends on plant demand. All three RO feed pumps and energy recovery turbines are rotated so that each operates the approximate same amount of time. This also is true of the two main RO units, A and B. A similar philosophy applies to the UV units, lift pumps and product transfer pumps that are rotated automatically.

## Makeup Water Treatment System

The MWTS consists of a blend of seawater permeate and MM processed creek water that is drawn from man-made reservoirs with lift pumps to feed the five triple membrane trailers (TMT).2 Each TMT is capable of producing 120 gpm. The TMT consists of ultrafiltration for pretreatment, electrodialysis reversal for dissolved solid reduction and RO for further reduction of ionic materials.

The RO permeate from each TMT is fed to a second pass of RO, housed in another trailer referred to as the RO polish trailer. The five RO polish trains reduce the conductivity to approximately 1 µs/cm. The RO polish reject streams are recycled back to the RO feed in the TMT to achieve higher water recovery.

The RO polish permeate is fed to a 600 gpm vacuum degasifier. The vacuum degasifier reduces the dissolved oxygen to less than 10 ppb (parts per billion). The degasifier effluent is pumped to an ion exchange trailer consisting of two stages of 40 3.6 cu. ft. portable vessels. The ion exchange trailer also contains a silica monitor, resistivity instrument, total organic carbon and pH meters to assure high purity water specifications. Critical water quality specifications for high purity water are 5 ppb silica, 20 ppb oxygen, 50 ppb TOC and above 18 MegOhm/cm for resistivity.

In addition to supplying 600 gpm of ultrapure water for the plant, the MWTS has a 100 gpm potable water system. This system consists of a separate RO unit with a carbon bed and MM pretreatment. After the RO unit, the flow continues to a calcium bed. Calcium hydroxide and sodium hypochlorite injection is used for bacteriological control. Carbon dioxide also is injected to adjust the pH to 8.5 for a noncorrosive water.

While this ultrapure water makeup system design was state of the art in the early 1990s when it was conceived, a current design (or plant upgrade) would most likely include electrodeionization technology to reduce the frequency of ion-exchange bottle change-out.3

## Seawater RO Performance

Performance was tracked according to a number of operating parameters: salt rejection, normalized salt passage, normalized product flow and differential pressure.

- **Salt rejection.** After 3,000 days of operation, salt rejection has been maintained at the target of 99 percent. The average salt rejection actually has increased a few tenths over this period of time due in part to fouling effects. No spikes in performance are noted. SWRO product quality averages 400 µs/cm conductivity. A graph of salt rejection vs. time is shown in Figure 3.

- **Normalized salt passage.** A slow decline in normalized salt passage is noted up until approximately 1,500 days of operation. After a plateau of 400–500 days of operation, the data shows an incipient increase in salt passage. The gap in data is where this parameter was not calculated. A graph of salt passage vs. time is shown in Figure 4.

- **Normalized product flow.** This flow was very steady until the point where the normalized salt passage showed an inflection point. The product flow began to decline slightly at this point. This is an indication of fouling and loss of product flow leading to a point where a membrane cleaning will become necessary. A graph of normalized product flow vs. time is shown in Figure 5.

- **Differential pressure.** The differential pressure shows a minor adjustment at about 1,200 days of operation. After that adjustment, differentials were steady until 2,100 days of operation where both stage one and stage two differentials began to migrate upward, also an indication of flow but steady fouling. The second stage appears to be fouling more quickly than the first stage. A graph of differential pressure vs. time is shown in Figure 6.

These long-term performance results appear to be nearly identical for both RO units. Minor differences are attributed to factors such as off-line time and temperature.

Energy consumption also was very stable at 17 kw hr/kgal at the seawater sites as seen in Figure 7. Energy users include the lift pump, UV lamps, RO pumps, metering pumps, auxiliary equipment and product transfer pumps. Energy use of the SWRO HP pumps only is approximately 15 kw hr/kgal.

Online availability for the SWRO unit has been 100 percent. At least one high-pressure SWRO pump always has been available for service. Over the entire 3,000 days of unit operation, there were only 16 days in which full capacity (two RO pumps and units) was not available. This represents a 99.5 percent full capacity availability.

SWRO permeate comprises the bulk of the available water in the twin reservoirs. This water then is drawn from the reservoirs and further treated for both drinking and domestic or water supply for power plant steam generation.

Overall, the water treatment system consistently has produced the full volume of in-spec water required by the power generation needs. The seawater treatment RO system consistently has produced high-quality product since start-up and commission. In addition, the SWRO membranes have not required a chemical cleaning since start-up.

This successful long-term performance of the SWRO system is a result of several factors. These include careful attention and maintenance of MM filters and bacteria growth in the RO pretreatment train. Important factors are as follows.

- Six parts per million (ppm) of ferric sulfate and one ppm of polyelectrolyte are injected into the feed stream prior to the dual media filters. Bacteria counts as colony-forming units (CFU) are very low leaving the media filters.

- Chemical pumps feeding the pretreatment train are calibrated and verified daily.

- Media filter pressure drop and rate

of increase of pressure drop is very carefully monitored. If there is a storm and more frequent backwash is required, the filters are taken off automatic operation and backwashed manually as required on a 24-hour basis. These filters are backwashed with RO concentrate. The high salinity helps to keep bacteria growth in check.

- When an RO line is shut down, the membranes are flushed with RO permeate. This presents a lethal concentration gradient to ambient bacteria populations since the RO permeate salinity level represents an extreme drop in salt concentration.

- UV treatment also is a key to success. Bacteria counts as CFU are near zero downstream of the UV unit.

- Silt density indexes (SDIs) also are carefully monitored. This is done in conjunction with observation of ocean conditions—swell frequency as an indicator of depth of swell and, therefore, ocean bottom turbulence. Anticipation of plankton blooms and plant shutdown also is critical.

These careful maintenance procedures are critical in maintaining the good functioning of the RO system.

The long, stable operating run with steady salt rejection indicates the excellent performance of this SWRO system.

This is an indication of an appropriate design and specification of pretreatment, SWRO array, membrane type and materials of construction.

The design also was appropriate to the feed source and production requirements. The extremely long period of operation without requiring chemical cleaning of the RO elements also is a testament to accurate design. Long-term high performance can be attributed in part to steady and timely maintenance of all equipment by well-trained and responsible operators. This includes efforts to combat seawater corrosion, motor maintenance, pump maintenance, periodic inspection and other preventative maintenance issues.

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