Low Energy Consumption SWRO

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ABSTRACT

The 38 million gallon per day (MGD) (143,000 cubic meters per day (m^3/d)) seawater desalination plant in Kwinana Beach (Perth), Western Australia started up in November 2006. A year and a half later, it remains the largest seawater reverse osmosis (SWRO) desalination plant in the Southern Hemisphere, the third largest SWRO plant in the world and reports the lowest energy consumption of any plant of its size. Built by Suez Degrémont and Multiplex Engineering Pty Ltd., the plant supplies approximately 17% of Perth's water supply, supplementing conventional freshwater resources which are in very short supply.

The plant was designed for maximum energy efficiency and minimum greenhouse gas emissions. It operates with twelve SWRO trains in the first pass, each with a production capacity of 3.5 MGD (13,350 m^3/d). Six high-pressure pumps on a common manifold or "pressure center" supply a portion of the high-pressure seawater fed to the SWRO trains. The remainder of the high-pressure seawater is supplied by arrays of ERI PX-220 energy recovery devices. The plant's hydraulic design was intended to provide for cost-effective operation over a wide range of flow and pressure conditions, thereby maximizing operational flexibility. To offset greenhouse gas emissions, the plant is entirely powered with electricity generated by a wind farm.

After a year of continuous production, the Perth plant has exceeded the designer's expectations. The energy consumption of the first pass SWRO train is approximately 8.3 kW-hours/1000gal (kWh/kgal) (2.2 kilowatt hours per cubic meter (kWh/m^3)). The total energy consumption for the plant is 12 to 13 kWh/kgal (3.2 to 3.5 kWh/m^3) including intake, pretreatment, both RO passes, post-treatment and potable water pumping to a reservoir 7.5 miles (12 kilometers (km)) away. This is the lowest power consumption ever reported for large-scale SWRO.

The author describes the design and operation of the Perth plant as a new standard for seawater desalination.

Keywords: desalination, reverse osmosis, energy recovery, pressure exchanger, specific energy

1 INTRODUCTION

Reverse osmosis is a water desalination process widely used around the world. The osmotic pressure of a salt water solution is overcome with hydraulic pressure, forcing nearly pure water through a semi-permeable membrane and leaving concentrated reject behind. In seawater reverse osmosis (SWRO) systems, an operating pressure of 870 to 1015 psi (60 to 70 bar) is required. Even at these pressures, a maximum of approximately 50% 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 high required membrane-feed pressure and the high-volume reject stream have historically limited the deployment of large-scale SWRO to regions where power is inexpensive and abundant.

However, SWRO technology consumes far less energy today than it did just a few years ago. Improved membranes, increased pump efficiencies and the implementation of isobaric energy recovery devices have dramatically increased the energy efficiency of these processes. The energy requirement for SWRO can be as low as that required by many traditional fresh water supply sources [1,2].

The Perth seawater desalination plant is located 25 miles (40 km) south of Perth at Kwinana Beach in Western Australia (WA). It began supplying municipal drinking water in November 2006. With a capacity of 38 MGD (143,000 m^3/d), it supplies nearly 20% of Perth's water demand [3]. The plant is the largest SWRO desalination operation in the Southern Hemisphere and the third largest SWRO plant in the world as of March 2008. The plant was built as a joint venture of Suez Degrémont and Multiplex Engineering Pty Ltd. and is operated by Australian Water Services, a subsidiary company of Degrémont.

As part of Water Corporation's and WA's commitment to promote energy efficiency and reduce greenhouse gas emissions, the Perth SWRO plant is the largest facility of its kind in the world to be powered by renewable energy. The plant buys its power from electricity generated by the Emu Downs Wind Farm, located 124 miles (200 km) north of Perth. The 83 megawatt wind farm consists of 48 wind turbines and contributes over 272 giga-watt-hours (GWhr) per year into the grid, fully offsetting the Perth SWRO Plant's estimated electrical requirement of 180 GWhr per year. In addition, a control system was installed for continuously monitoring plant discharges and automatically shutting down the process in the event of an exceedance [4].

The plant utilizes ERI® PX Pressure Exchanger® (PX®) energy recovery devices to reduce energy consumption. Each high-pressure pump feeds two SWRO trains with a higher efficiency than could be achieved with smaller pumps sized for single trains. The low-pressure supply pumps, booster pumps and second pass pumps operate on variable frequency drivers that provide for flexible operation and low energy consumption. These pumps and devices are combined with state-of-the-art low-energy membrane elements to make the Perth plant the highest-efficiency reverse osmosis plant of its size operating in the world today.

This paper describes the Perth plant process design with emphasis on those features designed to minimize energy consumption. Process performance data is presented and discussed.

2 PROCESS DESCRIPTION

The Perth plant draws feedwater from an open intake in nearby Cockburn Sound. The water temperature ranges from 64 to 79 degrees F (deg F) (18 to 23 deg C) and the salinity is 36 to 37 parts per thousand (grams per liter). Six supply pumps draw through screens and discharge to dual media filter vessels which in turn discharge through cartridge filters to the reverse osmosis process. The supply pumps are controlled by variable frequency drivers (VFDs) to save energy and assure constant feed pressure to the high-pressure pumps and energy recovery devices.

The first pass has twelve SWRO trains, each with a production capacity of 3.5 MGD (13,350 m^3/d) or a total of 42 MGD (160,000 m^3/d). Each train uses 1,134 Filmtec™ model SW30HR-LE400 membrane elements housed in Protec™ 7M side-port pressure vessels. They are fed with six Weir split-case centrifugal high-pressure pumps, each with a capacity of 5,037 gallons per minute (gpm) (1,144 m^3/hr) at 2,034 feet (ft) (620 m) of differential head, driven by 3,500 horsepower (hp) (2,600 kilowatt (kW)) motors. The best efficiency point of these pumps is approximately 86%. The trains are also fed with twelve Union® vertical booster pumps, each with a capacity of 2,910 gpm (661 m^3/hr) at 128 ft (39 m) of differential head, driven by 150 hp (112 kW) motors controlled by VFDs. Energy recovery is provided by twelve arrays of sixteen ERI model PX-220 energy recovery devices, each array with a capacity of 3,520 gpm (800 m^3/hr). One PX device array is shown in Figure 1 [5,6].

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Figure 1: PX device array serving one SWRO train.

The plant is arranged with six SWRO trains on each side of a central pump aisle. Three high-pressure pumps feed a high-pressure manifold or “pressure center” which in turn feeds a bank of six SWRO trains. Flow from the manifold to each train goes through a high-pressure control valve which allows adjustment of the membrane feed pressure. Each train has a dedicated PX-device array and booster pump. The PX device arrays are situated between the membrane-vessel stacks. A schematic diagram of the SWRO process is given in Figure 2 and a photograph is given in Figure 3.

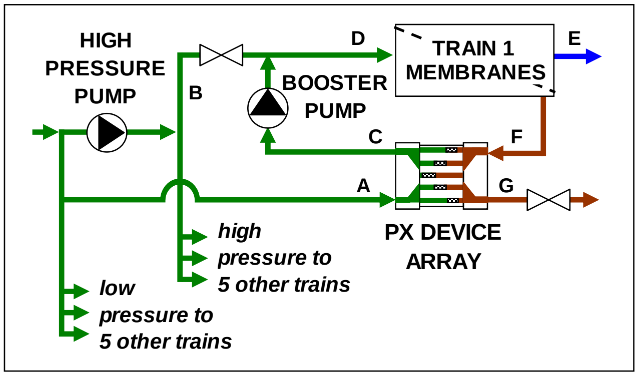

Figure 2: Schematic diagram of first-pass SWRO process.

Figure 3: First-pass SWRO trains.

To further reduce salinity and reduce the residual concentration of bromide, the first-pass permeate goes to a second pass consisting of six low-pressure reverse osmosis trains. All pumps of the second pass are equipped with VFDs to minimize energy consumption. Post-treatment chemicals include hydrated lime, gaseous chlorine and carbon dioxide. Product potable water flows through a fourhour buffer tank before being pumped approximately 7.5 miles (12 km) to the fresh water reservoir that supplies the city of Perth with drinking water. The second pass and post-treatment processes operate at 90% recovery for a final product flow rate of 38 MGD (143,000 m^3/d).

3 PX PRESSURE EXCHANGER ENERGY RECOVERY DEVICES

The PX Pressure Exchanger ® (PX®) energy recovery device captures the hydraulic energy from the high-pressure reject stream of reverse osmosis processes. It transfers this energy to low-pressure feedwater with an efficiency of nearly 98%. Pressurized feedwater from the PX device is sent to the membrane feed, merging with an approximately equal stream of pressurized water from a high-pressure pump. This significantly reduces the amount of water pressurized by the high-pressure pump. Because the PX device itself consumes no electrical power, the overall energy consumption of an SWRO process is cut in half or less.

In an RO process designed with PX devices, high-pressure membrane reject is directed to the membrane feed with a booster pump the as illustrated in Figure 2 above. The PX rotor moves between the high-pressure stream and a low-pressure stream, replacing the concentrate with feedwater. The speed of the PX rotor is set by the combined flow rate of the high- and low-pressure streams. There are no shafts, motors, or electronic controls on a PX unit, and the PX rotor, the device's only moving part, contains no pistons or barriers. When the rotor is not spinning, flow passes directly through the device making startup and shutdown easy. The high- and low-pressure streams are separated at all times, even when the rotor is not spinning, by the seal formed by the tight fit between the rotor and the surrounding ceramic components. In this regard, the PX ceramic components function as a mechanical seal for the high-pressure portion of the SWRO process.

The internal components of a PX device are illustrated in Figure 4. Pressure transfers from the high-pressure concentrate to feedwater through direct contact in "isobaric" or pressure-equilibrating chambers. Bores through a rotor serve as the chambers. The rotor is fit into a sleeve between two endcovers. The components are made of ceramic which provides high-strength, durability and immunity from corrosion. The narrow clearances between the components fill with water, creating an almost frictionless, continuously-regenerating hydrodynamic bearing.

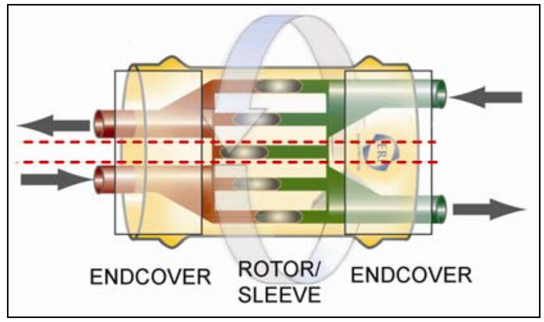

Figure 4: PX device ceramic components.

Direct contact between the concentrate and feedwater in the PX device's rotor results in a small increase in the salinity of the feedwater pressurized by the device. The PX rotor is designed so that the interface between the concentrate and feedwater in a rotor duct never reaches the end of the rotor before the duct is sealed. Mixing in the rotor is further minimized with long, small-diameter chambers and a short concentrate-feedwater contact time (0.05 seconds). Mixing is indicated as additional salinity in the membrane feed compared to the salinity of the system feedwater.

Hydraulic losses in a PX unit or PX device array include the flow from high- to low-pressure that lubricates the rotor and viscous friction along the flow paths through the device. The pressure-transfer efficiency of a PX unit or PX device array is the ratio of the hydraulic energy leaving the devices divided by the hydraulic energy entering. In most SWRO applications, efficiency ranges from 96 to 98%.

4 PROCESS PERFORMANCE

The power consumption reported by Perth plant personnel in October 2007 indicated that the high-pressure pumps were consuming an average of 3,248 hp (2,422 kW). Permeate production averaged 4,962 gpm (1,127 m^3/hr) for each pump. The booster pumps were consuming an average of 59 hp (44 kW) each. Therefore, the average specific energy performance of the SWRO process was 8.3 kW-hours/1000gal (kWh/kgal) (2.2 kWh/m^3). The rest of the plant consumes 3.8 to 4.9 kWh/kgal (1.0 to 1.3 kWh/m^3) including the power required for pretreatment, post treatment and transfer of the product water to the reservoir. Therefore, the total energy consumption for the plant is 12.1 to 13.2 kWh/kgal (3.2 to 3.5 kWh/m^3).

SWRO energy consumption varies significantly with feedwater properties. Nevertheless, the energy performance of the Perth plant compares favorably with the power consumption of comparably-sized modern SWRO facilities. For example, the 85 MGD (320,000 m^3/d) SWRO project in Ashkelon, Israel, the world's largest, was started up in 2004. After one year of operation, the energy consumption for the plant was reported to be 14.0 to 15.5 kWh/kgal (3.7 to 4.1 kWh/m^3) [7]. Energy consumption at the Perth plant also compares favorably with the power consumption at the 38 MGD (144,000 m^3/d) Tuas facility in Singapore which is approximately 16.7 kWh/kgal (4.4 kWh/m^3) [8].

Lubrication flow through the PX devices was approximately 1% of the concentrate flow to the array. The salinity increase at the membranes was 2.5% when the high-pressure flow rate from the PX arrays equaled the low-pressure flow rate to the PX arrays. The pressures of the high-pressure and low-pressure streams to the PX device array (process locations "B" and "G") were measured far upstream of the array. PX-device efficiency computed with these pressure readings was 95.7%. However, using pressure data collected at the inlets and outlets of the PX device manifolds, a transfer efficiency of 96.7% was computed. This performance exceeds the guarantees given by the manufacturer and contributes significantly to the energy-efficient performance of the plant.

5 CONCLUSIONS

After a year and a half of operation, the Perth plant is producing 38 MGD (143,000 m^3/day) of potable water at a total specific energy consumption level of as low as 12.1 kWh/kgal (3.2 kWh/m^3) – the lowest of any desalination facility its size. The PX energy recovery devices used in the plant are operating at the highest efficiency ever reported for such devices at this scale. Plant performance is consistent with the design goals. The Perth plant represents a significant milestone for the development of large-scale SWRO technology by operating on renewable energy at a very low energy consumption level.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

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