7 Years Operation of BWRO Plant with Raw Water from Coastal Aquifer for Agriculture Irrigation

Authors: *Carlos García, Francisco Molina and Domingo Zarzo*

Valoriza Agua, C/Molina de Segura, nº8, 30004, MURCIA, SPAIN. Tel: +34 968354028, Fax: +34 968213716. E-mail: csoto@gruposyv.com

TOPIC: Brackish Water Desalination

Abstract

In this paper it will be shown the most relevant aspects in the 7 years operation period in the management of the O&M (Operation & Maintenance) at BWRO (Brackish Water Reverse Osmosis) plant at Cuevas de Almanzora, Almeria, Spain. This plant has a current capacity of 25,000 m^3/day and it was built to supplying agricultural consumers in the proximities of the plant.

Cuevas de Almanzora BWRO plant is an exceptional plant in many aspects;
- is a plant working with brackish water, but it was designed to be able to working with seawater from the point of view of materials, qualities and pressures (except the high pressure pump), and even it could be converted easily into a seawater plant.
- extensive hydrogeological studies have been done, allowing the control of aquifer exploitation and water extraction in the seawater-brackish water interface
- Water is distributed to different agricultural users with different water quality requirements (it produces "*a la carte*" water)
- RO trains include interstage energy recovery device to improving the hydraulic equilibrium between stages and to reducing the energy consumption

In the current paper the following aspects will be presented:

- BWRO plant description
- Results of the aquifer hydrogeological studies for the determination of saline intrusion. Conclusions and operation guidelines.
- Operation of the plant. Results. Operational problems arising from increasing salinity and specifically from sulphates
- Description of the planned changes at the plant to allowing its future possible conversion into a SWRO plant
- O&M Costs

I. INTRODUCTION

1.1. Desalination for agriculture in the area

Spain suffers an important lack of water resources that is aggravated with time and includes cyclical drought periods. In the environment of this worrying situation, in general water uses are prioritized for human supply, leaving in second place other uses as agriculture irrigation or recreational uses as golf courses, irrigation of parks and gardens and urban services.

For this reason, the use of potable water is restricted for other uses being necessary to looking for other non conventional resources (reuse, brackish and seawater desalination). For example, in Spain the use of potable water for irrigation of golf courses irrigation is totally forbidden.

Then, in the case of Spain, farmers and other users of this water have assumed in their production costs the price of this new water coming from desalination or reuse installations.

From the scarcity period around 1995, many farmers and agriculture businessmen decided to install desalination plants in the South East of Spain (mainly Mediterranean coastal areas) to solve the problem of available resources. In Spain, these technologies were very used previously in Canary Island but it was this moment the beginning in the mainland. We estimate that between 1995 and 2000 were installed more than 200 desalination plants for this application in this area, with typical sizes rating between 100 and 5,000 m^3/day, with some plants treating more than 10,000 m^3/day.

Two examples of it are the Mazarron and Cuevas de Almanzora plants, with sizes of 13,500 and 25,000 m^3/day, respectively. Mazarron plant was built following a project from the owner and, although it incorporated some technical innovations as energy recovery devices (turbocharger) it was not successful due that the increase of salinity in less than a year from 9,000 ppm of TDS to more than 20,000 ppm of TDS, being finally re-turn into a seawater desalination plant with larger capacity. The case of Cuevas de Almanzora plant will be described in this paper.

The implementation of AGUA program from the Spanish Environment Ministry could change this situation because the large plants installed all over the Mediterranean coast could supply water for human consumption and for agriculture and services (although there is a discussion with the farmers about the final price of water) leaving abandoned or stopped the small facilities built in recent years some of which were even illegal.

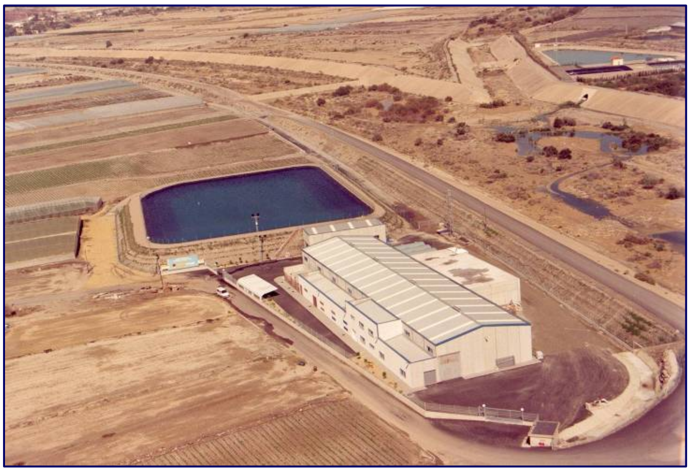

Figure 1. Cuevas de Almanzora BWRO

1.2. Description of the customer and their needs

The Comunidad de Regantes de Cuevas de Almanzora is an association of agricultural producers which supplies water for different clients and end users in the area of Cuevas de Almanzora, Palomares, Villaricos and Vera, in the Almeria province, Spain.

Until recent years, water resources of this community came from the dam of Cuevas, which recorded minimum levels in the last years, and the contributions of water transfers from other regions (too restricted). These allocations were insufficient as enabling many farmers to reduce land for their crops. Other additional problem was the increasing salinity of aquifers doing groundwater useless for agriculture purposes.

In 2002 the works of a new desalination plant began to solve the water problems of this community. The BWRO plant was designed for a total flow of 30,000 m^3/day, with the building, intake and other installations ready to treat 60,000 m^3/day. Given the increasing salinity forecasts and even the possibility of exclusive use of seawater, the plant was built with components prepared to treat seawater, including 1,200 psi pressure vessels, high pressure piping 904 L stainless steel, etc. This makes it possible to convert existing facilities to treat seawater at a reduced cost. The installation of RO trains (5,000 m^3/day each) was train by train observing the salinity increasing in the raw water. The construction was stopped with 4 trains which it was enough for the community needs and maintaining stable the aquifer. In recent years another 5,000 m^3/day were added with the incorporation of another small plant disused from a farm.

II. DESCRIPTION OF THE PROJECT

2.1. Basic Data

Location: Road between Villaricos and Palomares (Almería, Spain)
Owner: Irrigation Community Cuevas de Almanzora.
Design, construction and operation: Consortium between SADYT and Talleres y Gruas Gonzalez (local civil works contractor)
Project Type: Private installation partially subsidized by local government (Junta de Andalucia) including European Community funds and with an O&M contract for 15 years.

Technology: Reverse Osmosis Desalination Plant.
Purpose of Installation: To obtain quality water for agricultural irrigation.

Flow: 30,000 m^3/day in different stages (currently in operation 25,000 m^3/day)
Recovery: 65-70%
Water Quality: Brackish water underground from coastal aquifer. Conductivity between 9,000-20,000 µS/cm (with increasing salinity)
Treated water: Contract: < 500 µS/cm

The plant was executed in a record time;
Beginning of the works: September 2002
Term of execution: 8 months (6 months to start-up the first RO train)

2.2. Plant Description

Treatment Process

1) Water Intake

By wells (6 currently), with an average depth of 20-30 m. Depth of 50 m while maintaining the water level between 8 and 11 m.

2) Raw water tank 1,500 m^3
3) Physical pretreatment (sand filtration and cartridge filter):
    - 4 low pressure pumps 350 m^3/h
    - 1 backwash filter pump 450 m^3/h
    - 4 units sand filters 3,000 mm diameter and 11,000 mm length
    - 1 blower for filter backwash
    - 4 units of GRP cartrigde filters, with 150 cartridges of 40" length and 5 microns selectivity
4) Chemical pretreatment: Hydrochloric acid, Sodium hypochlorite, Sodium Bisulphite and antiscalant. Really only antiscalant is added currently.
5) REVERSE OSMOSIS TRAINS

- 4 high pressure pumps 350 m^3/h, 27.5 bar, with frequency variation, with 400 kW electric motor.

Nº de trains: 4
Unitary flow: 5,000 m^3/day
Total flow: 20,000 m^3/day

Figure 2. Cuevas de Almanzora BWRO plant

Additionally in the last years a small 5,000 m^3/day plant was transported and installed into the RO building increasing the total flow to 25,000 m^3/day. This small plant (in 2 trains) was installed with all the required pre-treatment (sand filters, cartridge filters, chemical dosing…)

Design Recovery: 65-70 %

Array: (34:17) x 6
Membrane: TORAY SU-720 F (1ª stage)/SU-820 FA (2ª stage)
Energy recovery system
There are installed energy recovery devices (Turbocharger) to recover some of the residual energy from brine, increasing the pressure between the first and second RO stages.

6) CIP system

With cleaning and flushing pumps 270 m3/h, cartrigde filter and 2 tanks with de 20 and 50 m^3, respectively, equipped with agitation and heat resistance.

7) Electrical installation

Plant has 3 transformers with 750 KVA each one, CCM, and SCADA system for control.

8) Product water pond

Works included an open pond with 23,000 m^3 capacity to store product water

9) Product water pumps

Plant includes 2 pumping stations:

1) pumping station to Cuevas de Almanzora, with 4 pumps with 290 m^3/h at 18.5 bar, which it sends product water to the water pipes net for distribution of community varying the flow and pressure depending on the needs of end users.

2) a second group of pumps to send water to Palomares village, with 3 additional pumps

10) Brine discharge

The facilities include a submerged pipe for discharge of brine that comes to join to other brine pipe from Pulpi (another desalination plant) and ends at 350 m of shoreline and 6.5 m deep at the mouth of the Almanzora River.

The outfall pipe is 650 mm in diameter with horizontal injection diffuser nozzles at the point of discharge. The point of discharge, derived from the environmental impact study, it was decided due to the characteristics of the river Almanzora with flooding periods and without sensitive species, without forgetting that this is a discharge of water with lower salinity than seawater made at the mouth of a river, which is an area degraded by sediment transport.

For optimization of operation management, plant is fed from different wells with different flows and salinities, depending on behaviour of each well (those are medium values);

- Well 1 : between 17.00 mS/cm and 18.00 mS/cm (practically not used)
- Well 2 : between 9.00 mS/cm and 15.00 mS/cm
- Well 3 : between 9.00 mS/cm and 15.80 mS/cm
- Well 4 : between 7.00 mS/cm and 8.60 mS/cm
- Well 5 : between 7.00 mS/cm and 8.80 mS/cm
- Well 6 : between 8.00 mS/cm and 10.00 mS/cm

2.2. Innovations

2.2.1. Plant ready to treat different water qualities

The plant was designed knowing the problem of increasing salinity in raw water, and then the concept of it was in 2 stages:
1st stage: recovery of water from the river mouth (although the intake is from wells) avoiding the seawater. Designed to treat water with conductivity between 7,600 – 30,000 μS/cm
2nd stage: Progressive incorporation of seawater treatment

In the lasts years the equilibrium of the system has been maintained with growing salinity although stable, and then is not still necessary the transformation into a seawater RO plant

Solutions to operate with growing salinity

- RO Plant designed to work with salinity 25,000-30,000 μS/cm
- High pressure pumps designed in a very conservative way and with frequency variation
- For correct hydraulic balance between stages it was included an energy recovery turbine (Turbocharger) and membranes are different on each stage:
    - Membrane 1st stage: SU 720 F (brackish water)
    - Membrane 2st stage: SU 820 FA (seawater)

But it every fails, we will go to the B-plan. The plant is easy to transform into a seawater plant due that the following facts;

- 1,200 psi pressure vessels
- 904 SS pipes, Sch 80 in high pressure
- GRP and materials resistant to seawater corrosion in pre-treatment
- Carbon steel filters with rubber lining
- High pressure pump has a longer shaft that would attach a Pelton turbine. Another option would be changing the pumps, and incorporating other energy recovery devices
- Other materials (valves, pipes, fitting, instruments, etc.) were designed too for seawater treatment

2.2.2. Production of “a la carte” water

Quality of water supplied is different depending on the requirements of each end-user. The quality requirements are different depending of the crops irrigated (tomatoes, lettuce, potatoes, melon, etc.), or type of user (agriculture irrigation, golf course, sometimes even drinking water for surrounding municipalities).

Quality of water supplied in controlled by means of an automatic blending of permeate and raw water with the control of conductivity of each flow. The price is different too and is calculated as function of registered quality or demand.

2.2.3. R&D Center

In recent times the plant has become into a research centre for Sadyt, having installed some pilot plants to research about brine dilution, ZLD of brine by means of evaporation-crystallization, etc., operating on the plant.

2.2.4. Trasar 3-D

Due that past problems with increasing concentration of salinity in raw water (and especially of sulphates) and the need to control the adequate dosage of antiscalant, it was agreed with Nalco the installation of a Trasar 3-D system, to control accurately this dosage.

Figure 3. Nalco Trasar 3-D device

2.3. Hydrogeological studies

In order to predict the behaviour of the aquifer with time and with the extraction of well water for the plant, a series of hydrogeologic studies were conducted

Studies:

- Infiltration and flows calculation (rainfall studies)
- Geologic and hydraulic environment
- Piezometric levels of groundwater, water quality and evolution with time
- List of water intakes
- Evaluation of resources
- Crops maps and water uses
- Pumping tests

These studies were completed with a campaign of geophysical exploration by means of Electrical tomography (technology based in the analysis of electrical resistance of ground materials). 16 profiles of electrical tomography grouped in 5 lines with direction NW-SE, perpendicular to the coast line. Each profile with 355 m lenght

Figure 4. Electrical tomography profiles

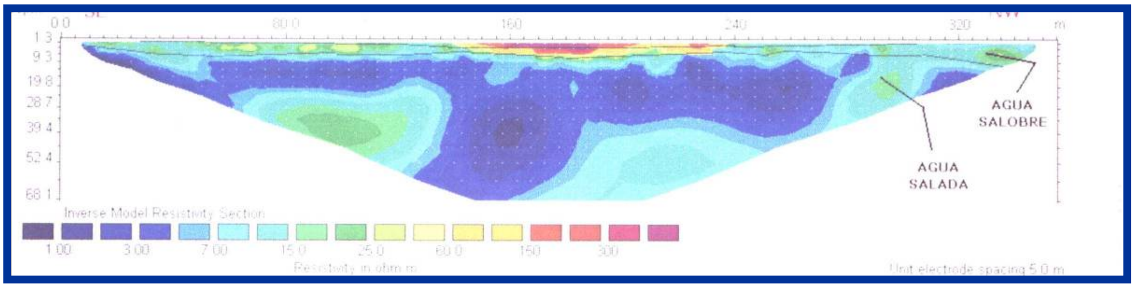

Figure 5. Example of profile. (red=water with low salinity, green=brackish water, blue=seawater)

There were observed 3 different stripes in direction NE-SW parallel to the coast;
High conductivity (close to the sea). Conductive Materials. Very salty water
High conductivity. Materials predominantly conductive. salty water
Moderated salinity. Thick materials with brackish water in the pores. brackish water .

This study allowed determine;
- most adequate area for well water intake and possible evolution of aquifer
- most adequate area for future seawater intake
-possibility to inject brine in the salty water area (this solution was discarded finally with the construction of the brine pipe).

2.3. Costs

2.2.1. Investment cost

The investment of the works was as follows;
Investment for the 1st stage of the plant: 12,182,727 €
Subsidy of Junta de Andalucía (local Government): 6,091,363 €

2.2.2. O&M costs

Water costs are different depending on raw water quality and product water quality required for each user. In next table a typical distribution of costs is shown. Normally the costs are below 0.3 €/m3.

Concept	**€/year**	**€/m³**
Variable costs		
Chemicals		0.048
Membrane replacement		0.020
Cartrigde filters and others		0,.004
Energy		0.127
Maintenance		0.01
Total variable cost		0.211
Fixed costs		
Personnel	148,750	0.030
Fixed maintenance	16,227	0.003
Other fixed costs	19,833	0.004
Total Fixed costs	184,811	0.048
TOTAL COST		**0.248**

Table 1. O&M costs for 17,000 μS/cm conductivity in raw water

Personnel costs are very reduced in this case (as usual in desalination plants for agriculture irrigation) because the plant is managed only with 4 persons and partially from distance by means of the sending of alarms to the cell phones of O&M personnel, avoiding in this way the presence of personnel by night or in weekends.

III. RESULTS

3.1. General Data

In the next graphs are shown some characteristics of raw water (conductivity, chlorides and sulphates) in the last 4 years.

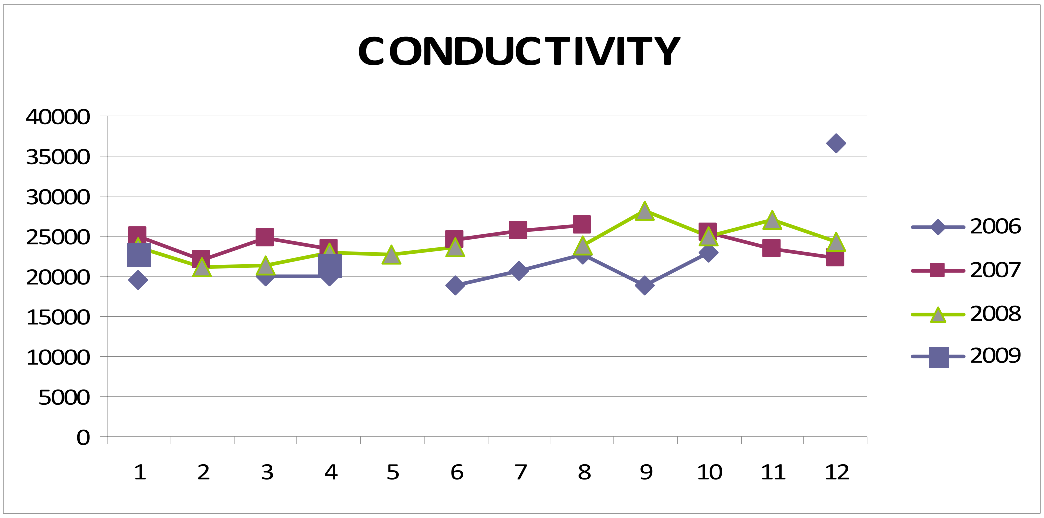

Figure 6.Conductivity of raw water

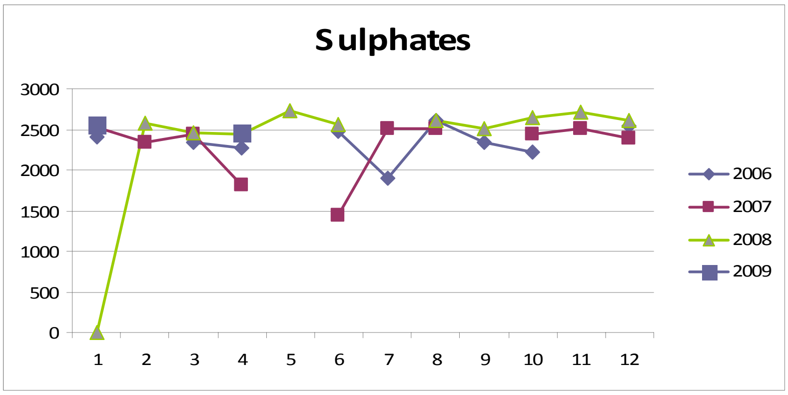

Figure 7. Sulphates in raw water

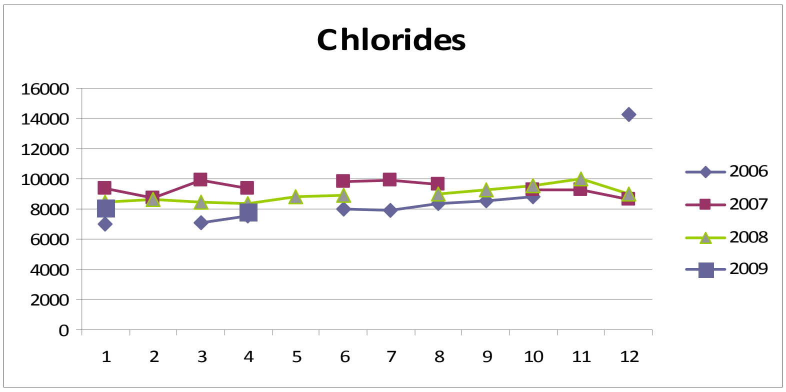

Figure 8. Chlorides in raw water

As it can be seen, the conductivity and chlorides in the last 4 years seem quite stable, but sulphates are showing a different tendency. This is important due that the peak of sulphates obtained in the first years of operation that forced the temporarily reduction of recovery and the change of antiscalant.

3.2. Problems at startup and first years

The plant started up in late May 2003 with salinity values in raw water of 9,200-9,400 µS/cm and a sulphate concentration of 2,800 ppm. Recovery was fixed at 63% using the antiscalant PermaTreat 191.

But soon it was found a progressive increase in conductivity in the raw water, reaching values of 10,000-10,200 µS/cm, in only one month, with a period of maximum conductivity of 12,000 in July 2003, although it was stabilizing this trend. At this time, the concentration of sulphate was at values between 3,000-3,300 ppm, which forced to reduce recovery between 55-56%. Given the low economic viability of this recovery, it was decided to change the dosage of antiscalant PermaTreat 191 by a more specific product such as PermaTreat 504, which allowed the system to raise the conversion to values of 70%.

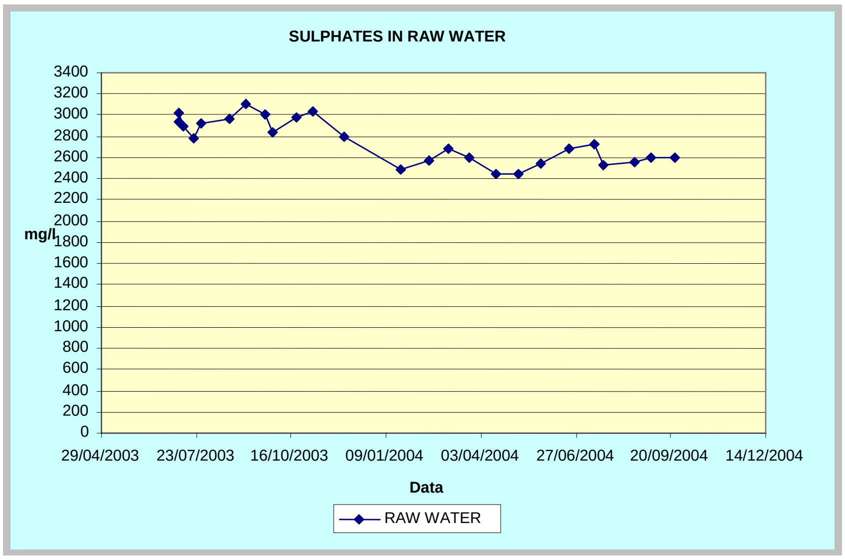

Figure 9. Sulphates in raw water 2003-2004

It also shows the evolution of sulfate with time, which reflects the rapid increase between the months of May and August of 2003, which later was moderating over time to remain stable in the last few months setting to 2,600 ppm.

Curiously, the level of sulphates it was sometimes over the level of sulphates in seawater, and the Chloride concentration was relatively stable. The interpretation of this problem was that perhaps it was due to aquifer material solution.

It must be said that the graphics shown are for the purpose of showing the trend of parameters, but it can not be interpreted rigorously, because it represents blended water values from individual wells (which it have different characteristics and location), and the operation has not always worked with all the wells and sometimes even in alternation.

3.3. O&M data

About the main process parameters it must be pointed that;

- Temperature is very stable all over the year with values around 20ºC
- no membranes have been replaced from the startup (7 years)
- cartridge filters has been usually changed 1 time per year
- only antiscalant is added as chemical treatment (Permatreat 191 and Permatreat 504 in the peak periods with high sulphate concentration)
- 1 chemical membrane cleaning is done per year

	pH raw water	**pH $_{prod.}$**	**Temp (ºC)**
Minimum value	**5.6**	**5.4**	**19**
Maximum value	**7.6**	**5.9**	**23**
Average value	**7.1**	**5.6**	**21**

Table 2. Some water parameters in 2009 (values obtained from 2 data per day)

	Cond. Raw water (µS/cm)	**Cond $_{product}$ (µS/cm)**	**Cond. Reject 1st stage (µS/cm)**	**Cond $_{1st\ stage}$ (µS/cm)**	**Cond $_{2nd\ stage}$ (µS/cm)**	**Cond brine (µS/cm)**
Minimum value	**14,400**	**335**	**20,200**	**143**	**249**	**23,265**
Maximum value	**20,800**	**551**	**34,900**	**578**	**651**	**60,020**
Average value	**17,369**	**431**	**30,933**	**399**	**441**	**44,135**

Table 3. Some water parameters in 2009 (values obtained from 2 data per day)

Pressures					
P 1st stage (bar)	**P oulet 1st stage (bar)**	**P inlet 2nd stage**	**P outlet 2nd stage**	**P outlet 2nd stage**	**P$_{backpressure}$**
19.7	**19.1**	**31.3**	**30.7**	**0.6**	**2.0**

Table 4.Typical operating values in year 2009

3.4. Energy consumption and energy tariffs

Energy recovery due to the Turbochargers is over 30%, with a specific electrical consumption in high pressure pumping of 0.9 kWh/m^3, and 1.9 kWh/m^3 in the whole plant including permeate pumping.

In the next table it is shown a typical table of results for the energy recovery for a raw water conductivity of 15,000 µS/cm;

	Pressure (bar)	Raw water Conductivity (mS/cm)	Product water conductivity (µS/cm)	Recovered pressure (bar)
TRAIN 1	19.0	15.00	150	9.5
TRAIN 2	18.5	15.00	145	8.5
TRAIN 3	19.0	15.00	155	8.5
TRAIN 4	18.2	15.00	180	8.0

Table 5. Energy recovery

Another very important issue in this plant is the use of special energy tariffs playing too with discontinuous operation. Plant stops automatically in peak and high-peak hours reducing in this way the energy costs. Unfortunately, sometimes the peak water demand is in months with more energy peak hours and then is more difficult to manage this situation.

Since the beginning of free market in the electricity sector in Spain the cost of energy have changed both in terms of power and energy increasing a 59% in terms of power and 35% in consumption terms. The type of rate that corresponds to our facility (rate 6.1), the costs set out in the regulated part of the electricity tariff for access to the free market are listed in table 6. Over these energy fixed as part of regulated tariff we must to increase the marketing and distribution costs with a formula such that:

Final Cost = Fixed cost + (Market Cost) x Passage Coefficient

Fixed cost = cost of the regulated rate indicated in table 6
Market cost = in the energy cost published daily with a day in advance
Passage Coefficient = is a variable rate set by the trader and It includes the benefit and cost of toll distribution

With this formula, there are two contract possibilities
- First option it is through a flat rate for each period and is renewed annually, in which the trading company after their market forecasts set a price that is unchangeable during the contract period
- A second is the type of Pool. This is our case and it consists in that the price varies by the monthly average for each period to which using the above formula. Thus we are not subject to a fixed price with the advantages and disadvantages that it implies.

• Advantages: due that the situation that currently is suffering the market, due that lower consumer demand for the fall of national productivity it makes energy more affordable now and below average prices that companies offer.
• Disadvantages: it could be possible that changes in market prices rising sharply and there is no possibility of changing the form of contract until after the lifetime of this.

Power Term €/kW year	P1	P2	P3	P4	P5	P6	INCREASES
2008	10,092230	5,050488	3,696118	3,696118	3,696618	1,686408	
2009-January	10,092230	5,050488	3,696118	3,696118	3,696618	1,686408	0,00%
2009-July	13,119911	6,565634	4,804953	4,804953	4,804953	2,192330	30,00%
2010 January	16,268690	8,141386	5,958142	5,958142	5,958142	2,718489	24,00%
(proposed) 2010 July	17,082124	8,548455	6,256049	6,256049	6,256049	2,854414	5,00%

Consumption Term €/kWh	P1	P2	P3	P4	P5	P6	INCREASES
2008	1,930500	1,693400	1,287000	0,730700	0,471900	0,429000	
2009-January	3,571400	2,963500	1,698800	0,964500	0,622900	0,429000	0,00%
2009-July	4,642800	3,852600	2,208400	1,253900	0,809800	0,557700	30,00%
2010 January	6,964200	5,201000	2,771500	1,379300	0,890800	0,557700	0,00%
(proposed) 2010 July	7,312410	5,461050	2,910075	1,448265	0,935340	0,585585	5,00%

Table 6.Tariff 6.1.

Since it came into force the free market in Spain we had the two forms of contract. At first our method was tied to a fixed rate contract with an average cost of 0.07-0.08 € per Kw- hr. After analyzing the market trends it was decided to change the type of contract to the second option provided with a commitment to venture with our client that obliges us to share the benefit. Since then the cost per kWhr is below 0.06 €.

IV. CONCLUSIONS

The main conclusions obtained during this experience are indicated next.

- Desalination plants treating underground brackish water require rigorous studies of the aquifer to test their possible temporal evolution and the impact on water extraction and exploitation

- Aquifer studies can also determine the most appropriate for deposits, the optimal operating system and the location of the discharge

- The design of a facility of this type, and more so, in coastal aquifers, must be flexible and able to respond to different situations of water quality an expected worsening

- The desalination plant in Almeria Cuevas de Almanzora is a unique facility in many ways
    - is a plant that is currently working with brackish water, but is ready to work with sea water, in terms of materials, qualities and pressures (except pumps)
    - there were made rigorous hydrogeological studies, which control the exploitation of the aquifer and the extraction of water to be desalinated brackish water interface of sea-water - water distributed to different users with different requirements (produced water "on demand")