

From Pilot Plant to Full Scale Plant Expansion with Isobaric ERDs

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Abstract

The Tordera research and development pilot plant was built by Acciona Agua (Acciona), a leading designer and builder of seawater reverse osmosis (SWRO) plants. The pilot plant is located inside the existing Tordera SWRO plant in the town of Blanes, Spain near Barcelona. The pilot plant consists of two different (independent) pretreatment systems that feed one SWRO system. The SWRO equipment includes a high pressure pump, a circulation pump and an ERI PX Pressure Exchanger isobaric energy recovery device (ERD). Post-treatment equipment is installed to make the product water potable. All the equipment is designed to handle a wide range of flows and pressures and the system has been design to operate with or without the isobaric ERD.

The pilot plant was designed to allow researchers to conduct rigorous “A-B” comparison studies. Research topics included pretreatment, energy consumption, process flexibility and process reliability. The pilot plant is also used for training process engineers and plant operators.

The owner of the Tordera plant requested an increase in production capacity. A detailed feasibility analysis was undertaken which considered the technical advantages and results obtained from the performance of the isobaric ERDs evaluated in the pilot plant study. Based on the results of the analysis, Acciona decided to expand and retrofit of the Tordera plant. The existing energy recovery turbines were removed and decommissioned from service. An array of fifteen (15) PX-260 PX Pressure Exchanger devices and a circulation pump were added to the existing high-pressure pumps and motors. Additional membranes were added to increase the capacity of each of the four (4) SWRO trains from 8,000 to 16,000 m³/day.

The authors provide detailed analyses of SWRO productivity, energy consumption, flexibility and reliability of the Tordera SWRO process, as well as pilot plant test results for a wide-range of process conditions. Major considerations that should be addressed in the design and operation of SWRO processes are discussed. A case is made for the inclusion of an energy analysis in pilot testing and the feasibility of implementing large-scale plant expansions through retrofits with isobaric ERDs.

I. INTRODUCTION

The Tordera Plant, located in Blanes, Spain, is Catalonia's first large seawater desalination plant. The plant was contracted to Acciona Agua by the Catalan Regional Government's Water Agency in 2001. It was originally built to supply 28,800 m³/day of fresh water to the Gerona area. It began operation in 2003 and is currently run by AIE ITAN Delta del Tordera and UTE ITAM Tordera, with a 50% share by Acciona Agua.

At Tordera, as at other seawater reverse osmosis (SWRO) pilot plants, high pressure pumps consume more than 70% of all energy used in the desalination process, regardless of plant size. Original equipment manufacturers (OEMs) have long been looking for a solution to the high energy consumption in a drive towards optimization and cost reduction. Additionally, while pilot plants are useful for the study of pre-treatment designs and membrane performance, they have not been widely used for examining energy performance and process reliability.

The pilot plant at Tordera was designed to treat a flow of 20-22 m³/hr of well water, taken from the supply of the desalination plant before the water is subjected to any treatment. Acciona wanted to test energy recovery device (ERD) performance as part of a research project to enhance the SWRO process.

II. PROCESS DESCRIPTION

2.1 Pilot Plant Overview

A photograph of the Tordera pilot plant is given in Figure 1. The pilot plant draws feedwater from the main plant's wells through two pretreatment lines. Pretreatment line A is a microfiltration system that includes a coagulant dosage system and coagulation–flocculation chambers, followed by a decanter where the traditional lamellas have been substituted by polyvinylidene fluoride (PVDF) membranes. These are reinforced hollow fiber membranes for the separation of sludge. Pre-treatment B consists of coagulation in line with static mixers and a microfiltration system based on PVDF integral hollow fiber membranes.

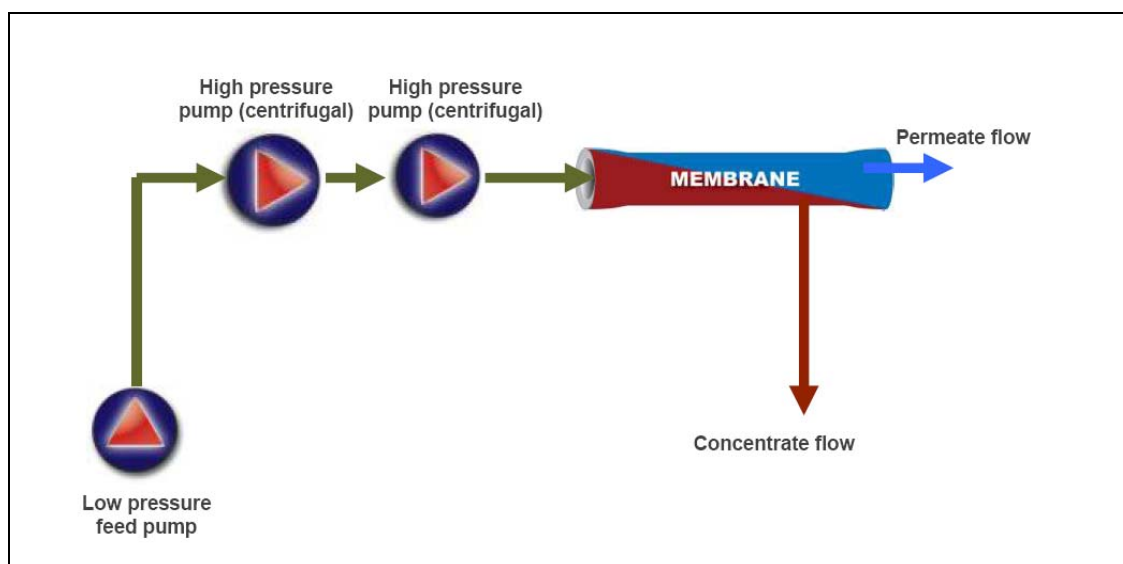


Figure 1 – Illustration of the Pilot Plant without Isobaric ERD



Figure 2 – The Tordera Pilot Plant

Subsequently, the treated water is pumped into the reverse osmosis (RO) membrane system. There are three different lines. The first RO line is made up of two membrane stages, each with eight 8040-size membrane containers and an intermediary booster pump between the stages. The second line consists of an 8040-size RO membrane container operating as a single stage. The first and second lines can be supplied from either pre-treatment line. These lines are equipped with centrifugal high-pressure pumps each with a capacity of 15 m³/hr at 800 meters of differential head. The best efficiency point of these pumps is approximately 80%. They are driven by 15 kW motors controlled by variable frequency drives (VFDs). Acciona Agua installed high-accuracy instruments to measure pressure and flow and an electrical meter to measure power consumption in the SWRO section of the pilot plant.

The third line is a second pass, low-pressure reverse osmosis system where permeated water obtained from the first and second RO lines is further treated. A dosage of sodium hydroxide is used to increase the pH to improve the efficiency of boron removal.

2.2 Retrofitting the Pilot Plant

The pilot plant was not initially equipped with ERDs. However, Acciona Agua wanted to be able to study the reliability and performance of these devices in a pilot plant. There were several different ERD options available, including isobaric pressure exchangers, turbine-based devices, reverse-running axial piston pumps and reverse-running centrifugal pumps. Acciona Agua selected the PX Pressure Exchanger device from Energy Recovery, Inc. (ERI) after an evaluation of factors such as efficiency, ease-of-use and maintenance requirements. Additionally, ERI is the only vendor that offers a small (20 gpm) isobaric ERD. This was a requirement because the plant was designed to operate with a recovery of 40-50% and, consequently, a maximum flow to the ERD of 20 gpm.

On November, 2007, the pilot plant was retrofit per schematic diagram in Figure 3 and in the photograph in Figure 4. An ERI PX-30S ERD and a Grundfos vertical circulation pump were added to

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the single-stage SWRO train described above. The circulation pump has a capacity of 7 m³/hr at 50 meters of differential head and is driven by a 7 kW motor controlled by a VFD. Since the start up date, the ERD has been operating without problems at constant efficiency

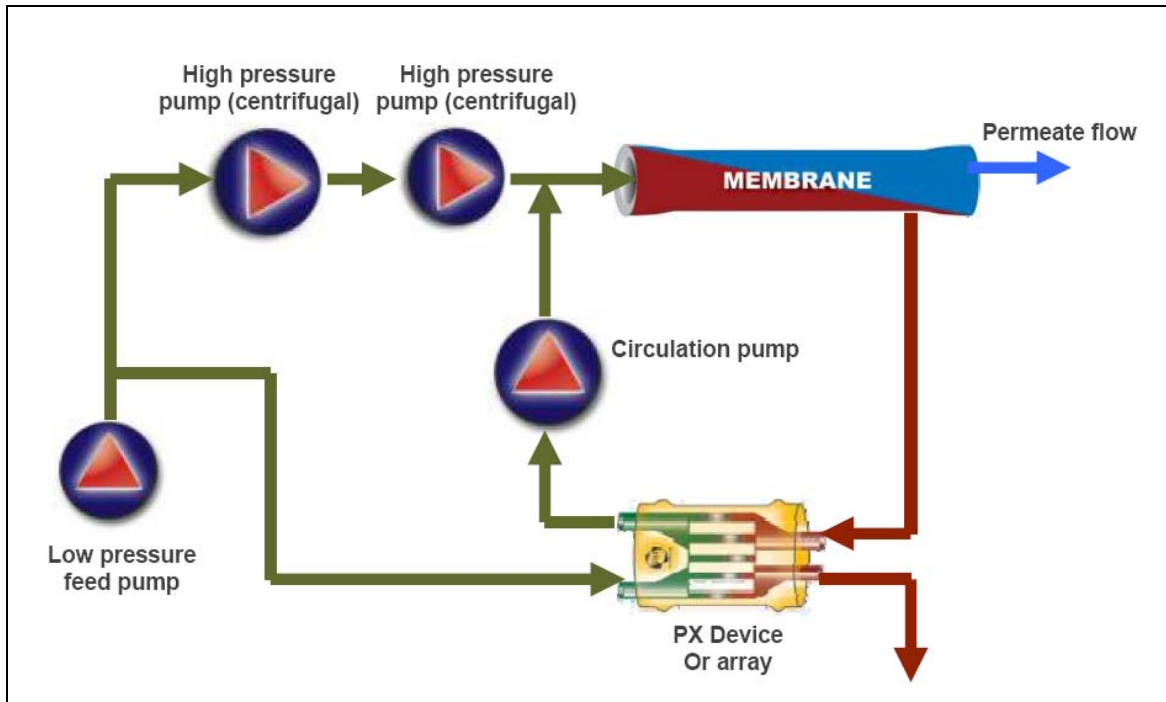


Figure 3 – Illustration of the Pilot Plant with Isobaric ERD



Figure 4 – The SWRO Process at the Tordera Pilot Plant

The pilot plant was designed to be operated with and without the ERD for an “A-B” comparison of its energy consumption performance.

2.3 The Tordera Desalination Plant

Operation of isobaric ERDs was new for the Tordera desalination plant which had been operating with turbine ERDs for five years. The plant consisted of four seawater reverse osmosis (SWRO) trains, each with a production capacity of 7,200 m³/d, for a total water production capacity of 28,800 m³/d. These were fed with five (4+1) split-case centrifugal high-pressure pumps, each with a capacity of 667 m³/hr at 683 meters of differential head and a best efficiency point of approximately 85%.

The pumps were driven by 1,482 kW motors equipped with VFDs and Pelton wheel energy recovery turbines with a capacity of 880 m³/day each. The best efficiency point of the Pelton wheels was approximately 88%. One high-pressure pump, in combination with a Pelton wheel, is always in standby mode so that only four trains operate at a time. A schematic diagram of one of the SWRO trains is given in Figure 5 and a photograph in Figure 6.

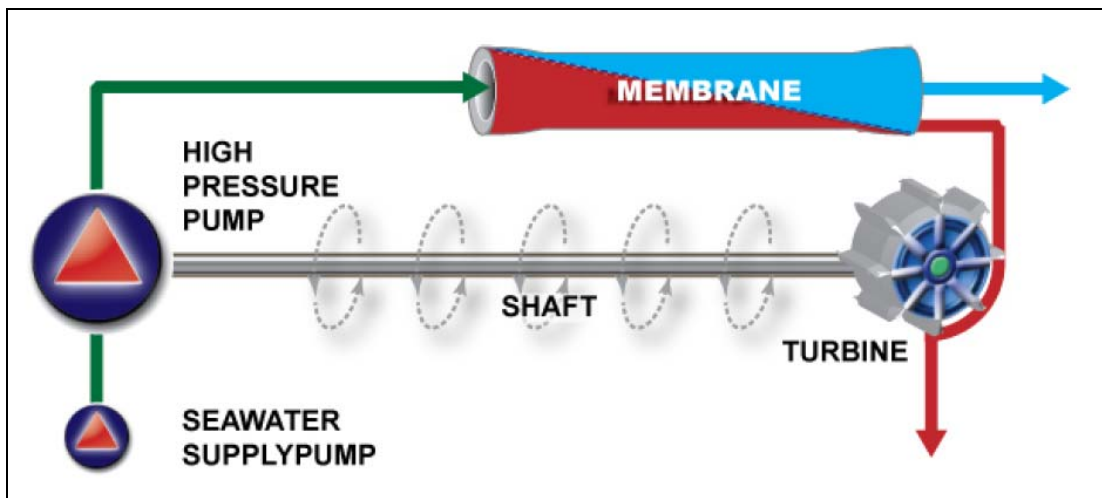


Figure 5 – Graphical Representation of SWRO Section of the Plant



Figure 6 – The Legacy Design of the Tordera Plant

The SWRO trains were fed by five centrifugal pumps which draw feedwater from ten open wells of 150 meters depth through screens that run approximately 2 km to the seawater inlet tank in the desalination plant. An initial chlorination of the water takes place in this tank to prevent any bacterial growth that could impede the plant's operation.

Once other chemicals have been added to the water to adjust certain parameters, the water goes through four of five sand filters which, in turn, discharge through cartridge filters to the reverse osmosis process. Independent pipes connect the treated water to the high-pressure pumps. The post treatment includes adding lime and carbon dioxide to the permeated water to modify its hardness and acidity and make it drinkable.

2.4 Retrofitting Tordera Desalination Plant

The Catalan government sought to expand the capacity of the Tordera plant due to the “decreto de sequia” or the need to relieve the severe drinking water shortages in the region due to increases in population and tourism. The Catalan Regional Government's Water Agency awarded the project to expand the Tordera plant to Aqualia and Acciona Agua in 2008. The project had a goal of doubling the plant's water production capacity, increasing it from 28,800 m³/day to 57,600 m³/day.

To reduce the energy consumption of the plant, it was decided to remove the Pelton wheels and replace them with high-efficiency isobaric ERDs. The high-pressure pump motors were replaced with larger 1600 kW motors so that the same pumps could be used without the Pelton wheels. The new layout, illustrated in Figure 6, includes five new circulation pump and isobaric ERDs. Each train uses 15 ERI model PX-260 devices with a maximum capacity of 59 m³/hr and a maximum efficiency of 98%. The ERD arrays each require one circulation pump (for a total of 5) with a capacity of 809 m³/hr at 55 meters of differential head, driven by 160 kW motors controlled by VFDs. The best efficiency point of these pumps is approximately 85%.

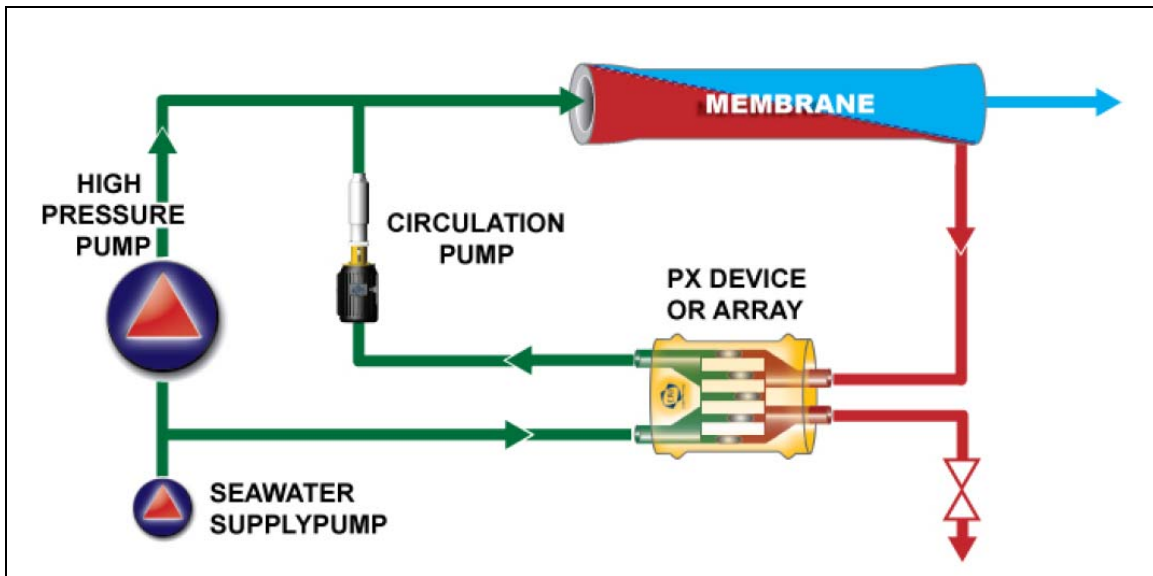


Figure 6 – Graphic Representation of the SWRO Section of the Plant after Retrofit



Figure 7 – SWRO Section of the Plant after Retrofit

Technical improvements were made to reduce environmental impact and energy consumption. The existing well water intake system was replaced with an open intake system, drawing water directly from the sea. The number of SWRO membranes were doubled to handle the additional permeate flow. Each train uses 1,414 membrane elements housed in 202 side-port pressure vessels for the first pass. A second pass was added for boron removal. Each second-pass train uses 140 membrane elements housed in 20 side-port pressure vessels.

V PROCESS PERFORMANCE

5.1 Pilot plant:

The pilot plant without an ERD included two high-pressure pumps and membrane elements. After retrofit with a PX-30 ERD and a circulation pump, the pilot plant operation changed as illustrated in Table 1.

Table 1 – Operational data of the pilot plant

		Before retrofit	After ERD retrofit
Membrane inlet flow	m3/hr	8.6	8.6
Permeate flow	m3/hr	3.8	3.8
Recovery	%	44.1	44.1
Membrane inlet pressure	bar	55.1	61.3
HHP inlet flow	m3/hr	8.6	3.8
Estimated HPP efficiency	%	57%	34%
PX device – HP OUT flow	m3/hr	--	4.7
PX device – LPOUT flow	m3/hr	--	4.7
PX device – HP OUT pressure	bar	--	59.3
PX device – LP OUT pressure	bar	--	2.5
Net transfer efficiency	%	--	94.8
Salinity increase at the membranes	%	--	3.26
HPP A power	kW	13.9	12.0
HPP B power	kW	12.6	10.7
Circulation pump power	kW	0	2.1
Total power	kW	26.5	24.8
Specific energy	kWh/m3	6.98	6.58

The high-pressure pumps, sized for the original plant, were oversized for operation with the ERD. Consequently, pump efficiency reduced significantly after the ERD retrofit resulting in only minimal energy savings. Nevertheless, the retrofit did reduce energy consumption.

If the membrane capacity had been increased as part of the retrofit such that the high-pressure pump flow rate remained at the original flow rate, the retrofit process could have performed as shown in Table 2 below. If the pumps had been further optimized and operated at their best efficiency point after ERD retrofit, the process could have performed as shown in the last column in Table 2.

Table 2 – Hypothetical power consumption and efficiencies comparison for the pilot plant

		With ERD and medium HPP efficiency	Optimized configuration
HPP efficiency	%	57%	80%
HPP A power	kW	6.5	9.5
HPP B power	kW	6.5	
Circulation pump efficiency	%	---	48%
Circulation pump power	kW	2.1	0.6
Total power	kW	15.1	10.1
Specific energy	kWh/m ³	4.00	2.68

5.2 The Tordera Desalination plant

The Tordera desalination plant before retrofit included a feed-water pump, 1 high-pressure pump equipped with a Pelton turbine and membrane elements. After the retrofit with a new high-pressure pump motor, additional membrane elements, PX-260 devices and a circulation pump, the plant operated with significantly lower specific energy consumption. Operational data from before and after the retrofit is given in Table 3 below.

Table 3 – Operational data of Tordera desalination plant without isobaric ERD

		Before retrofit	After ERD retrofit
Permeate flow	m ³ /hr	310	713
Recovery rate	%	45.3	48.0
Membrane inlet flow	m ³ /hr	685	1,483
Membrane inlet pressure	Bar	70.2	65.7
Membrane salinity increase	%	--	2.3
Turbine inlet pressure	Bar	67.6	--
DEVICE EFFICIENCIES			
HP pump efficiency	%	85	85
HP pump motor efficiency	%	95	95
Turbine efficiency	%	80	--
Net transfer efficiency	%	68	0
Circulation pump efficiency	%	--	85
Circulation pump motor eff	%	--	95
VFD efficiency		--	97
PX device net transfer efficiency	%	--	96
POWER CALCULATIONS			

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Mechanical energy recovered	kW	548	--
HP pump power	kW	983	1,582
Circulation pump power	kW	--	92
Total power	kW	983	1,674
Specific power consumption	kWh/m ³	3.17	2.35

The data in Table 3 show that the high-pressure pump efficiency did not change with the retrofit as it had in the pilot plant. This is because the efficiency curve of the larger pump is much smaller than that of the pump used in the pilot plant. Energy recovery device efficiency and membrane salinity increase in the pilot plant was similar to that in the full-scale plant indicating that the performance of these devices scales well. Although overall power consumption of the full-scale plant increased after ERD retrofit, permeate production more than doubled. As a result, specific power consumption reduced by about 26%. Specific energy consumption in the retrofit plant was less than that predicted for the optimized pilot plant shown in Table 1 because of the higher pump efficiencies in the full-scale plant.

VI CONCLUSIONS

Several noteworthy insights have been presented in this paper. These include the following:

- SWRO process retrofits with isobaric ERDs and additional membranes and pretreatment capacity increases the production and reduces the specific power consumption of the plant;
- Small capacity isobaric devices are a feasible option for pilot plants or small size RO plant operators or OEMs;
- The benefits of operating isobaric ERDs in small RO plants will be reflected and enlarged in full scale RO plants;

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