

# Desalination in Morocco and presentation of design and operation of the Laayoune seawater reverse osmosis plant

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## Abstract

Desalination is the commonly used process of exploitation of non-conventional resources in Morocco. The experience of ONEP (Office National de l'Eau Potable) in this field is more diversified because of the variability of the processes used. This experience is the subject of the first part of the paper. The second part presents the largest desalination plant currently in operation in Morocco which is Laayoune Seawater Reverse Osmosis Plant. It is operated by ONEP and has a capacity of 7000 m<sup>3</sup>/d. Pretreatment consists of chlorination, acidification (H<sub>2</sub>SO<sub>4</sub>) required for adequate coagulation, coagulation using ferric chloride, pressure filtration through a sand filter, acidification (H<sub>2</sub>SO<sub>4</sub>) to reduce the precipitation of calcium carbonate at the membrane level, injection of an antiscalant (Flocon 100) to reduce the precipitation of sulphates at the membrane level, microfiltration using 5µm cartridge filters, and dechlorination using sodium metabisulphite. The plant uses a brine staging design concept and has four trains, each with a capacity of 1750 m<sup>3</sup>/d. The RO section of the plant uses Dupont polyamide hollow fine fibre membrane. The main design features of the plant and the experience gained in the first year of operation are outlined. The third part presents the design features of the plant at the present time. It also presents the problems which occurred during five years of operation (up to now). Some solutions for the problems are presented.

*Keywords:* Reverse osmosis; ONEP (Office National de l'Eau Potable); Pretreatment unit; Post-treatment unit; Aggressivity

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## 1. Introduction

Desalination is the commonly used process of exploitation of non-conventional resources in Morocco. The ONEP (National Office of Drinking Water) and the OCP (Office Chérifien des Phosphates) are the main developing agen-

cies. The OCP chose distillation to produce water for industrial use, this has been performed by Phos-Boucraa firm in Laayoune due to the TDS sought which is 25 ppm. The experience of the ONEP in this field is more diversified because of the variability of the process used.

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## 2. ONEP experience

### 2.1. Processes developed by the ONEP

Since 1973, the National Master Plan of drinking water supply has given rise to the necessity of resorting to desalination of brackish water and seawater as a source of drinking water supply.

Tests of demineralization have been performed in the central laboratory this year. Results of these tests showed that a pilot experiment in the city of Tarfaya would be of great use.

In 1975, the first demineralization unit was established in Tarfaya. This unit was designed for the electro dialysis demineralization of brackish water containing 5 g/l of dissolved salt. A production capacity of 75 m<sup>3</sup>/d was expected to fulfill the drinking water needs.

In 1983, the ONEP received a new demineralization installation based on the reverse osmosis process to strengthen the electro dialysis unit of demineralization of Tarfaya.

The same year, the ONEP undertook the

implementation of a project elaborated to improve drinking water quality, thanks to the assistance of the Program of United Nations for Development (PNUD) and the collaboration of KIWA Institute in Netherlands in the field of demineralization of brackish water.

Within the context of this project, the reverse osmosis unit of Tarfaya has been considered as a pilot unit (Table 1); its objective is to allow the ONEP technical staff to be familiar with this process and also to compare it to other processes based on electro dialysis and steam compression installed in Boujdour since 1977, producing 250 m<sup>3</sup>/d of drinking water.

### 2.2. Actions undertaken by ONEP

In the concern for facing the problem of water needs in the provinces of the South and overcoming water shortage amplified by demographic and industrial development of the region, the ONEP reinforced the production of freshwater (Table 2) through the implementation of three plants in Tarfaya, Boujdour and Laayoune based on reverse osmosis.

Table 1  
Comparison between different processes to improve drinking water quality

City	Process	Type of water	Capacity production, m <sup>3</sup> /d	Date	Observations
Boujdour	Steam mechanical compression	Seawater	250	1977	Renovated in 1990
Tarfaya	Electrodialysis	Brackish water	75	1976	Improved in 1988
			120	1983	
Smara	Reverse osmosis	Brackish water	330	1986	

Table 2  
The implementation of the production of freshwater based on reverse osmosis

City	Process	Type of water	Capacity, m <sup>3</sup> /d	Observations
Laayoune	Reverse osmosis	Seawater	7000	Launched 10/95
Boujdour	Reverse osmosis	Seawater	800	Launched 10/95
Tarfaya	Reverse osmosis	Brackish water	864	Works start in 2000

### 3. Laayoune desalination plant

Laayoune seawater reverse osmosis plant insures the production of 7,000 m<sup>3</sup>/d of drinking water.

Added to the brackish underground water (5,616 m<sup>3</sup>/d with a TDS of 1,600 mg/l), the total capacity is brought up to 12,600 m<sup>3</sup>/d of drinking water supply, devoted for human consumption of the inhabitants of Laayoune city and its neighbour agglomerations.

In April 1993 a contract was awarded to the group constituting Polymetrics (USA), Hydrex (France), Sogea (France) for the design, supply, construction, and commissioning of the plant on a turnkey basis.

The contractors' tender book, in addition to the control and supervision of the project works, was insured by ONEP. The plant operation (even during the testing period) was insured by ONEP technicians with the technical assistance of the contractor.

#### 3.1. Plant design concept

- The water intake is insured through beachwells.
- The daily nominal production of the installation will be of 7,000 m<sup>3</sup>/d, divided into four trains, each one of 1,750 m<sup>3</sup>/d. An extension will be possible by adding two other similar trains.
- The produced water will have a total salinity (TDS) of 1,000 mg/l. A TDS peak of 1,100 mg/l will be tolerated.
- The RO plant will work continuously.
- The design of the RO modules is based on the following:
  - (a) Daily nominal capacity: 7,000 m<sup>3</sup>/d.
  - (b) Number of trains: 4.
  - (c) Maximum ratio conversion: 45%.
  - (d) Energy recovery of the brine: Yes.
- The maintenance of the components will be

easy and the module replacement will be possible during ongoing production.

- The choice of the material will be made in a way that it can resist against the aggressivity of the fluids and the medium with which it will be in contact.
- The process will be controlled and supervised by a synoptic panel of control, installed in the command room.

The design condition for raw seawater is shown in Table 3. A block flow diagram for the R.O. facility is shown in Fig. 1.

#### 3.2. Plant layout

As shown by the plant schematic in Fig. 2 and the block flow diagram Fig. 1, the different buildings are arranged efficiently to accommodate space limitations.

The raw seawater coming from the beachwells flows into the seawater reservoir (2 × 750 m<sup>3</sup>). It is sent to the pretreatment unit, the high pressure pumps and then to the RO modules. The permeate (product water) is stored in the product water tanks which are located outside of the building.

The total plant space is:

- (a) From west to east — 180 m.
- (b) From north to south — 164 m.

#### 3.3. Plant description

The plant consists of the following systems:

- (1) Seawater supply system
- (2) Pretreatment unit
- (3) High pressure pumps and RO trains
- (4) Post treatment Unit
- (5) Product delivery
- (6) Electrical power supply
- (7) Central control room
- (8) Auxiliary systems

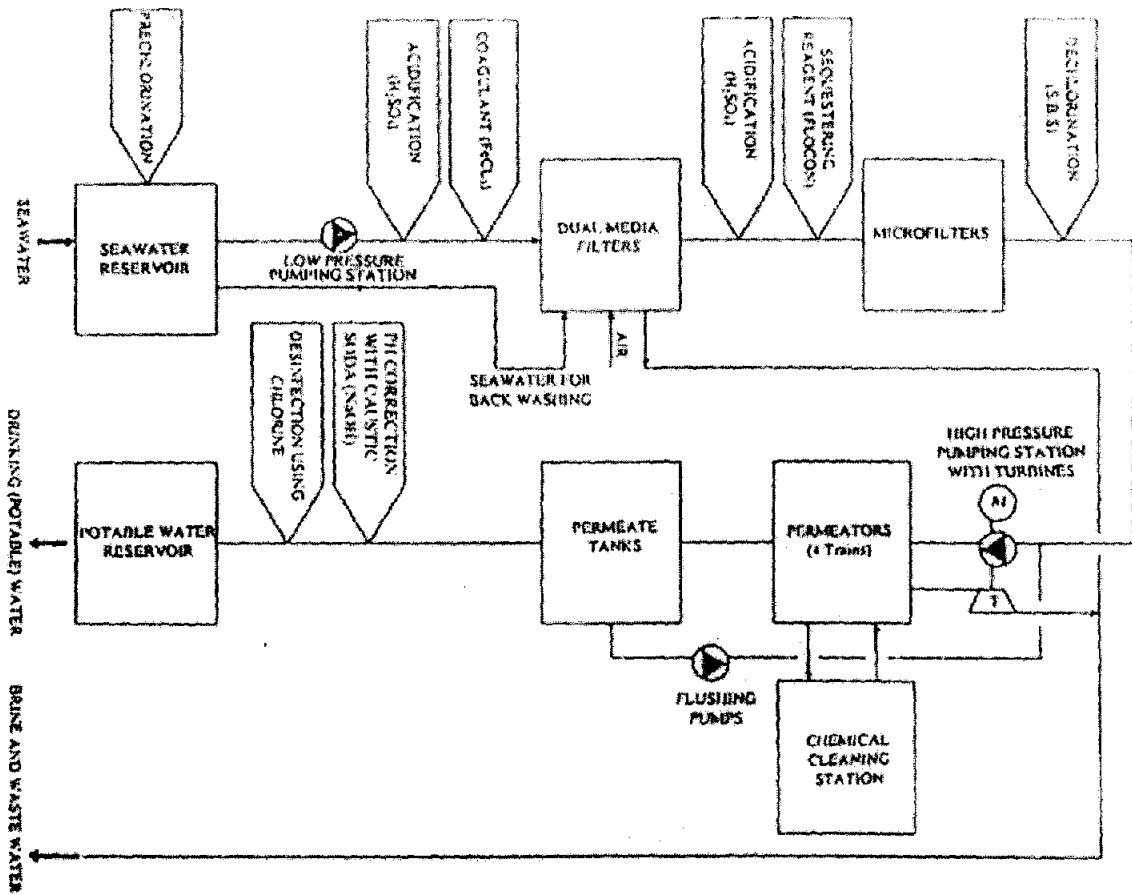


Fig. 1. Block flow diagram.

### 3.3.1. The seawater supply system

Raw seawater is taken from the Atlantic Ocean through twelve beach-wells, of which only six are equipped. The equipment consists of 144 m<sup>3</sup>/d submerged pumps. The other six beach-wells were drilled to reinforce (for the midterm) the plant capacity which will reach 14,000 m<sup>3</sup>/d of desalinated water. Among the six equipped beach-wells, five are in operation and the sixth is on standby. The average well depth is 40 m below the surface. The material used is in general stainless steel 316L.

The raw seawater pumped from the beach-wells flows through a concrete canalisation (diameter = 500 mm; length = 6,797 m) before being stored in the seawater reservoir.

The seawater is pumped from the above-mentioned reservoir to the pretreatment unit by five booster pumps, four of which are in operation, the fifth being on standby. Two additional pumps are to be installed during the foreseen short term extension which will raise the total production to 10,500 m<sup>3</sup>/d of drinking water.

Table 3  
Design condition of raw water

Chemical composition	Amount
Total dissolved solids, mg/l	40,077
pH	8
Total alkalinity as $\text{HCO}_3^-$ , mg/l	162
Calcium $\text{Ca}^{++}$ , mg/l	464
Magnesium $\text{Mg}^{++}$ , mg/l	1,477
Sodium $\text{Na}^+$ , mg/l	12,255
Potassium $\text{K}^+$ , mg/l	441
Strontium $\text{Sr}^{++}$ , mg/l	15.4
Barium $\text{Ba}^{++}$ , mg/l	0.4
Silica $\text{SiO}_2^-$ , mg/l	1.4
Sulphate $\text{SO}_4^-$ , mg/l	3,075
Chloride $\text{Cl}^-$ , mg/l	22,109
Bromide $\text{Br}^-$ , mg/l	75.5
Fluoride $\text{F}^-$ , mg/l	1.5

Average temperature of seawater: 17–20°C;

Design temperature: 18°C.

### 3.3.2. The pretreatment unit

Raw seawater is pretreated through the following stages:

1. Prechlorination using chlorine gas (fed at the reservoir entry).
2. Acidification ( $\text{H}_2\text{SO}_4$ ) eventually required for an adequate coagulation of the suspended matter.
3. Coagulation using ferric chloride  $\text{FeCl}_3$ .
4. Pressure filtration through a sand bed in four horizontal cells (total length = 9 m; diameter = 2.9 m; material = gained reinforced plastic GRP). All cells are backwashed in sequence with raw seawater and air. Two additional cells could be installed to raise the total production to 10,500  $\text{m}^3/\text{d}$ .
5. Acidification ( $\text{H}_2\text{SO}_4$ ) to attenuate the precipitation of calcium carbonate ( $\text{CaCO}_3$ ) at the membranes level.

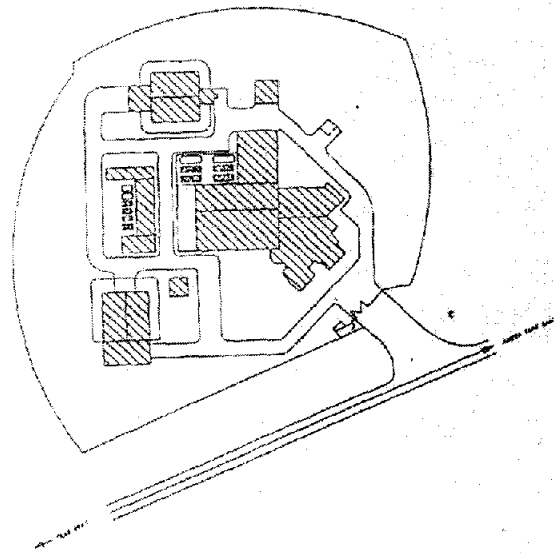


Fig. 2. Plant model.

6. Injection of a sequestering reagent (Flocon 100) to attenuate the pre- cipitation of sulfates at the membranes level.
7. Microfiltration (diameter = 5 mm) through 4 cartridge filters which remove particules larger than 5  $\mu$  and provide a final protection for the high pressure pump and RO section. Two additional cells could be installed within the foreseen extension of the plant.
8. Injection of sodium metabisulphite (SBS) to neutralize the remaining residual chlorine in order to protect the membranes

The construction material of the low-pressure canalizations and equipment is gained reinforced plastic (GRP).

### 3.3.3. High pressure pumps and RO trains

The high pressure pump and RO section of the plant is divided into four trains, each with a production capacity of 1,750  $\text{m}^3/\text{d}$ . One stand-by high pressure pump (the fifth), is installed and connected to the four trains. An adequate space has been reserved for two additional high

pressure pumps and two trains in order to increase the present production to 10,500 m<sup>3</sup>/d of drinking water.

The pretreated (clean) water is pumped up to a pressure of 60 bars by 4 high pressure 8 stages centrifuge pumps having a capacity of 3,888 m<sup>3</sup>/d each. The maximum design pressure is 70 bars. Each pump is coupled to a turbine for brine energy recovery. The recovered power is around 40% of the total energy required by the high pressure pumps.

The high pressure pumps are made of duplex stainless-steel (chrome = 24–26 %; nickel = 7–9%; molybdenum = 2–3%).

The RO section is the heart of the plant. In this section, 45% of the feed water is recovered as product water. The remaining 55% (brine) is depressurized through the turbine and returned to the ocean using a brine pumping station. This latter is equipped with three submerged pumps, two in operation and one on standby. The capacity of each pump is 12,960 m<sup>3</sup>/d.

The four RO trains are at present equipped with 94 Dupont B10–6845 T (hollow-fine fibre) RO modules, arranged on two stages (brine-staging : 47/47 or 1/1).

Sixteen additional modules per train will be connected progressively during the next 4 years in order to maintain a production of 1,750 m<sup>3</sup>/d per train by the end of the fifth operating year (as agreed with the contractor).

The permeate flows to post treatment unit.

The construction material of the high-pressure canalisation is AVESTA 254 Smo (high resistance against corrosion).

### 3.3.4. Post treatment unit

Caustic soda is added for pH adjustment to minimize corrosion in the product water delivery pipes and the distribution network.

Chlorine is added to disinfect the product water before its distribution for human consumption.

### 3.3.5. Product delivery to the city

The drinking water produced in the RO plant flows to a product water reservoir and is pumped to the “carrefour reservoir” (located 9 km away from the plant) by two product water pumps, one in operation and one on standby. Each pump has a nominal capacity of 10,800 m<sup>3</sup>/d and a third pump with a capacity of 3,500 m<sup>3</sup>/d has been installed and is used when the production is assured only by two trains.

The drinking water coming from the RO plant is mixed with the brackish underground water (within the above mentioned reservoir) and then pumped to the city of Laayoune.

### 3.3.6. Electrical power supply

The power energy supply of the plant is insured through a 22 kV electrical line which belongs to the ONE (National Office of Electricity).

The high pressure pumps are provided with three electrical transformers of 1,000 KVA capacity (22 KV/5.5 kV), two in operation and one on standby. The low pressure equipment is provided with three other transformers of 315 KVA capacity (22 kV/220–380 V), one of which is on standby.

The RO plant needs a nominal power supply of 2 MW.

### 3.3.7. Central control room

The entire process of the plant is insured by an automate. The visualisation of the plant's equipment state (in operation or stopped mode) is given by a synoptic. A computer with a printer allows the following:

1. To operate the plant through the automate.
2. To date the operations of the process.
3. To display on screen, store then print all the operations.

Table 4  
Comparison between train operating parameters and simulations resulting from module constructor software

Designation	Train 1		Train 2		Train 3		Train 4	
	Real	Predicted	Real	Predicted	Real	Predicted	Real	Predicted
Pressure, bar								
Feed	62	62	67	67	66	66	68	68
Brine	58	60.9	63	65.8	62	64.8	64	66.8
Product	0.58	0.60	0.66	0.70	0.60	0.60	0.62	0.60
Flows, m <sup>3</sup> /h								
Feed	161	160.1	162	163	162	163.2	162	163.7
Brine	88	87.9	89	89.5	90	89.6	91	89.5
Product	72.2	72	73	73.3	73.4	73.7	73.5	73.5
Permeate								
Conductivity	492	705.4	470	588.6	521	607.6	619	568.8
TDS, mg/l	246	352.7	235	294.3	260.5	303.8	309.5	284.4
No. of modules	94	97	96	84.2	94	86.8	94	82.6
Conversion	45	45	45	45	45	45	45	44.9

### 3.3.8. Auxiliary systems

1. Instrument and service air
2. Air conditioning
3. Chemical cleaning system for RO modules
4. Chemical waste disposal system
5. Chemical laboratory

## 4. Operation

### 4.1. Beach wells

#### 4.1.1. Groups of raw water pumps

Raw water pumps undergo important degradations due to the corrosion by seawater. Equipment materials of wells (tubes, pumps, risers) are of stainless steel 316. Its use is acceptable in such working environment.

The causes of motor degradation are stated as follows in the order of importance:

1. The non-conformity of motor constitution material with the stainless steel materials used in the sea.

2. Pumps hydraulic operating conditions which are unfavourable.
3. Pumps position with regard to wells' tubes.

#### 4.1.2. Bacterium proliferation in the wells

The presence of micro-organisms inside the wells was mentioned. The analyses showed the presence of a biological film stuck to the riser internal part. The use of hard oxidants (chlorine or  $\text{KMnO}_4$ ) may accelerate the corrosion process.

It is preferable to use a biostatic treatment in order to avoid the bacterium proliferation in the wells. This treatment may be done by a monthly injection of a reducing agent such as sodium bisulphite with an amount of 1 g/l.

### 4.2. Desalination plant

#### 4.2.1. Pretreatment

A SDI measurement series was undertaken in September 1998 by ONEP. Sample taking spots

are indicated in Fig. 3. The series conclusion is as follows:

- The SDI values in the beach wells vary from 0.14–1.8 with a global SDI of 1.06 at the desalination plant entrance in which occurs the mixture of water provided by different beach wells.
- The SDI increases substantially at the raw water tank. This is probably due to the partial detachment of the tank internal protection which leads to material drainage in the tank.

In general, the SDI average value at the desalination plant entrance (about 1.06) shows that the use of pretreatment is not required. Other current measurement series are taking place in order to decide whether the use of filtration is required or not in the future.

#### 4.2.2. RO system

The comparison between the train operating parameters and the simulations resulting from the module constructor software is shown in Table 4. We conclude from the table above that:

Table 5  
Data used for economic analysis

Total investment cost, DHS	230,000,000
Civil works cost, DHS	46,000,000
Equipment cost, DHS	184,000,000
Actualization rate, %	10
Availability of the plant, %	90
Amortization period	
for the civil works, y	40
for the equipment, y	15
Electrical power, DIIS/kWh	1
Chlorine, DHS/t	6,500
Sulfuric acid, DHS/t	4,560
Flocon, DHS/t	68,400
Caustic soda, DHS/t	5,700
SBS, DHS/t	17,100

- The first train performances are better than others and even than the constructor predictions. These are mainly seen in the pressure feed and the number of operating modules.
- The pressure drop through membranes are higher than the constructor predictions, in general about 4 bars. The value of these pressure drops should have been about 1 bar.

#### 4.2.3. Post-treatment

The aggressivity correction facility of the produced water actually insured by caustic soda

Table 6  
Product water cost

Plant conditions	Designed	Actual operation
Chemical consumption, g/m <sup>3</sup>		
Chlorine	5	3
Sulfuric acid	65	20
Ferric chloride	–	–
Flocon	17	10
SBS	7	10
Caustic soda	69	50
Power consumption, kWh/m <sup>3</sup>	5.82	5.52
Recovery ratio, %	45	45
Production, m <sup>3</sup> /d	7,000	7,000
Chemical cost, DHS/m <sup>3</sup>	2.00	1.25
Electrical cost, DHS/m <sup>3</sup>	5.82	5.52
Amortization cost of the civil works, DHS/m <sup>3</sup>	1.67	1.67
Amortization cost of the equipment, DHS/m <sup>3</sup>	10.50	10.50
Operation and maintenance labor, DHS/m <sup>3</sup>	0.82	0.82
Membrane replacement, DHS/m <sup>3</sup>	1.40	1.40
Cartridge filter replacement, DHS/m <sup>3</sup>	0.14	0.07
Product water cost, DHS/m <sup>3</sup> (US \$/m <sup>3</sup> )	22.35 (2.48)	21.23 (2.36)

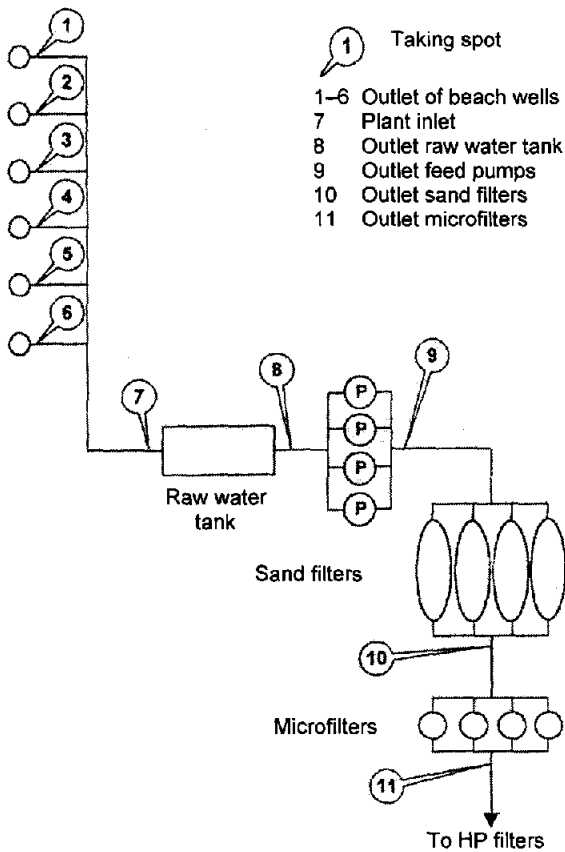


Fig. 3. Sample taking spots.

dosing is inefficient because it does not allow to bring up this water to its calco-carbonic equilibrium. In fact, the produced water damages the equipment and attacks the transport canalisation. It is confirmed through the pH increase in the produced water, which reaches the value of 10 at the level of the “carrefour reservoir” (located 9 km away from the station), while it was of 9 at the outlet of the plant.

The only solution to this consists in remineralizing the produced water on the basis of calcium ( $\text{Ca}^{++}$ ) and bicarbonates. A study is being carried out to install a filtration upon a medium constituting of calcium and magnesium in order to correct adequately the aggressivity of the water before being transported.

### 5. Economic analysis

A product water cost analysis was made based on the basis of the original design conditions and the present conditions. Tables 5 and 6 show the data used as a basis for the product water analysis.