Barcelona: 200000 m^3/day of Potable Water coming from Mediterranean Sea

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Abstract

The Barcelona Desalination Plant with a production of 200,000 cubic meters per day is currently the largest seawater reverse osmosis project in Europe to supply potable water and one of the largest in the Mediterranean Sea and the world.

This Project is developed by Aguas del Ter-Llobregat (ATLL), public company of the Catalonian Government (Generalitat of Catalonian). A Joint Venture of Degrémont, Aigües de Barcelona and Dragados-Drace will built the plant and operate it for 2 years.

The desalination plant will be able to produce approximately 20% of the total potable water demand for Barcelona's Metropolitan area. This plant is a key part in the strategy of potable water supply of the region due to rainfall reduction the last years and the limitation of the existing supplies. This plant also allows improving the water quality (specially TDS) in Barcelona's southwest area. This project is integrated in the Spanish Government Program "AGUA" to built more than 20 desalination plants in the Mediterranean coast to produce over 1,500,000 m^3/day for potable water and irrigation use.

The plant supplier was selected in July 2006. A pilot plant was operated for several months to help in the design of some operational parameters of the pre-treatment and RO and also to establish a better evaluation of the seawater quality. The construction of the desalination plant started in February 2007 in order to produce potable water for Barcelona area in January 2009.

The reverse osmosis plant is located in El Prat, an industrial area not far from Barcelona Airport, close to one the waste water treatment plants of Barcelona.

The intake is placed under the influence of Barcelona harbour and the outfall of Llobregat River. Due to this location two types of seawater intakes were evaluated: the first an open intake at 2000m offshore and 25m above the sea level and the second by infiltration with 50 horizontal drain pipes placed a few meters under the seabed in the permeable marine subsoil with an unitary length over 300m.
The brine from the RO plant is pumped to the WWTP outlet facility in order to use the same discharge pipe to the sea.

The selected pre-treatment (4 stages) is one the more complete and robust conventional pre-treatment in seawater desalination. It consists in a battery of high-rate flotators (AquaDAF^{TM}) followed by two steps of dual media filters (the first with gravity Mediazur^{TM} DMF and the second pressurised DMF) and finally cartridge filters of 5 micron. The last pre-treatment steps is fed using variable speed filtered seawater pumps up to the HP Pumps inlet.

The reverse osmosis is composed of 10 seawater RO trains with unitary production of 20000 m^3/day working at 45% recovery rate.

Eleven HP pumps, one on spare, feed the 10 racks. Energy Recovery is done using isobaric chambers in order to allow good optimisation of the energy consumption.

A deep study was performed to select the supplier of energy recovery system considering all factors for long time operation.
The potabilisation plant consists of limestone, carbon dioxide and chlorination. Treated water is stored in an onsite tank and transferred via variable speed pumps to the potable water distribution network of ATLL.

The treated water will comply with the Spanish Drinking Water Guidelines, specially the Boron (less than 1 mg/l)

Due to environmental discharge requirements and ATLL requirements the plant also incorporates a complete sludge treatment facility.

The design of the plant has incorporated the last innovations of the desalination market in order to have a very good operational flexibility to ensure the production over 60 GL per year as well as the minimum energy consumption and operating costs.

I. INTRODUCTION

The Barcelona Desalination Plant with a production of 200,000 cubic meters per day is currently the largest seawater reverse osmosis project in Europe to supply potable water and one of the largest in the Mediterranean Sea and the world.

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The reverse osmosis plant is located at El Prat, an industrial area not far from Barcelona Airport, close to one-wastewater treatment plants of Barcelona.

Figure 1 – Situation of the Open Intake, Seawater Pumping Station and SWRO Plant

II. PREVIOUS STUDIES

The Joint Venture prepared the project taken into account the difficulties about the seawater origin/quality.

Three specific Water Studies were done, starting one year before the presentation of the Proposals and completed with one after client's final decision.

One study per season to evaluate the evolution of the seawater quality, and its influence in the design of the RO Plant (SDI, Temperature, TDS,…) depending on the source of seawater.

The main objectives of the studies were to:

- Improve knowledge of the raw water quality.
- Validation of the pre-treatment process.
- Determination of the optimum chemical regime and design parameters.

2.1 Seawater Analyses

During the four seasonal studies the seawater of the two different sources was analysed just to have a precise knowledge of the quality of the water.

	Open Intake	Beach Wells
Cations		
NH_4, mg/l ……..…….…….…	0,02	0,50
K, mg/l ……..……..	450,00	440,00
Na, mg/l ..……	12.227,50	12.000,00
Mg, mg/l ...……..……	1.412,50	1.320,00
Ca, mg/l ….....……..……	455,00	440,00
Sr, mg/l …..…….	8,45	8,55
Fe, mg/l	0,02	0,40
Ba, mg/l ……	0,03	0,03
Total cations	14.553,52	14.208,87
Anions		
HCO_3, mg/l ……..……..	169,00	188,00
NO_3, mg/l …..…….	0,20	2,50
Cl, mg/l …….	21.789,61	21.136,37
F, mg/l	1,43	1,35
SO_4, mg/l ……......	3.155,00	3.135,00
Total anions	25.115,24	24.461,32
TDS, mg/l ..…….	39.668,76	38.670,19
B, mg/l	5,30	5,30
Mn, mg/l …….…….……	---	0,30
SiO_2, mg/l ……...	0,01	0,48
pH ……	8,12	7,80

Table 1 – Seawater Analyses

2. 2 Description of the Studies

During the studies, it was performed direct filtration on 1 or 2 stages and made a comparison with a clarification stage (flotation or settling) in front of the filtration. The filtration performances with different media effective size were also studied.

This type of studies was made several times during the last years, with a bench scale pilot. The calibrations were done by comparison with bigger pilots (Degremont Research center, Wadi Ma'In - Jordan, Taweelah and Fujairah – UAE, Minera Escondida – Chile, Perth – Australia, Macao – China …) and also with full-scale plants (Bahia de Palma, Carboneras and El Atabal – Spain, Gibraltar – UK, Bredeah – Algeria, Fujairah – UAE…).

The results achieved during all those manipulations show a good correlation between the different sizes of process.

After determination of the optimum chemicals regime (pH, coagulation/flocculation), clarification and filtration tests were made with thousands of liters of seawater.

Several configurations were tested:

- Direct filtration (one stage)
- Direct filtration (two stages)
- Settling + One stage filtration
- Settling + Two stages filtration
- Flotation + One stage filtration
- Flotation + Two stages filtration

Testing different filtration medias, velocities, pressurized vs. gravity, dual media vs. mono media,…

Measuring SDI, Turbidity, clogging velocities, Fe, Coefficient K (sludge cohesion index),…

2. 3 Conclusions

The SDI level, after the last stage of filtration, achieved during the tests, it's always less than 3, with independence of the source of water, but the results were better with the water from the beach wells, but it will be necessary to confirm the results in the pilot plant.

The selected pre-treatment line will be one of the most completes ever, including 4 stages; this process is already in operation in another Degremont's reference (El Coloso SWRO plant – Chile [1]). It will be tested and optimized during Pilot Plant trials.

Clarification process performed with the high rate AquaDAF™ (successful system in difficult Pacific seawaters [2]), due to the quality of sea raw water (potential algae bloom and organic matter presence), no polymer needed. Two stages of dual media filters, due to high clogging velocity on mono media filters (filtration cycles less then 12 hours in some periods), with coagulation upstream each stage, because of the high SDI values measured on raw water. Finally a cartridge filter stage of 5 microns before RO membranes.

III. PILOT PLANT

Since February 2.007 the Pilot Plant, scale system of the full-scale SWRO Plant, will be in operation to demonstrate the capacity of the different processes (The final results will be presented during IDA 2.007 Conference), to face all types of water and to acquire the necessary specific experience required before the commissioning and the operation of the plant.

The pilot plant has 3 different process lines working in parallel.

Two of them are conventional pre-treatment (Settling or Flotation + Filtration + RO + Reminéralization) and the other has a membrane pre-treatment after flotation.

The pilot plant can produce more than 200 m3/day of desalinated water, with a pre-treatment capacity of 750 m3/day.

3.1 Description

The Pilot Plant has the following main processes:

- It's feed with the 2 different sources of Seawater, representatives of the full-scale plant intakes.

Line A

- A lamellar settling unit (Pulsatube) for 20 m3/h production of clarified water
- A conventional filtration skid composed of 2 pressure filters in series. The filtration capacity is around 20 m3/h; feed pumps controls the flow rate through each filter and pressure sensors provide the pressure drop monitoring. The skid incorporates all ancillary equipments for air and water filter backwash, in the same conditions as the industrial one, the 2 stages of filtration can work with different medias.

Line B

- A high rate AquaDAF^{TM} unit (production capacity up to 40 m3/h) with 2 mechanical flocculation chambers in series followed by a flotation cell equipped with the AquaDAF^{TM} patented floor system; the skid mounted unit incorporates an air pressurization tank, the recycling pump and all ancillary equipments for coagulant dosing pH, adjustment and periodic de-sludging, etc. This AquaDAF^{TM} will be by-passed during normal seawater conditions (low SS, low organic contents), but can be brought to full flow in a very short time.
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Line A & B

- The filtered water from line A or B feeds the RO pilot unit equipped with 1 pressure vessel containing 7 elements. The pilot unit is assembled on a monoblock frame incorporating the pre-filters (5 µm), a booster pump, a HP pump, dosing equipments and the pressure vessel. It allows for an independent loop control of the feed flow, the working pressure and the dosing of antiscalant and caustic soda if a pH correction is required. It is equipped with 2 flow meters (permeate and reject flows), pressure gauges to monitor precisely the membranes head loss over time. The maximum permeate production capacity of the pass is around 4 m3/h.

Line C

- A high rate AquaDAF^{TM} unit (production capacity up to 32 m3/h) with hydraulic flocculation chambers in series followed by a flotation cell equipped with the AquaDAF^{TM} patented floor system; the skid mounted unit incorporates an air pressurization tank, the recycling pump and all ancillary equipments for coagulant dosing pH, adjustment and periodic de-sludging, etc. This

AquaDAF™ will be by-passed during normal seawater conditions (low SS, low organic contents), but can be brought to full flow in a very short time.

- A membrane pre-treatment skid. The production capacity is around 15 m3/h.
- The pre-treated water from line C feeds this RO pilot unit equipped with 1 pressure vessel containing 7 elements. The pilot unit is assembled on a monoblock frame incorporating the pre-filters (5 µm), a booster pump, a HP pump, dosing equipments and the pressure vessel. It allows for an independent loop control of the feed flow, the working pressure and the dosing of antiscalant and caustic soda if a pH correction is required. It is equipped with 2 flow meters (permeate and reject flows), pressure gauges to monitor precisely the membranes head loss over time. The maximum permeate production capacity of the pass is around 5 m3/h.

Lines A, B & C

- The permeated water from the RO skids can go to a Reminéralization skid with limestone columns + CO_2 adjustment.

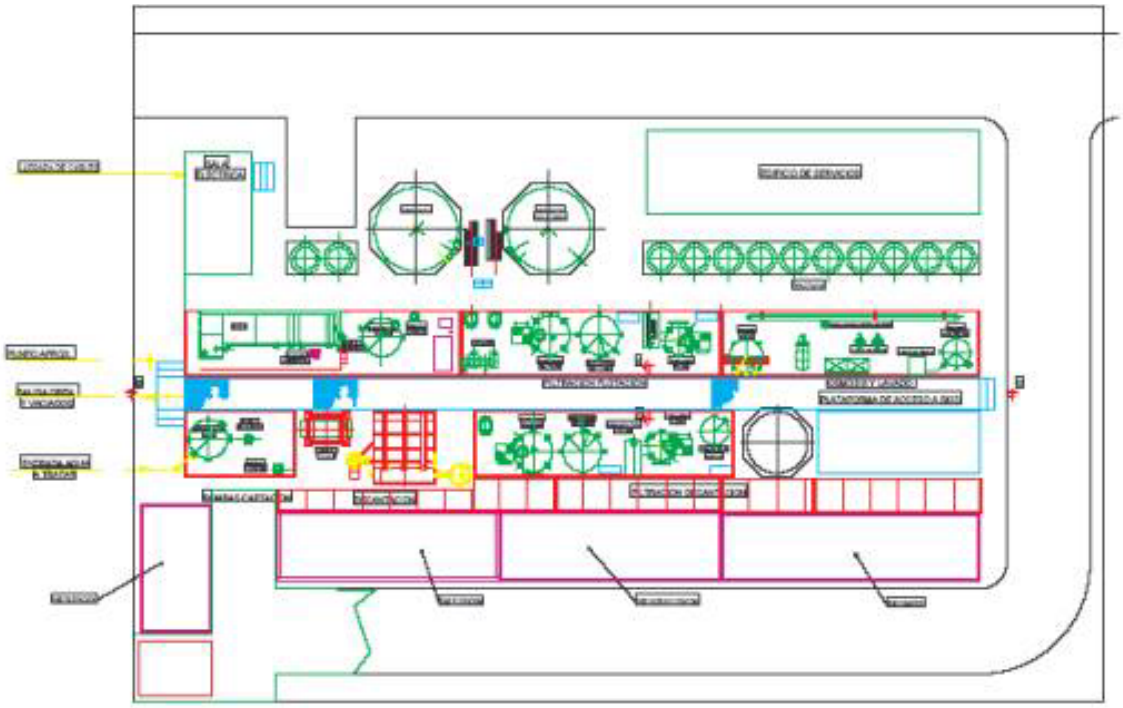

Figure 2 – Pilot Plant layout

IV. SEAWATER INTAKES

During the last year and a half, the Joint Venture studies the 2 different alternatives of intakes, mainly about the quality of the water and the warranty of provision.

Thousands of liters of seawater were collected from the drain pipes (beach wells), of the pilot plant of ATLL, installed in the area of the possible future intake; and from the location of the offshore open intake (2 km away of the coast and 25 m depth).

Figure 3 – Water from the beach wells

Figure 4 – Offshore seawater sampling

In addition a study of the influence of the Llobregat River in the two sources was done.

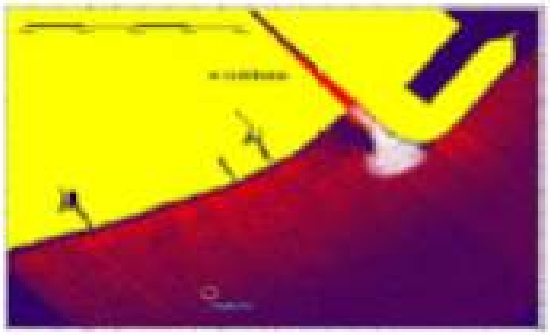

Figura 101. Dispersión de partículas de 100 µm en el caso 9.

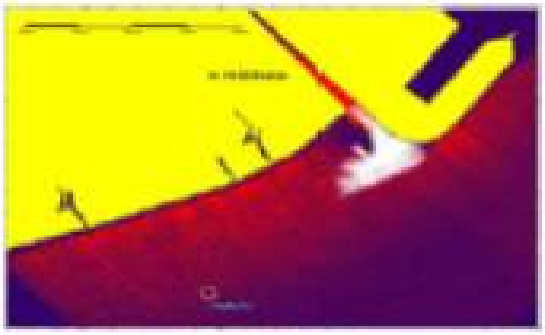

Figura 102. Dispersión de partículas de 50 µm en el caso 9.

Figura 103. Dispersión de partículas de 25 µm en el caso 9.

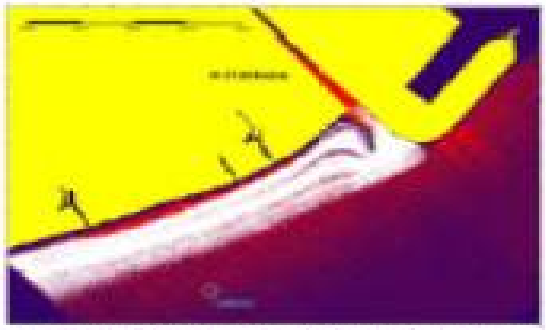

Figura 104. Dispersión de partículas de 10 µm en el caso 9.

Figura 105. Dispersión de partículas de 5 µm en el caso 9.

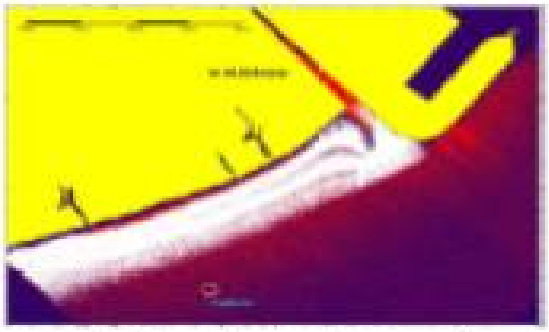

Figura 106. Dispersión de partículas de 2 µm en el caso 9.

4.1 Beach wells

About the horizontal drain pipes there are a lot of doubts about the evolution of this new type of system, and the results of some references are not so go as expected (San Pedro del Pinatar I - Murcia).

ATLL has made a study, for more than 2 years, of the evolution of the capacity (variation of flow) and the quality of seawater.

The Joint Venture has analyzed some samples of the seawater coming from the beach wells, and tested it in the bench scale pilots.

The results of those trials give the following conclusions:

- The beach wells' SDI varies from 10 to 26, and the Turbidity from 2.1 to 7.3 NTU.
- During heavy rainfalls the quality of the seawater gets worse, due to the influence of Llobregat River (confirming the study conclusions).
- In some samples there are high levels of Iron, Manganese, Ammonium,…
- The pre-treated water SDIs are 0.5 less than the open intake ones.

4.2 Offshore open intake

The open intake seawater could be influenced by the harbour, the Llobregat River, the WWTP discharge pipe.

Samples from the open intake has been analyzed, and tested in the bench scale pilots.

The results of those trials give the following conclusions:

- The sea raw water SDI varies from 6.5 to 41, and the Turbidity from 0.3 to 2.8 NTU.
- There is no significant influence on seawater, due to heavy rainfalls (Llobregat River – according with the study conclusions).
- Potential presence of algae bloom and organic matter, it makes necessary a complex pre-treatment, that is going to be tested in the pilot plant.

4.3 Selection of the seawater intake

An open intake will be the source for the SWRO plant of Barcelona, although it gives a little worse quality of water, it has less problems of evolution with time, assures a greater availability, it is not affected by the Llobregat River in case of great storms as the beach wells (as shown in the study of the influence of the River), and the consumption of reagents in the pre-treatment is similar in both sources.

V. DESCRIPTION OF THE FULL SCALE PLANT

Seawater Intake

The selected seawater source is the offshore open intake located at 2,000 m from the coast at 25 m below the surface. There is a pumping station, 3.5 km away from the SWRO plant, with 6 pumps for 21,000 m3/h total flow of seawater.

Pre-treatment

It has the following processes:

- **Shock chlorination system**. Three dosing points; Offshore works, pumping station and before the first stage of pre-treatment.
- **Chemicals dosing system**. FeCl3, H2SO4, Coagulant Aid. There are static mixers and/or coagulation chambers with flash mixers, before each stage of pre-treatment.

- 10 high rate **AquaDAF™** units with 2 mechanical flocculation chambers, in series, equipped with 4 flash mixers each, followed by a flotation cell equipped with the AquaDAF™ patented floor system. There is a by-pass of the AquaDAF™ during best seawater conditions.
- 20 **first stage gravity dual media filters**, each filter of the Degremont´s Mediazur type being capable of handling up to 1.200 m3/h.
- 24 **second stage pressurized dual media filters**, each filter of the Degremont´s FH type being capable of handling up to 900 m3/h.
- 18 **cartridge filters** with 360 cartridges of 5 microns each.
- **Chemicals dosing system**. Sodium Bisulphite, Anti-scalant, Caustic Soda. There are static mixers before and after the cartridge filters to ensure the reactions.

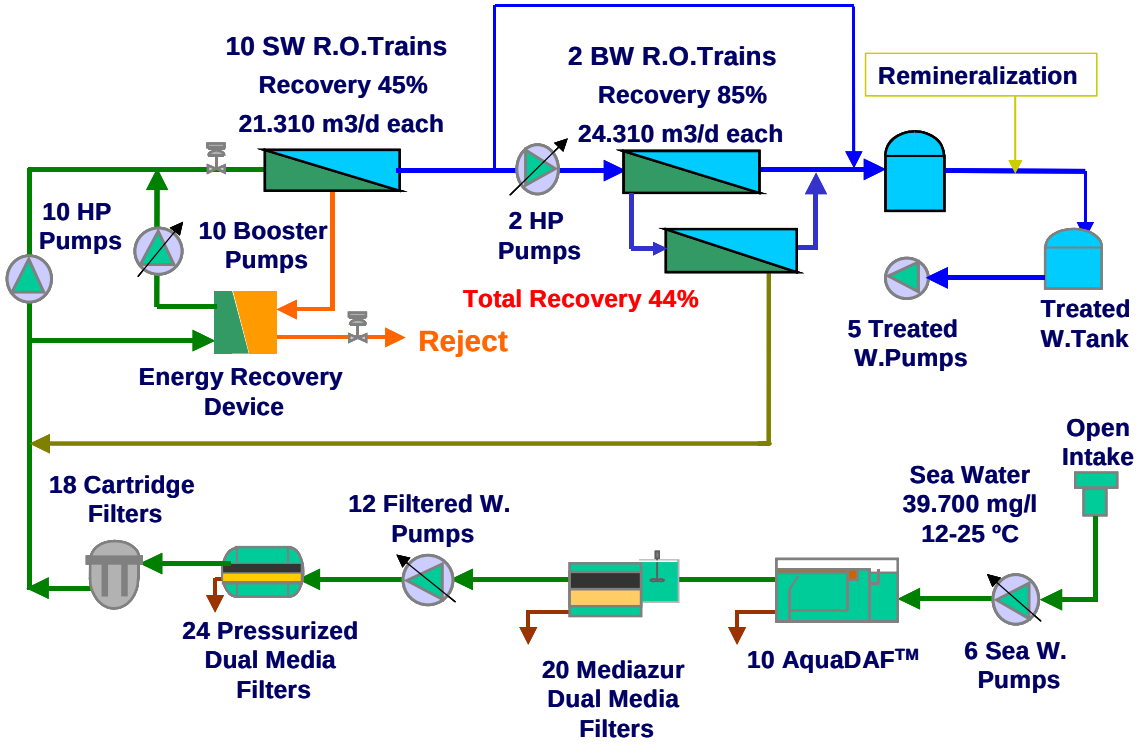

Figure 6 – Barcelona SWRO plant 200.000 m^3/day

RO plant

In accordance with the tender and national drinking water regulations the permeate water before Reminéralization has to be less than 400 mg/L of TDS, and less than 1 mg/L of Boron, the RO design incorporates a double passes system as follows:

- **1st pass:** 10 trains, each one with 240 PV x 7 elements with a recovery rate of 45%.
- **2nd pass:** 2 trains, each one with 100 PV x 7 elements with a recovery rate of 85%. The trains have two stages (75 PV in the 1st stage and 25 in the 2nd). 75% of 1st pass permeate flow is by-passed to be blended with the 2nd pass permeate flow ensuring a blended water with less than 1

mg/L of Boron. The brine produced by the 2nd stage being of a much lower salinity than the seawater, it is recycled in front of the first pass

- **pH adjustment before the 2nd pass,** addition of NaOH to reach a pH around 10 to achieve a significant boron removal in the 2nd pass.

Post-treatment

To respect Spanish, European and Client's standards, the final stages of the plant are Reminéralization and disinfection processes:

- **CO_2 + Limestone Filters**: In pipe CO_2 injection and limestone gravity filters.
- **Chlorination**: final disinfection for the distribution network of drinking water.

VI. ENERGY RECOVERY DEVICE

The energy consumption is a key point in RO projects, and in this case it was one of the most important studies made during proposal time, and it is under continues review due to optimize the water cost.

Three Energy Recovery Devices (EDR) were studied, Pelton Turbines – ERI PX – Calder DWEER, not only about energy efficiency, even experience, maximum associated RO rack size, cost,…

About the well-known Pelton Turbines, the study shows that their strong points are, experience (hundreds of references all around the world), easy to operate and price; but it has a hard competence against new generation ERD in big plants, with expected long time of operation, with a wide range of temperature, changing conversion conditions, due to less flexibility, limitation of size, and worse energy efficiency.

The selected technology in Barcelona SWRO plant is a new generation ERD (PX or DWEER), mainly because of the energy consumption (around 0.5 kWh/m^3 less than Pelton Turbines), and the flexibility.

Between those 2 systems there are some different points that are being evaluated in the final study, about operation and maintenance, flexibility, warranty figures, term of manufacture,…

PX has higher mixing (increasing the pressure needed in RO) than DWEER, but it has lowest losses in Low Pressure and High Pressure circuits. A precise energy efficiency study is in progress at this time.

The decision will be taken in accordance with ATLL in next months and will be part, with the study final conclusions, of the presentation in the 2.007 IDA Congress.

The figure 7 shows the comparison between the three main technologies existing nowadays in the market. A reduction of more than 0.45 kWh/m^3 RO 1st Pass permeate water, due to the efficiency of the new ERD (PX – DWEER) vs. Pelton is achieved. No significant difference at this time between the 2 new generation ERD.

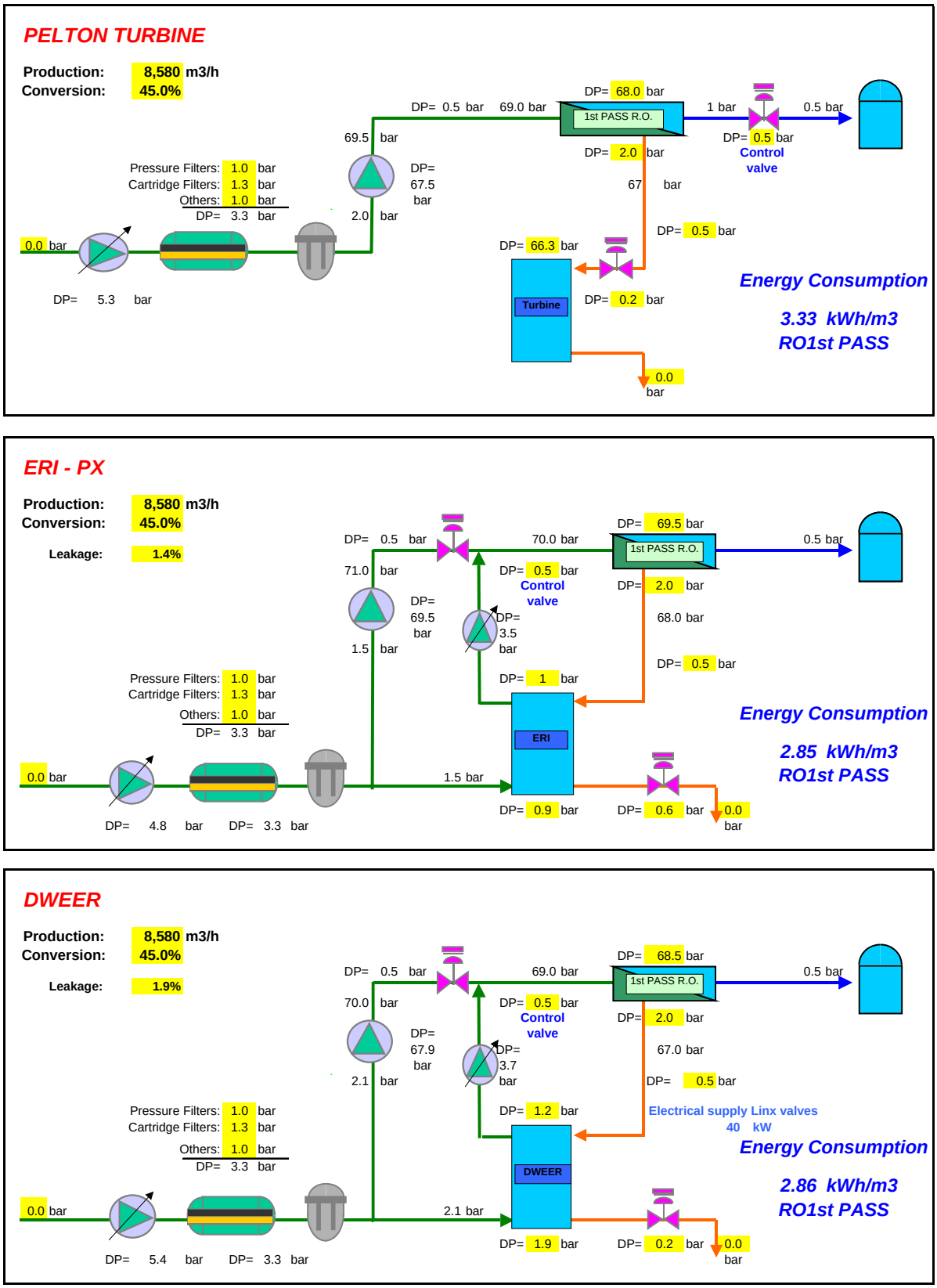

Figure 7 – Pelton Turbine vs. PX vs. DWEER

VII. CONCLUSIONS

The Barcelona SWRO plant with a production of 200,000 m3/day will be the largest seawater reverse osmosis plant in Europe to supply potable water. It will be a key plant for Barcelona Area, and a reference for The Mediterranean countries.

An extraordinary Pilot Plant will be in operation to optimize and adapt the main processes to the quality of seawater, always focused in RO process.

Open intake is finally selected, due to the raw water availability warranty. There will be the hardest and most efficient conventional pre-treatment, (as it was proved before by Degremont references with difficult seawaters), with special mention on the high rate AquaDAF^{TM} and successful Degremont's Dual Media Filters.

The plant will include a new generation ERD, which allows to get one of the lowest energy consumption ever, with one of the biggest RO racks ever designed, getting without problems the expected warranties, specially the Boron requirements, with a low reagents consumption, respecting the environmental exigencies, in a very short delay of construction, and in accordance with European and Spanish regulations.

VIII. REFERENCES

1. Sanz, M.A. – 4 Stages Pre-treatment Reverse Osmosis for South-Pacific Seawater:El Coloso Plant (Chile) – SP05-154
2. Bonnelye, V. – RO pre-treatment: High rate flotation to face bad seawater conditions – SP05-086