Boron experience at 53 MGD Valdelentisco SWRO plant

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Abstract.

This sea water desalination plant is one of the largest RO plants in the world, with a sea open intake. The production is actually used for drinking and in the next future to be use for irrigation upon completion of the distribution pipelines.

Since the commissioning of the first racks on January 2008 up to now, Valdelentisco plant has been successfully operating according the design parameters.

Boron initial requirement was designed to fit a maximum concentration of 1 ppm. After some initials discussions about the process design, a double stage with a single pass was implemented to achieve the final permeate quality.

Boron limits set by WHO are discussed as the values have been changing revision to revision since the first guidelines. This paper shows the results of the permeate boron concentration, which levels are inside the requested limits in spite of the seasonal temperature fluctuations changing from 14 to 26 C. Temperature and pH relation with Boron content are also presented as results of the operation of the plant.

Additionally to the plant performance, a comparison between the CAPEX and OPEX for a single and double pass shows the importance of a proper process design and the impact in the investment and operational costs.

I. Introduction

The Valdelentisco desalting plant is located in the west of the municipal area of Cartagena, in the South East of Spain on the Mediterranean coast.

Works began in 2005 and finished in June 2007. The desalting plant is in operation since last year 2008 at 20% of the total future capacity. The actual installed capacity is 74.000 m^3/day and the works to increase the production up to136.000 m^3/day are in progress.

Although the plant was initially conceived solely for the purposes of agricultural irrigation, the approval of a subsequent enlargement led to the incorporation of the Mancomunidad de los Canales del Taibilla as a user of the water for drinking purposes.

At tendering phase 0,5 ppm of Boron was requested as base solution and 1 ppm as an alternative proposal. Due to the CAPEX and OPEX costs the 0,5 ppm solution was rejected and the alternative proposal of Boron level lower than 1 ppm was implemented.

II. Plant characteristics

The main characteristics of the process are listed in table 1 below.

Table 1. Basic characteristics of the process	
Daily production	200,000 m3/day (72 Hm3/year)
Conversion rate	50 %
No. of RO stages	2
No. of RO passes	1
No. of process lines	16
No. of pressure vessels	142 per rack
Total no. of membranes	15,904
Type of intake	Open sea intake
High-pressure pumps	16, shared chamber
Sand filters	60, each with surface area of 40 m^2
Filter bed	Dual media sand/anthracite
Filter cartridges	20 units of 15 cartridges
Power	50 MVA
Consumption	4,34 kWh/m^3

2.1 Water intake and disposal

The water intake is performed by open sea intake 25 m below sea level, for which purpose 1250 metres of underwater piping has been placed. 775 m of this is made from high-density polyethelene, with a diameter of 1,800 mm. The rest of the distance was a 2,000 mm diameter polycrete pipe. This last stretch, from the entrance to the intake chamber to the area of the breaking waves was implemented by tunnelling.

The sea water intake is done using a circular collection tower of 5.3 m diameter and 6.15 m high, with four 1.2 m diameter collectors.

Disposal is made with a brine outfall of high-density polyethelene, with a 1,400 mm diameter, stretching from the area of the collection chamber down to bathymetric height -22 m. At the end of this pipe there is a system of diffusers, which guarantee the dilution of the brine before its exit to the sea.

2.2 Sea water pumping

From the 2,000 m^3 collection chamber, located 9 m above sea level, the sea water is pushed firstly to the reception tank and subsequently to the first filtration stage, situated 32 m above sea level, through the use of 10 submerged pumps, each with a throughput of 1800 m^3/h.

The 1,600 mm fibre-reinforced plastic piping runs along the left bank of the Rambla de Valdelentisco, with the return pipe carrying the brine from the plant running parallel to it.

From the tank situated 32 m above sea level, the raw water is pushed through 16 horizontal pumps, at a rate of 1,000 m^3/h, towards the sand filters. From this tank onwards, the piping and equipment split into two sub plants, each with a production rate of 100,000 m^3/day.

2.3.- Physical pre-treatment

In the collection chamber and before the pumping units, the system uses two bar-screens in order to avoid the entrance of solid material larger than 16 mm.
The pressure filters each have a total surface area of 40 m^2. The first filter stage has 60, 10.5 m long filters with a diameter of 3.6 m, made from carbon steel, with a vulcanized interior and a filter bed of sand and anthracite.

The fine filtration stage is formed of 20 cartridge filters with a 5 micron nominal selection, each fitted with 15 cartridges. The cartridge shells are made from internally vulcanized carbon steel.

2.4.- High-pressure pumping and membrane trains

From the two 1,200 mm pipelines of filtered water, the high-pressure pumps draw in the water to push it to the reverse osmosis stacks. The plant contains 16 1,450 kw turbopumps, equipped with Pelton turbines in order to recover some of the energy.

The high-pressure pumps each provide a flow of 1030 m^3/h at 66 bar, with a performance rate of 86%. The second stage uses 6600 m^3/h pumps with a differential pressure of 11 bar and is fitted with a 315 kW motor with frequency driver.

The racks are composed of 142 pressure vessels, set out in two stages and with a single pass, with 7 membranes per tube, therefore providing a total of 15,904 membranes for the entire plant. The first stage contains 85 pressurized tubes of 1000 psi while the second stage uses 57 tubes of 1200 psi. The recovery rate built into the design is 50%.

2.5.- Post-treatment

In the plant, the re mineralization of permeate is only carried out through the addition of Calcium hydroxide and CO2. In this way the corrosiveness of permeate is corrected and an alkalinity and hardness are obtained equal to those of Calcium bicarbonate.
The SAR level of the water intended for irrigation is also adjusted to a value less than 8 in order to maintain the soil stability.

III. Boron discussion

3.1 For drinking water

Boron issue has brought up into design consideration and tender conditions for Desalination plants in the last 10 years. Boron levels requirements change from country to country and different standards.

The impact of boron on the human health is controversial and hence, drinking water guidelines for boron vary greatly amongst government authorities throughout the world. Boron in drinking water varies from 1 to 5 mg/L depending on the water source. WHO has provided a provisional guideline for boron in drinking at 0.5 mg/L. On the other hand, the Japanese, Canadian and Australian water quality standards have fixed the limit of boron concentration in drinking water at 1 mg/L, 5 mg/L and 4 mg/L respectively. All these guideline values were set provisional because none of the toxicity research studies have provided clear evidence about the toxicity of boron. Moreover, it is difficult to achieve the low limits (<0,5 ppm) by RO without a second pass, increasing the CAPEX and OPEX of the plants.

Following table shows the standards of main industrialized countries so as the World Health Organization (WHO) [1].

Table 1

Standard	Maximum level (mgr/l)	Year
WHO 2nd Edition	0.3	1993
WHO 3rd Edition (T)	0.5	2004
Japan DW Quality	1	2007
European DW Directive 98/83	1	1998
EPA/ USA (not included)	1.4	2006
Australian DW	4	2004
Canadian	5	1990

T = provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

In Saudi Arabia the boron levels in drinking water from Desalination plants are between 2 and 3 ppm since last 25 years and there is no specific related problems for human health, at least that have been reported up to now. See Survey of Boron Levels in Seawater Desalination Plants in Saudi Arabia by Radwan A. Al-Rasheed, Saad Al-Sulami and Ghazi Hasan for more information.

According The EU Drinking water Directive: The Boron Standard and Scientific Uncertainty by Erika Weinthal and others published by Wiley Inter Science in 2005, in Cornia river basin Italy, the local population has for generations been drinking water in which the boron content has reached 4 mgr/l.

Turkey has some of the highest deposits of boron and resulting in high boron concentrations in drinking water. Sayli (1998, 2001) studied reproductive success in highly exposed populations (0.7-29 mg B/L) compared with low boron exposure areas (0.05-0.45 mg B/L) and found no significant differences.

WHO agreed that the need to review boron in the rolling revision would be considered once new data became available. The GDWQ WG meeting (Geneva, 2006) decided to reconsider boron for the Fourth Edition. The GDWQ WG meeting (Berlin, 2007) agreed on a path forward. The GDWQ WG meeting (Singapore, 2008) agreed to post the revised background document on boron to the web for public comment as soon as possible. The document (WHO/HSE/WSH/09.04/5W – Boron in Drinking Water DRAFT) posted for public comments suggests a boron level that would be rise to a guideline value of 2.4 mg/l.

"Using an uncertainty factor of 60 applied to the BMDL05 of 10.3 mg/kg of body weight, the TDI is therefore 0.17 mg/kg of body weight rounded to 0.2 mg/kg of body weight per day. Extensive data from the UK and the USA on dietary intakes of the group of primary concern indicates that intake from sources other than water is low and so the allocation to drinking water could be significantly increased without approaching the TDI. A source allocation of 40% would give rise to a guideline value of 2.4 mg/litre. "

As a result of change in any of the following parameters, the boron level in the drinking water could be modified:

- Uncertainty factor for intra species variation (6)
- Uncertainty factor for inter species variation (10)
- Total Uncertainty factor (60)
- Body weight (60 kg)
- Water allocation in daily intake (10%)
- Drinking water per day (2 litters)
- No Observable Adverse Effect Level (9,6 mgr/kg of body weight per day)

With the values between brackets is calculated the actual value of 0,5 mgr/litre boron level as per WHO guidelines.

Therefore Boron level increase is expected in the next WHO guidelines for drinking water and if this happens the Boron won't be longer an issue in the quality of permeate water from RO desalination plants, avoiding the implementation of the second pass and reducing the CAPEX and OPEX around 20 %.

3.2 For irrigation water

According Leeden et al. (1990) some crops as Lemon and Orange are very sensitive to Boron, classifying the water for irrigation as excellent if the Boron level is below 0.33 ppm and good if the concentration is between 0,33 and 0,67 ppm. Other authors as Rowe and Abdel-Magid (1995) distinguish between short and long term water uses and consider 0.75 ppm for long term irrigation and 2 ppm for short term use as boron limits above the crops are affected.

Some Desalination plants as Ashkelon requested for Boron level below 0,5 ppm as the water is used for citrus irrigation. Mazarron plant in Spain is providing water with Boron above 1 ppm for citrus irrigation, although this water is mixed with well waters reducing the boron levels below 1 ppm.

Most of desalination plants for irrigation mix the permeate with waters from other sources as wells or sewage treatment plants effluents, therefore unless all the permeate is exclusively and totally used for citrus irrigation, the Boron level in the permeate for irrigation is not a problem.

A clear example of this case is Valdelentisco plant. Initially during the tender phase the farmers asked for boron level lower than 0,5 ppm as an important percentage of irrigated crops were citrus. Once the bids were compared and they noticed than permeate water with boron lower than 0,5 ppm was 15 to 20 % more expensive than the one with level below 1 ppm, they accepted as good water the last one. In this case the investment was also penalized by 20 % for the 0,5 ppm required equipments and installations and half of the cost is supported by the farmer end users.

IV. Boron at Valdelentisco Plant

4.1 Boron at tender phase

A clear example of this case, is Valdelentisco plant. Initially during the tender phase the farmers asked for boron level lower than 0,5 ppm as an important percentage of irrigated crops were citrus. Once the bids were compared and they noticed than permeate water with boron lower than 0,5 ppm was 15 to 20 % more expensive than the one with level below 1 ppm, they accepted as good water the last one. In this case the investment was also penalized by 20 % for the 0,5 ppm required equipments and installations. Following table shows different bids for 0,5 and 1 ppm options.

Table 2

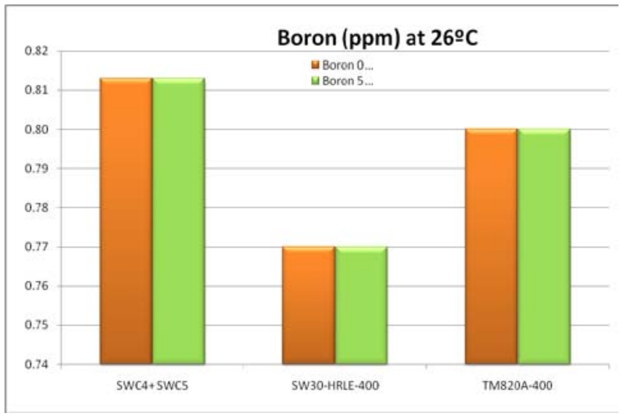
CAPEX (Euros)	Boron level		Difference	
	< 1 ppm	< 0,5 ppm	%	Euros
A	89,314,830	104,523,625	17%	15,208,795
B	87,798,694	99,754,669	14%	11,955,975
C	74,622,458	89,050,000	19%	14,427,542
D	76,355,477	88,229,000	16%	11,873,523
E	77,261,180	87,345,550	13%	10,084,370
AVERAGE	81,070,528	93,780,569	16%	12,710,041

An average increase of 16 % was reached for the tendered 120.000 m^3/day capacity. Considering the extension into 200.000 m3/day production, the extra cost due to the implementation of the second pass to get a permeate with boron level lower than 0,5 ppm was closed to 20 M Euros.

4.2 Boron at design phase

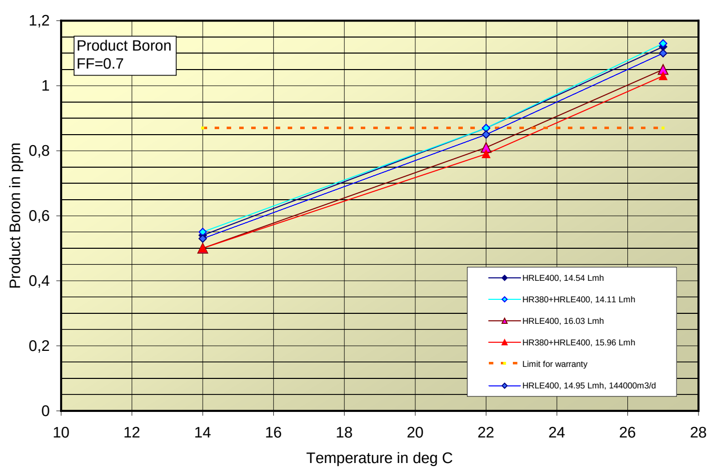
A deep analysis of membrane manufacturers was carried out during the design phase, including not only Boron rejection but also working pressure and permeate quality. Three membrane manufacturers were compared regarding the boron guaranteed in relation with temperature and pH.

Figure 1



Once the membrane manufacturer was selected the final design was adjusted based on the final warranty. In the graph number 4, it is shown the maximum Boron guaranteed by Dow depending of temperature for a pH of 7,95. Basically the warranty sets boron level below 1 ppm up to 22 °C what happens 80 % of the time. According the projections [3] Boron level could reach up to 25 °C what happens 90 % of the time, but the manufacturer adds a warranty factor of 1,15 to guarantee the values of the software projections.

Figure 2



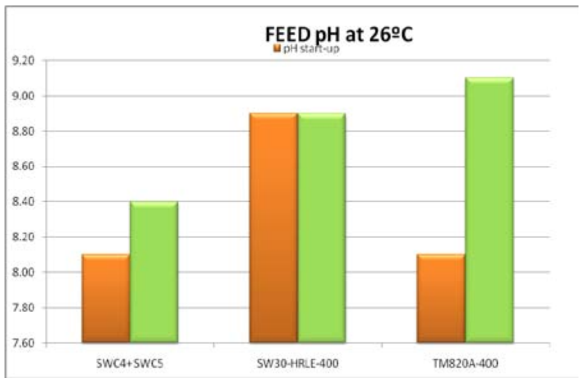
The decision to select a single pass with Boron level below 1 ppm at pH 8, could carry out a non compliance with water quality requirement for 20 % of the time. Nevertheless some factors were considered to support such risky decision.

- Boron limit of 1 ppm. There was no clear statement regarding the health effect on humans so as the limit had been changing in the latest WHO revisions and a further new limit could be set.

- pH adjustment through caustic addition between stages could increase the boron rejection if needed for high temperatures
- membrane projections showed a higher Boron rejection than guaranteed by membrane manufacturer and a safety factor was used for calculations
- Temperature distribution at site was percentil 90 % below 25°C and percentil 96 % below 26 °C, what means boron level are above 1 ppm 10 % of the time (1 month).

Membrane manufacturers predict differently caustic addition from 19 to 41 ppm required in order to reach the desired pH set point to guarantee the boron rejection inside the required levels.

Figure 3



4.3 Boron at operation phase

Figure 4

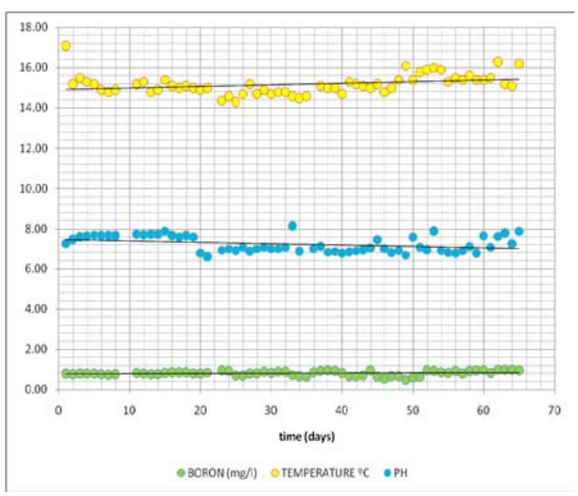
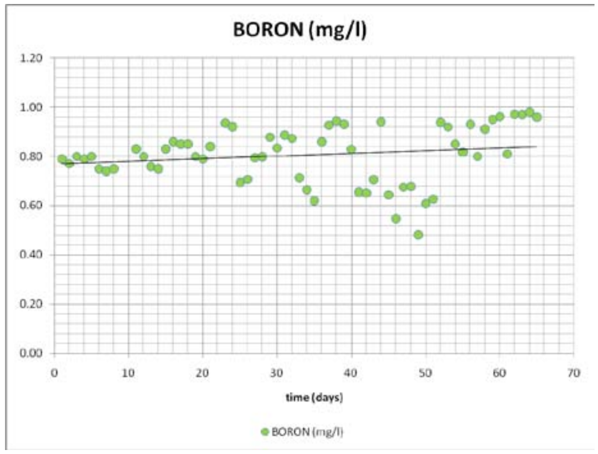
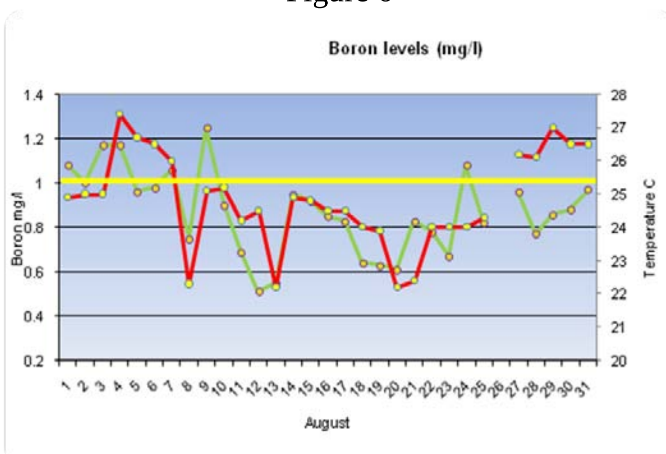


Figure 5



The results on site showed that at pH values higher than 8.1, 40% higher than design predicted value of caustic was required to keep the Boron rejection level as expected.

Figure 6



Finally, Fig. 6 shows the boron rejection and temperature fluctuations for natural pH of seawater 8,1. As seen in the graph, the boron rejection predicted by the manufacturer was lower than actual. At the same time, the projected increase in boron rejection as a result of higher feed pH operation is higher than it is obtained in reality.

V Boron economics

As mentioned before an average increase of 16 % was reached for the extra cost due to the implementation of the second pass to get a permeate with boron level lower than 0,5 ppm. So the extra cost for Valdelentisco plant was closed to 20 M Euros for 0,5 ppm boron levels.

Regarding OPEX, the difference between 1 and 0,5 ppm boron levels was 7 cts Euro/m^3, what means more than 125 M Euros for the plant life of 25 years. Therefore the difference in boron levels for the plant is 145 M Euros without considering any financing updating over the 25 years life time.

This figure equals to a plant of 150.000 m3/day capacity and considering that during the last 7 years, more than 8.2 M m3/day new sea water capacity has been installed worldwide, the extra cost of installing a second pass for boron rejection below 0.5 ppm is estimated in more than 1,07 bUSD which is equivalent to 1,069,743 m3/day of production with Boron lower than 1 ppm.

Table 3

Standard	m^3/day	M USD
Annual new contracted capacity ('00-'08)	34.810.068	
Annual new on line capacity ('00-'08)	27.337.885	
Membrane plants (50%)	13.668.943	
Seawater plants (60%)	8.201.365	
CAPEX (1000 USD/m^3 installed)		8.201
CAPEX (0,5 ppm boron)		1.069
Equivalent capacity	1.069.743	

V Conclusions

1. Boron limit in different standards should not be longer a problem as there is no clear results of tests and the local use of waters with high contents in Boron has shown no impacts to human health

2. Boron at operation phase at Valdelentisco plant was higher than expected according manufacturer software projections, especially for low temperatures.

3. Boron rejection at higher pH than projected and therefore the NaOH consumption is higher than expecting increasing the operation costs.

4. More than 1.07 billion USD invested in the last 8 years in new SWRO plants all over the world to reach boron levels in product water below 0,5 mgr/l.

VI References

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5. Boron rejection in SWRO at high pH conditions versus cascade design. M Faigon and D. Hefer published by Elsevier, Desalination, 2006.

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VI Acknowledgements

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