ENVIRONMENTALLY SOUND DESALINATION AT THE PERTH SEAWATER DESALINATION PLANT

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Abstract

Water scarcity is recognized as a significant problem in Australia and throughout the world. Yet the demand for fresh water continues to grow, driven by the need for drinking water to satisfy the world's growing population, changing weather patterns, an increasing need for water for agriculture and industry and the concentration of populations in urban areas that lack sufficient fresh water resources. Water scarcity can be addressed, in part, through conservation efforts and better use of conventional resources. However, resource limits and the environmental impacts associated with increased use of surface water limit the viability of these options. At the same time, seawater reverse osmosis desalination has emerged as an affordable and environmentally preferable water resource.

The city of Perth recently increased its water supply capacity through implementation of the Perth Seawater Desalination Plant (PSDP). This plant and others around the world incorporate low-energy membranes, high-efficiency pumps and isobaric energy recovery devices to reduce energy consumption. The cost of water production can be comparable to or less than that of new conventional sources of supply. The energy consumption of PSDP is carbon neutral, meaning that it is 100% offset with renewable energy. In addition, its brine discharge has been shown to have no adverse impact on the environment.

The authors discuss water scarcity and demand in an Australian context. The design and operation of the Perth plant are presented as a standard for seawater reverse osmosis plants and a model for sustainable water production from the sea.

Introduction

Water scarcity is recognized as a significant problem in Australia and throughout the world. Yet the demand for fresh water continues to grow, driven by the need for drinking water to satisfy the world's growing population, changing weather patterns, an increasing need for water for agriculture and industry and the concentration of populations in urban areas that lack sufficient fresh water resources. Humanity now uses more than half of the available surface fresh water on earth. (Lubchenco 1998) In 2003, the United Nations Population Fund predicted that global consumption will increase by 40% by 2025. (UNPF 2003) A study conducted by the International Water Management Institute projects that by 2025, 33% of the population of the developing world will face severe water shortages. (WMI 2000) The uneven geographic distribution of fresh water supplies compounds this problem; at least 300 million people live in regions that already have severe water shortages. By 2025, the number could be 3 billion. (Simon 1998).

In part because of population growth, existing water resource infrastructures are being strained in many regions. For example, the Serpentine Dam was constructed in 1961 to supply water to the city of Perth. At the time, Serpentine Dam had a 98% assured yield of 51 million m^3/year. Its yield has since been de-rated on three occasions down to 15 million m^3/year and in 2006 it was mostly a dry dam basin with a yield of just 5 million m^3/year. (Crisp et.al. 2007) For another example, in 2008, the annual run of salmon into the San Francisco Bay in California dropped to 10 percent of the size of the run just a few years ago. Scientists believe that one of the major causes of the sharp decline was record pumping at water projects in the Sacramento-San Joaquin River Delta to farms and cities in Southern California. The river flows in the 2007 spawning season were reduced to 55 percent of their natural level with devastating impact on the 2008 salmon population. (Kay, 2008)

Climate change will likely increase the demand for water and further disrupt existing water supply resources. Temperatures are expected to increase by 0.3 deg C per decade. (IPCC 2007) The Melbourne Water Climate Change Study estimated that this increase will cause an 8% reduction or possibly as high as an 11% reduction in rainfall by 2020. (Howe et.al. 2005) Climate change is expected to increase the ratio of rain to snow, delay the onset of the snow season, accelerate the rate of spring snowmelt, and shorten the overall snowfall season, leading to more rapid and earlier seasonal runoff

(Kiparsky and Gleick 2003). According to the United Nations Intergovernmental Panel on Climate Change, "increases in average atmospheric temperature accelerate the rate of evaporation and demand for cooling water in human settlements, thereby increasing overall water demand." (IPCC 2001) In addition, rising sea levels may exacerbate seawater intrusion problems in coastal aquifers or rivers that communities currently depend on for water. (Cooley et.al. 2006).

Water scarcity can be addressed, in part, through conservation and recycling as well as through better use of conventional resources. Adelaide's water use reduction and recycling strategy could alleviate 37 GL of demand through conservation to offset approximately 15% of the city's 2005 consumption level. An additional 33 GL could be generated by 2025 with through large-scale stormwater use projects, household rainwater tanks and recycling. (Government of South Australia 2005) Through an aggressive and successful water plan, the City of Melbourne has reduced water use by 22% since the 1990s. (Victorian Government 2007) By executing this plan over the next 50 years, Melbourne estimates it can alleviate half the water shortfall it faces through conservation. (Melbourne Water 2006) However, for both Adelaide and Melbourne, at least half the projected increase in supply will need to come from new water sources. Both are actively developing major desalination projects to meet part of this need.

Perth Seawater Desalination Plant

The city of Perth recently increased its water supply capacity through implementation of the Perth Seawater Desalination Plant (PSDP). The PSDP commenced delivering an annual capacity of 45 million cubic meters of drinking water into the region's Integrated Water Supply Scheme (IWSS) in November 2006. The PSDP, located at Kwinana, 30 kilometres south of Perth, Western Australia. At a peak capacity of 144 megaliters per day, the $387 million plant (which includes $64 million of integration assets), is the largest operating seawater desalination plant outside of the Middle East and Australia's first large-scale desalination facility for public water consumption. At full capacity, it is the biggest single water source feeding into the IWSS, providing some 17 per cent of Perth's water needs.

The plant utilizes reverse osmosis; 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 semipermeable membrane. In seawater reverse osmosis (SWRO) systems, an operating pressure of between 60 and 70 bar is typically required. Even at these pressures, a maximum of approximately 50% of the available pure water can be extracted before the osmotic pressure of the concentrate makes additional extraction too expensive. The rejected concentrate leaves the process at nearly the same pressure as 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, the application of larger pumps with higher efficiencies and variable speed control, and the implementation of isobaric energy recovery devices (ERDs) have dramatically increased the energy efficiency and viability of these processes. (Mickols et.al. 2005)

A process diagram of the PSDP is shown in Figure 1 below. The plant draws feedwater from an open intake in nearby Cockburn Sound. The six supply pumps draw through screens and discharge to twenty-four dual media filter vessels which in turn discharge through cartridge filters to the reverse osmosis process. The seawater supply pumps are controlled by variable frequency drivers (VFDs) to save energy and assure constant feed pressure to the HP pumps and energy recovery devices.

A single pipe conveys treated water to the HP pumps and energy recovery devices. The high-pressure (HP) pumps are sized and operated for maximum efficiency. ERDs are employed in arrays dedicated to each membrane train. High-pressure water from the ERDs and HP pumps flows to state-of-the-art low-energy first-pass membranes. The permeate flows to a second pass for further reduction of the total dissolved solids (TDS) and the bromide concentration. Product potable water flows through a four-hour buffer tank before being pumped approximately 13 kilometers to the fresh water reservoir that supplies the city of Perth with drinking water. Reject brine, after use as backwashing the dual-media filters, is pumped 0.5 km out to a diffuser field in Cockburn Sound.

As part of Western Australia's commitment to promote energy efficiency and reduce greenhouse gas emissions, the PDSP is the largest facility of its kind in the world to be carbon neutral, powered by renewable energy. The plant buys its power from electricity generated by the Emu Downs Wind Farm, located 200 kilometers 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. (Crisp 2007)

As a result of the innovative design and successful performance of the performance of the plant, the PDSP was recognized as the Desalination Plant of the Year in 2007 by Global Water Intelligence. It has been heralded as a landmark in the development of the Australian water industry. It is regarded as a world-leading model for future sustainable seawater desalination plants globally.

SWRO Energy Consumption

Typically 50 to 75% of the energy consumed by an SWRO plant is used to drive the motors of the high-pressure pumps of the first pass. (Mickols et.al. 2005) Isobaric ERDs reduce the load on these pumps using the energy contained in the first-pass membrane reject stream.

A simplified process 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 permeate from the membranes or as spent low-pressure concentrate from the ERDs. An energy recovery efficiency of 98% can be achieved with state-of-the-art isobaric ERDs.

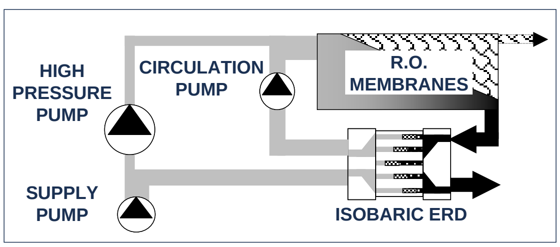

Figure 2 Simplified diagram of an SWRO process with isobaric ERDs

The benefit of ERDs for SWRO process energy reduction is illustrated in Figure 3. Starting with the Jeddah 1 plant in Saudi Arabia which had no energy recovery and consumed over 8 kWh/m^3 in the SWRO portion of the process (Hassan et.al. 1991), SWRO energy consumption was first lowered by implementing Francis turbines as was done in Las Palmas, Gran Canaria (Talo et.al. 2007), then by Pelton turbines as was done in Trinidad (Thompson et.al. 2005). It should be noted that the Pelton turbines in the Trinidad plant are very large and considered state-of-the-art. Nevertheless, the isobaric ERDs and other process improvements in operation in the PSDP cut SWRO plant energy consumption from approximately 3.8 kilowatt hours per cubic meter of permeate produced (kWh/m^3) to 3.2 kWh (Stover 2008) or about 16%.

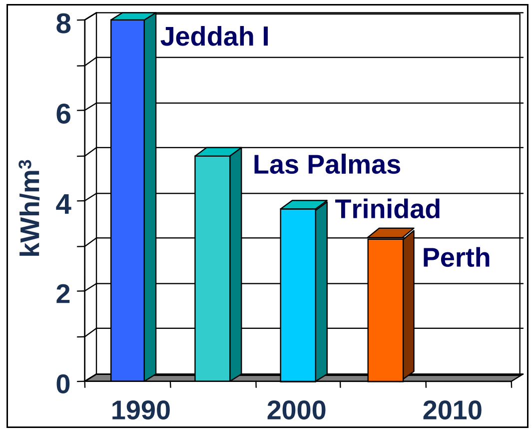

Figure 3 Evolution of SWRO energy consumption

The importance of isobaric ERDs for reduction of energy requirements and associated environmental impacts in SWRO technology received international recognition by desalination operators and users. The Energy Recovery, Inc. PX Pressure Exchanger® device was awarded Environmental Contribution of the Year in 2007, in part because the energy savings demonstrated in Figure 3.

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 compared to the power required to convey surface water to Los Angeles: about 2.9 kWh/m^3. 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 instead compared to the cost of alternative means of new supply. For this comparison, the cost of a 190 mega-liter per day plant with conveyance piping was compared to the cost of a comparable recycled water facility. The SWRO cost range was 0.63 – 0.74 USD/m^3 compared to 0.81 USD/m^3 for recycled water. (Dundorf et.al. 2007) 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. (Dingfelder 2004)

The overall energy consumption of SWRO in general and the PDSP in particular can be put into perspective by considering the energy consumed by a commercial airliner. The plant produces enough water for the homes and gardens of about 450,000 people. The energy required to do so is about one third of the energy consumed by one Boeing Jumbo Jet flying continuously. Such a jet uses approximately 77 MW of power for take-off and 65 MW of power to cruise compared to 21 MW of power for the PSDP. (Crisp 2008)

Other Environmental Factors

In addition to energy consumption, other potential environmental impacts to consider and manage carefully are concentrate and solids disposal. The discharge products from an SWRO process can include the seawater intake screen washings, clarified backwash effluent from the media filtration plant, reverse osmosis plant seawater concentrate stream, neutralized RO plant chemical cleaning wastewater and RO plant flushing water. At the PDSP, solid wastes from the intake screens, media filters and lime system are captured in the wastewater treatment clarifier. The sludge from the clarifier is dewatered by centrifugation to a spadeable cake for disposal to landfill. This decision was made due to the presence of coagulate particulate and colloidal material from the influent seawater, and concerns about possible discoloration of the nearby beaches should this backwash be discharged at sea. Offsite environmental management considerations include the salt content of the sludge; the quantity of the sludge; and handling quality of the sludge.

Significant concern has 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. To meet the strict environmental requirements for discharge into Cockburn Sound, the seawater concentrate is returned from the PDSP 470 meters into the ocean via a 40-port diffuser at the end of the discharge pipeline. The velocity of the discharge through is 4 m/s through nozzles spaced at five meter intervals to ensure total mixing of seawater concentrate within 50 meters of each side of the pipeline. Instruments that continuously monitor plant discharges automatically shut down the process in the event of an exceedance. In addition, the intake is designed for low-flow to effectively limit uptake of marine life. (Crisp et.al. 2007) An underwater video recently taken by the Water Corporation of the plant’s intake and outfall after 18 months of operation show them teaming with marine life including sensitive species such as sea sponges and sea horses.

Conclusions

The Perth SWRO plant has demonstrated that seawater desalination can be implemented on a large-scale in Australia affordably and with minimal environmental impact. The plant has demonstrated low energy consumption, achieved in part with the incorporation of isobaric energy recovery devices, the use of renewable energy and the minimization of environmental impacts at the intakes and outfalls. These features establish the plant as a global model for new sustainable water resources.

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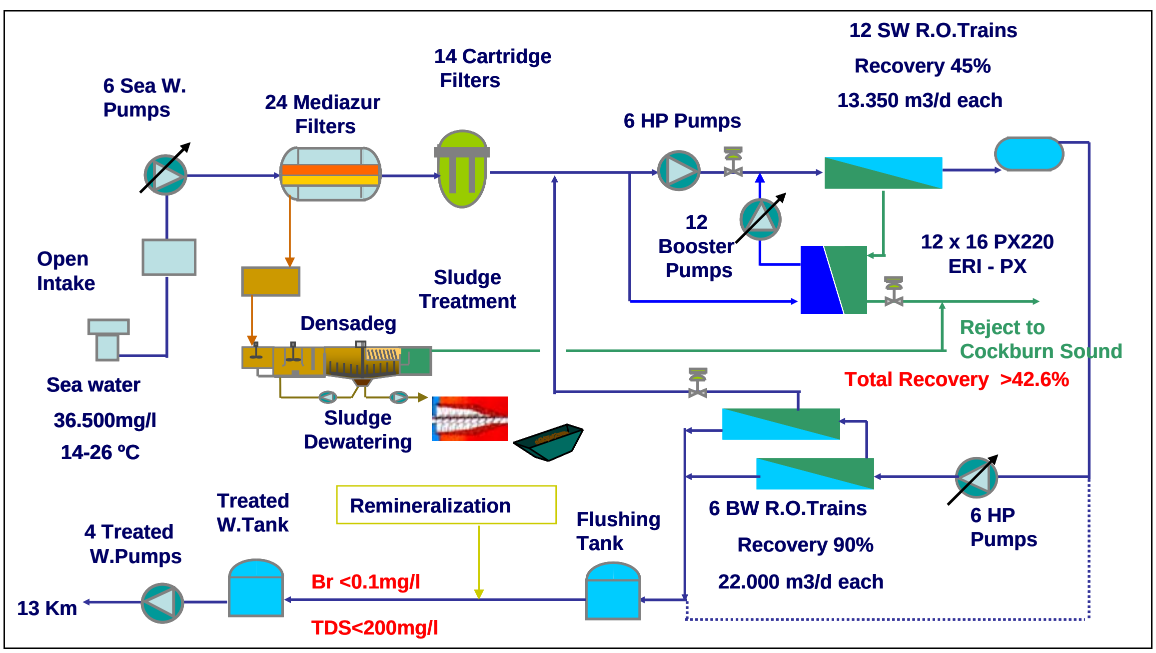

Figure 1 Perth seawater desalination plant process diagram