Expansion Retrofit of the Via Maris Palmachim Seawater Reverse Osmosis Plant

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Abstract

The Palmachim Desalination plant is one of the largest seawater reverse osmosis (SWRO) desalination plants in Israel with a capacity of 120,000 cubic meters per day (m^3/day). Built by the Via Maris Desalination Ltd. consortium, the plant consists of six (6) parallel SWRO trains, each with a permeate production capacity of up to 20,000 m^3/day. In addition its high-capacity SWRO trains, the Palmachim plant is unique because it was designed to be easily turned on, off or slowed down. Electricity tariffs in Israel are significantly higher during the day than at night with a cost ratio of up to six to one. The plant's flexibility allows the operators to minimize energy consumption during the day when the power cost is high by shutting down up to 85% of the plants capacity.

The original SWRO train design had a dedicated high-pressure pump (HPP) equipped with an energy recovery turbine (ERT). ERTs, also known as Pelton wheels, were standard equipment in SWRO plants designed and built in the 1990s and early 2000s. The maximum hydraulic efficiency of the very large ERTs at Palmachim is 88% and the net transfer energy recovery efficiency (water to water) is 76%.

SWRO process retrofits offer the opportunity to increase permeate production with minimal new equipment and construction. Therefore, when feasible, retrofits are generally an environmentally favorable alternative to constructing new plants. An SWRO process retrofit involves replacing some or all of the ERT capacity with isobaric energy recovery devices (ERDs). Isobaric ERDs are positive displacement devices that operate with energy transfer efficiencies as high as 98%.

Each retrofit presents unique challenges. The Palmachim SWRO plant required an increase in production capacity, an improvement in energy consumption and a minimization of the capital costs for the expansion while maintaining the high reliability and operational flexibility of the original design. Therefore, the membrane feed flow will be increased with PX Pressure Exchanger ERDs and circulation pumps while the original HPPs, motors and ERTs continue to operate without modification. This new hybrid energy recovery design requires that the ERTs, the HPP motors and the ERDs operate in balance at their best efficiency points, maintain the flexibility of starting and stopping on a daily basis, and prevent overflowing, overloading or otherwise straining any of the system components.

The authors provide a detailed analysis comparing SWRO productivity, energy consumption, flexibility, reliability and CO_2 emissions of the Palmachim plant before and after the retrofit.

I. INTRODUCTION

Reverse osmosis is a water desalination process used widely 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 60 to 70 bar (870 to 1015 psi) 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 (1). The rejected concentrate leaves the process at nearly the membrane-feed pressure. Efficient recovery of the pressure energy from this stream is essential for making SWRO desalination economically viable.

Membrane recovery rate is defined as the permeate flow rate divided by the membrane feed flow rate. A high recovery rate means a high process yield. However, in a desalination process, operation at high recovery results in higher average concentrate salinities in the membrane elements, higher osmotic pressures and higher membrane feed pressures compared to operation at low recovery. In addition, supersaturation of the concentrate at high recovery rates can result in scaling and high membrane flux can result in fouling. On the other hand, low recovery rate operation directly reduces process yield and can result in excess pretreatment and supply-pumping expenses. Permeate recovery rate optimization, therefore, is a critical exercise for RO process design and operation (2). Because energy consumption and related CO2 emissions are by far the greatest environmental impact of a SWRO process, energy-efficient operation is important for minimizing greenhouse gas production.

The Palmachim Desalination plant was designed for maximum energy efficiency and operational flexibility. Comprised of large SWRO trains, it operates with high-pressure pumps and energy turbines that approach maximum achievable efficiencies. Although it has operated reliably and well, the demand for product water from the plant has increased since startup. In addition, the plant operators were interested in energy consumption reductions available with new desalination equipment technologies. For these reasons, a two-phase retrofit of the plant was undertaken.

The first phase of the retrofit will involve adding isobaric energy recovery devices (ERDs), additional membrane vessels and pretreatment capacity to the existing system, increasing train capacity from about 15,800 to 24,000 cubic meters of permeate per day (m^3/day). The second phase of the retrofit will involve adding additional ERDs, vessels and pretreatment and the removal of the existing energy recovery turbines (ERTs) or Pelton turbines to increase train capacity to about 35,000 m^3/day. These retrofit designs and their associated benefits are discussed below.

II. ORIGINAL ERT PROCESS

The Palmachim Desalination plant is one of the largest SWRO desalination plants in Israel, producing 35 million cubic meters of permeate per year. Built by the Via Maris Desalination Ltd. consortium, the plant began operations in 2007. Water produced by the plant enters the municipal supply for use in general domestic, industrial and agricultural applications.

2.1 Original SWRO Process Description

The plant is fed eastern Mediterranean seawater from an open intake. The feedwater has a salinity of up to 42,000 mg/L total dissolved solids. The feedwater temperature varies seasonally from 17 to 31 degrees Centigrade. Pretreatment consists of dual-media and cartridge filters.

The SWRO portion of the plant consists of six (6) parallel trains, each with a dedicated feed booster pump, high-pressure pump and membrane array. Pressure is recovered from the membrane reject stream with energy ERTs mounted on the high-pressure pump shafts. Spent reject is returned back to the sea by gravity. A simplified schematic diagram of one SWRO train is given as Figure 1.

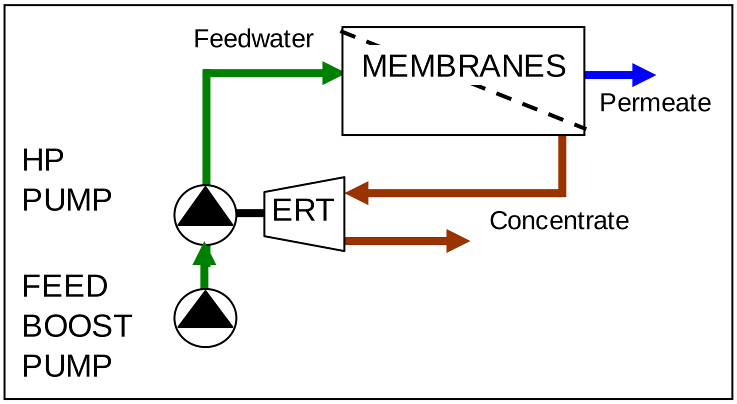

Figure 1 – SWRO Train with Original ERT Design

The SWRO trains normally operate at just under 16,000 m^3/day but can produce up to 20,000 m^3/day. The pumps produce 1,540 m^3/hr at their best efficiency points and up to 2000 m^3/hr. Their motors can take up to 1,835 kilowatts (kW) of power and deliver up to 1,800 kW of brake power. Very large ERTs, such as those in the Pamachim process, have two wheels (runners) which can be operated independently. Two wheels increase the capacity of the ERT. Each ERT turbine wheel can handle 375 to 475 m^3/hr of reject flow. A photograph of an ERT is given as Figure 2.

Figure 2 – Palmachim Two-Runner ERT

The large size of the pumps and ERTs contribute to their high efficiency. Designed to be operated with feed booster pumps, the high-pressure pumps have relaxed (increased) net positive suction head requirements which allows them to be designed for additional efficiency. As a result, the high-pressure pumps operate at up to 87% and each ERT wheel operates at up to 88% efficiency. This compares favorably to smaller pumps and ERTs which typically operate at less than 84% efficiency. The net transfer efficiency or water to water energy recovery efficiency is the product of the pump and ERT efficiency. The net transfer efficiency in the original SWRO trains is just over 76% at the best efficiency point making whereas the net transfer efficiency of a more typically-sized SWRO train is less than 70%. Palmachim is one of the most efficient ERT-based SWRO processes in the world.

2.2 Original SWRO Process Operation

In addition to high efficiency, the SWRO trains are designed for flexible operation. The motors of the high-pressure feed-booster pumps are equipped with variable frequency drivers (VFDs) which can be used to vary the pressure at the pump outlets from 4 to 18 bar. This allows the output of the high-pressure pump outputs to be manipulated without large and expensive VFDs on their motors.

The trains are easy to startup and shut down. The feed booster pumps partially pressurize the SWRO trains through the high-pressure pumps. This flow turns the turbines which result in additional pressurization (up to 40 Bar). The high-pressure pump motors are then engaged (using a soft starter). The result is a smooth, gradual pressurization achieved without a high-pressure control valve. Shutdown is similarly smooth.

Easy startups and shutdowns and variable operation give the plant's operators the flexibility to significantly adjust the plant's output and energy consumption. Electricity tariffs in Israel are significantly higher during the day than at night with a cost ratio of up to six to one. The plant's flexibility allows the operators to minimize energy consumption during the day when the power cost is high by shutting down up to 85% of the plants capacity. In addition, the plant has proved to be highly reliable providing over 99% availability.

III. HYBRID ERT-ERD EXPANSION RETROFIT

The demand for potable water in Israel has increased. The Palmachim plant sought a means to increase permeate production using its existing equipment without the undergoing a full expansion retrofit. In addition, the plant sought to maintain or increase the operational flexibility it enjoyed with the original plant design. Therefore, the design team developed an innovative hybrid ERT-ERD retrofit scheme.

3.1 Hybrid Retrofit Process Design

The hybrid ERT-ERD retrofit design uses the original pumps, motors and ERTs. Additional membrane pressure vessels are added to the original vessels, increasing the maximum permeate production capacity to 1,080 m^3/hr from less than 700 m^3/hr. Additional membrane feed flow is provided by an array of energy recovery devices (ERDs), an associated circulation pump and additional low-pressure pretreated water. This increases the flow rate of concentrated reject from the membrane elements accordingly and the additional reject flow is the high-pressure supply to the ERDs. The ERDs transfer the pressure of the reject stream to pretreated feedwater. This stream joins the high-pressure pump output to feed the membranes. A schematic diagram of the process is given in Figure 3.

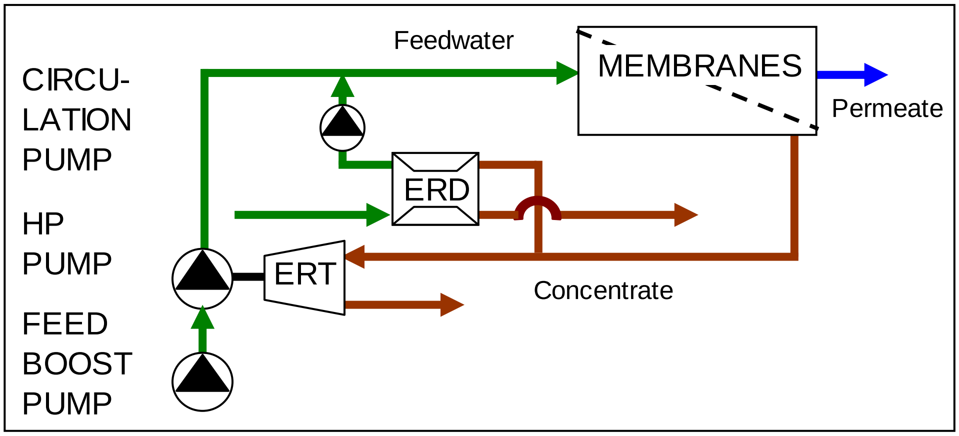

Figure 3 – SWRO Train After Hybrid Retrofit

For ERDs, each SWRO train will be equipped with arrays of 13 model PX-260 PX Pressure Exchanger devices. These are positive displacement isobaric devices in which pressure transfer occurs through direct contact between the high-pressure membrane reject and pressurized seawater. They operate at up to 98% pressure-transfer efficiency. Each PX-260 unit has a capacity of 41 to 59 m^3/hr, providing a flow range of plus or minus 18% from the mid-flow rate or up to 31% turndown capacity from maximum flow. This flow range is greater than that of the ERTs which can be turned up or down 15% from their mid-flow rate when considering a "normal" operation conditions using all inlet valves of the turbine. The capacity of each ERD array is up to 767 m^3/hr. Therefore, they supplement the original membrane feed flow by up to 50%. This increases the SWRO train capacity to a maximum of nearly 26,000 m^3/day.

The footprint of the PX devices and circulation pumps is about 5 square meters. The ERD arrays will be fit between the membrane racks and the installation will not require new civil work. Additional high-pressure piping will be added to connect the ERDs and circulation pumps to the new membrane elements. Low-pressure pretreated water will be piped to the ERDs from the pretreatment system. Because the ERDs do not require or benefit from boosted feed pressure, the feed booster system will remain dedicated to the high-pressure pumps and will not affected by the retrofit.

3.2 Hybrid Retrofit Plant Operation

Startup with the hybrid retrofit SWRO process begins with low-pressure feedwater to the ERDs. Next the circulation pump is started. Once low-pressure seawater is circulating through the membrane array, the ERDs and the circulation pump, the ERT, feed booster and high-pressure pump are started in the same manner as in the original SWRO design. One inlet valve per ERT wheel is shut down and the extra power of the electric motor will supply the required power to the high-pressure pumps. The feed booster partially pressurizes the membranes, the ERTs increase the pressure by turning the high-pressure pump, and finally the high-pressure pump motor is started to fully pressurize the system. The procedure is simple to execute and provides the smooth pressurization achieved with the original design. Shutdown is the same procedure in reverse.

In the retrofit Palmachim plant, membrane recovery can be adjusted by changing the feed booster pump speed or by changing the speed of the circulation pump. This gives the plant operators the flexibility to change how the plant operates as water conditions change or the cost of power changes. However, there are some practical limits to recovery variation as illustrated in Figure 4.

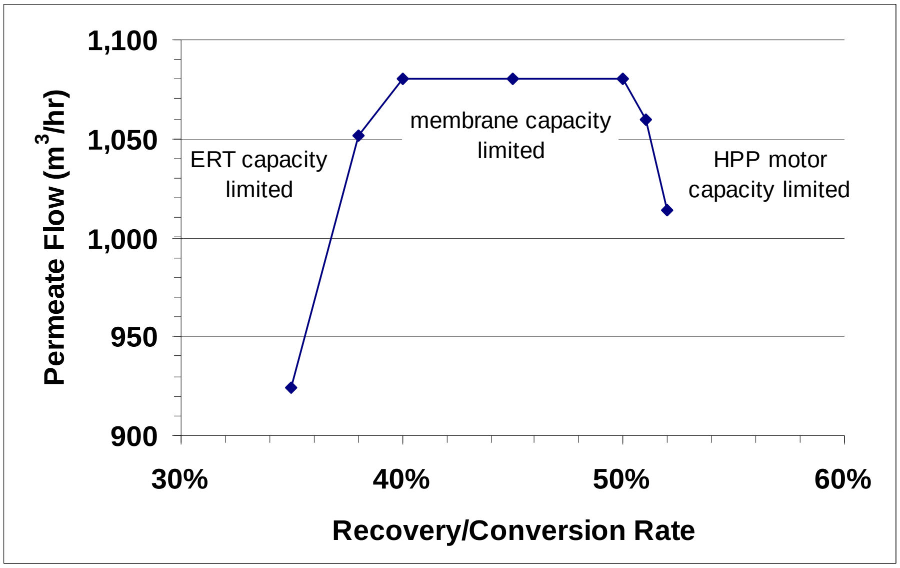

Figure 4 – Maximum Achievable Permeate Production Rate

In Figure 4, the maximum achievable permeate production rate is plotted as a function of membrane recovery rate. From 40 to 50% recovery, permeate production is limited only by the membrane elements themselves. Above 50% recovery, the concentrate flow rate to the ERT is reduced, putting an extra load on the high-pressure pump motor. In addition, high recovery rates correspond with higher membrane feed pressures, so the head requirement of the pump is increased. Permeate production is, therefore, limited by the capacity of the high-pressure pump motor. Below 40% recovery, reject flow to the ERT and ERDs is high. Therefore, maximum permeate production is limited by the capacities of these devices. It should be noted, however, that a range of 40 to 50% recovery is relatively wide and sufficient for all of the plant's operating requirements.

The SWRO specific energy consumption is the power consumed by the feed booster, high-pressure pump and circulation pump divided by the permeate flow rate. In the Palmachim plant, the estimated specific energy consumed by the original ERT SWRO process in the production of 667 m^3/hr of permeate as a function of recovery rate is illustrated with the red (upper) data set in Figure 5. This is compared with the expected energy consumption by the hybrid process producing 1,000 m^3/hr of permeate as a function of recovery rate illustrated with the blue (lower) data set in Figure 5.

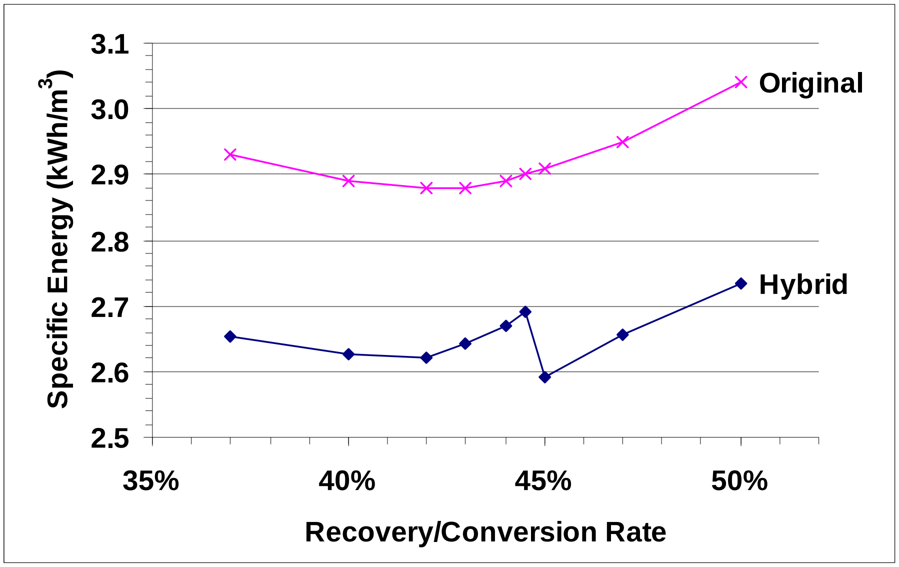

Figure 5 – Estimated SWRO Specific Energy Consumption

The specific energy consumption of the hybrid process is lower than that of the original process because of the higher efficiency of the ERDs. At recovery rates below 42%, both ERT wheels must be operated at high flow rates. In addition, pretreatment equipment and operation is more costly, but this is not considered in either Figure 4 or 5. At recovery rates between 42% and 45%, the higher pressures associated with higher recovery rates increase the power consumed by the high-pressure pump in both the original and hybrid processes. At 45% recovery, the reject flow rate is low enough to allow one ERT turbine wheel to be turned off in the hybrid process. This shifts the energy recovery duty from the ERTs to the more efficient ERDs and significantly lowers specific energy consumption. As recovery is increased above 45%, increasing membrane feed pressures increase the energy consumed by the high-pressure pump in a similar manner in both the original and hybrid processes.

3.3 Improved Process Performance

A comparison of the estimated performance of a single SWRO train at 45% recovery before and after retrofit is shown in Table 1. 45% recovery is estimated to be the optimum recovery rate for the plant. Also shown in Table 1 are estimated performance figures for a full retrofit to be discussed in the following section. In the comparison, the same high-pressure pump flow rate was assumed in all cases.

Table 1 – Retrofit SWRO System Performance

	Permeate Capacity (m3/day)	HPP Motor Power (kW)	Specific Energy (kWh/m3)	CO2 Emissions (g/m3)
Original Design	15,806	1,128	2.91	286
Hybrid Retrofit	23,998	1,714	2.59	254
Full Retrofit	34,677	2,467	2.38	233

The data in Table 1 show that the hybrid retrofit increases permeate production by an estimated 50%. It also shows that specific energy consumption after the hybrid retrofit was estimated to reduce by about 11% from the original design. As shown in Figure 5, the estimated specific energy reduction ranges from 7% to 11% at recovery rates between 37 and 50%. The estimated specific CO_2 emissions will reduce in proportion to the specific energy reductions. Not quantified in the analysis are the greenhouse gas emissions saved by expanding the plant within its current footprint rather than constructing new civil works.

IV. FULL EXPANSION RETROFIT

While the hybrid retrofit meets the design goal of increasing production and decreasing specific energy consumption with minimal modification of the existing system, a greater production increase and energy savings can be achieved with a full retrofit. In a full retrofit of an ERT-based SWRO process, the turbines are removed altogether. The resulting process, which is a standard isobaric ERD design (3), is illustrated in Figure 5.

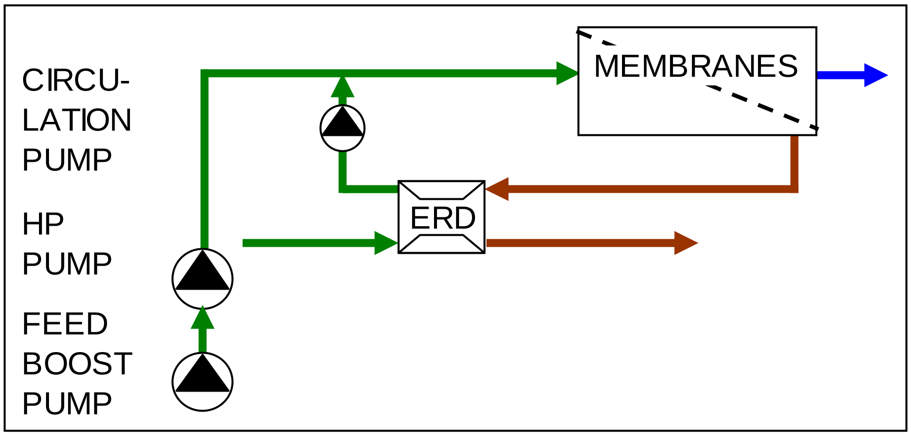

Figure 5 – SWRO Train After Full Retrofit

A full retrofit makes use of the original high-pressure pump, however, the motor must either be of sufficient size to handle the full load of the pump without assistance from the turbines or be replaced with a larger motor. Many plants operating with ERTs have full-sized motors as mitigation against possible turbine malfunctions, however, this is not the case in the Palmachim plant so new motors will be required. Sufficient new ERD and circulation pump capacity must be installed together with supplemental membranes, pretreatment capacity and post-treatment capacity.

Although the high-pressure pump flow rate is the same in the full retrofit as in the original design, the membrane feed flow is increased by about 120% or by a factor of 2.2 compared to the original design. Production can be comfortably increased to 140% compared to normal operation of the original design or to a daily output rate of 37,900 m^3 per train or 83 million m^3 per year for the plant. A full retrofit saves significant energy compared to the original design because the additional membrane feed flow requires very little additional energy input. As illustrated in Table 1, a full retrofit is estimated to reduce specific energy consumption by 18%.

V. ENVIRONMENTAL SUSTAINABILITY

SWRO process retrofits offer the opportunity to increase permeate production with minimal new equipment and construction. High-efficiency isobaric ERDs are available with sufficiently small footprints to be integrated into existing process layouts. As illustrated by the Palmachim retrofit, even large, energy-efficient plants operating with state-of-the-art ERTs can reduce energy consumption on a per-unit-permeate basis by nearly 20% by retrofitting with isobaric ERDs. The potential benefits of retrofitting less-efficient, medium-sized plants are even greater. For these reasons, retrofits are an environmentally favorable alternative to constructing new plants.

As discussed, another aspect of the Palmachim plant design that is important for managing energy consumption is flexibility. Both the hybrid and full retrofit designs have equal or greater flow ranges compared to the original ERT design. This flexibility is primarily used in Palmachim to minimize production during peak periods and maximize it during non-peak periods. However, the process recovery rate can also be adjusted in response to changing feedwater or membrane conditions. For example, recovery can be reduced to lower membrane feed pressure and energy consumption by the high-pressure pumps. Alternately, recovery can be increased to minimize seawater intake and pretreatment requirements.

VI. CONCLUSIONS

An SWRO process retrofit involves replacing some or all of the ERT capacity with isobaric energy recovery devices ERDs. SWRO process retrofits offer the opportunity to increase permeate production with minimal new equipment and construction and reduce energy consumption per unit of permeate produced. Therefore, when feasible, retrofits are generally an environmentally favorable alternative to constructing new plants. The Palmachim plant plans to implement their retrofit in two phases starting with adding ERDs to the original plant design, followed by adding additional ERDs and removing the original ERTs. Specific energy consumption and CO_2 emissions reductions from the original plant design of 11% and 18% for the two phases, respectively, are expected. In addition, the retrofit designs increase operational flexibility.

VII. REFERENCES

1. Mickols, W.E., Busch M., Maeda, Y., Tonner J.. A Novel Design Approach for Seawater Plants, Proceedings of the International Desalination Association World Congress, Singapore 2005.

2. Stover, R.L., Fernandez, A.O., Galtes, J.. Permeate Recovery Rate Optimization at the Alicante Spain SWRO Plant, Proceedings of the International Desalination Association World Congress, Dubai, UAE 2009.

3. MacHarg, J.P. and G.G. Pique, How to Design and Operate SWRO Systems Built Around a New Pressure Exchanger Device, International Desalination Association World Congress Manama, Bahrain 2002.