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Engineering design of Skikda Seawater Desalination Plant

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ABSTRACT

Skikda Seawater Desalination Plant (SWDP) is located in the northern part of Algeria (Mediterranean Sea) and will have a total production of 100,000 m^3/d. It is being developed under a 25-year DBOOT contract with Algerian Electrical Company (AEC) in a Joint Venture named GEIDA (Befesa–Sadyt) in order to supply water for human consumption to the area. Based on reverse osmosis (RO) technology, the raw water is driven from a seawater open intake to the pre-treatment stage which consists on two filtration steps with sand and anthracite. After cartridge filters as a security barrier prior to the RO process, this is designed with five independent RO lines equipped with pressure exchangers as energy recovery devices. Finally, the post-treatment will be made by means of dolomite filter beds to get the optimal quality conditions. This paper shows the design of a high efficiency SWDP that will significantly increase the water resources of the region.

Keywords: Desalination; Reverse osmosis; Engineering; Seawater; Design

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1. Introduction

The Algerian Government basing on achieving a sufficient potable and industrial water capacity to satisfy actual and future country's needs in coastal areas and not subject to climate vicissitudes started to developed an ambitious water policy in the north of Algeria.

In this sense and in order to cover Skikda Region needs, North-East of Algeria, Algérie de Electricité (AEC) launched an international request for investors based on a BOT basis in year 2004 for funding a Special Purpose Vehicle Company (SPV) together with EAC itself and Algérie des Eaux (ADE) to promote the construction, operation and maintenance during 25 years of a 100.000 m^3/d seawater desalination plant (SWDP) in the region. Water produced is to be sold on a fixed plus variable tariff scheme to a consortium formed by ADE and Sonatrach and is expected to cover potable water needs of 700,000 equivalent inhabitants and industrial uses of the petrochemical industries nearby.

After being awarded and having successfully completed the first Algerian funding financial closure of a project of this kind, the Spanish consortium Geida formed by Befesa Agua, S.A.U. and Sadyt started construction of the plant in the beginning of 2006.

The objective of this paper is to present the guidelines of the design of the plant and its process to serve to the purpose of the contract for 25 years.

Start-up and commissioning of the plant is nowadays in progress and expected to be completed by November 2008 although from the first moment that a unit is in operation that will be ready for production according to the contract. Specific location of the plant presents several advantages and drawbacks that will be described

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further on. Generally speaking, the surrounding can be described as a very industrialized area mainly dedicated to petrochemical purposes.

Seawater is withdrawn from an open intake and on its design some constraints have been considered, the existence with a considerable marine traffic and possible interferences with other outfalls nearby. Some preliminary studies regarding an intake system based on beach wells were undertaken during initial engineering stages of the project but this option was considered not feasible because of hydrogeolical conditions of the site and because it might not guarantee seawater supply during the whole contract duration.

Seawater characteristics are those typical of the Mediterranean Sea with a constant medium to high TDS content but acceptable levels of TSS and turbidity values. Temperature variations are also those typical of this sea, ranging from 18 to 27°C.

The pre-treatment of the seawater can be defined as traditional and robust but flexible since it comprises 2 stages of filtration on dual filter media each. Chemicals expected to be used are ferric chloride, sulphuric acid, sodium hypochlorite, sodium bisulphite, anti-scalant and dolomite for pos-treatment conditioning. Opposite to the pre-treatment design, the reverse osmosis (RO) process is conceptualized under independent lines philosophy (5 lines). A single step RO is considered at 47% recovery rate. After pos-treatment in dolomite beds and addition of hypochlorite water is ready for distribution through a pumping station that is also part of the scope of the project.

2. Plant location

The plant plot is located within a petrochemical complex near the shoreline, in what is called development area No. 1 (DEV 1), about 2 km east of the city of Skikda (about 500 km east of the city of Algiers) (Fig. 1).

The plant plot at DEV 1 has an area of 4 ha and it is limited by the sea in the north, by the Skikda Oil Refinery Plant in the south and by Polymed Industry in the west.

Fig. 1. Top view of Skikda and process building.

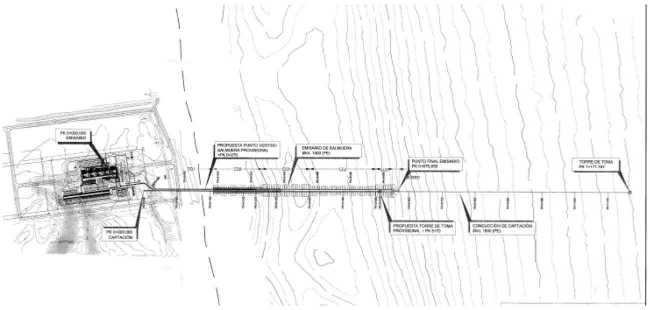

Fig. 2. Scheme of the seawater intake and outfall.

The attention must be drawn to the fact that Polymed Industry already has a marine gas pipeline and a loading buoy 1.5 km offshore, direction south-north and not further than 100 m from the available plot that restricts the possibilities for the seawater intake line and outfall line to eastern part of the sea (Fig. 2). This issue had to be taken into consideration when performing analysis to decide intake and outfall point locations (marine environment affections, brine dispersion studies, intake water analysis, spill risk evaluations, etc.).

3. Design data

3.1. Seawater characteristics

Although seawater analysis campaigns have shown certain variability on the water characteristics, basically regarding some key parameters that affect the pre-treatment (turbidity, TSS, etc.) (Table 1), the design of the SWDP was finally done to cope with. The analysis shown bellow was taken as the baseline for design purposes. Temperature variations are those expected in the Mediterranean Sea, and total dissolved solids showed to be very constant.

3.2. Product water requirements

As it is stated per contract, product water requirements listed in Table 2 are to be met in the design.

3.3. Plant design conditions and other requirements

Plant design conditions and other requirements are listed in Table 3.

Table 2
Physical and chemical characteristics of product water

Maximum TDS after post-treatment, ppm	<500
Alkalinity, ppm as $CaCO_3$	Max. 65
Total hardness, ppm as $CaCO_3$	50–65
pH	8–8.5
Langelier index	0–0.4

Table 1
Physical and chemical characteristics of raw water

Physico-chemical properties					
Turbidity, UNF	1.75		pH	8.05	
Colour, Pt-Co	1.53		Conductivity @ 20°C, mmhos/cm	54,404.37	
Odour, TON	n.a.		TDS, ppm	39,333.38	
Visual aspect	n.a.		Alkalinity, ppm $CaCO_3$	156.05	
Temperature, °C	18–27		Hardness, ppm $CaCO_3$	6,416.97	
Ions					
Cations	ppm	meq/l	Anions	ppm	meq/l
Ca^{++}	464.21	23.16	$SO_4^{=}$	3,049.00	63.48
Mg^{++}	1,278.94	105.21	Cl^-	21,582.74	608.77
Na^+	12,285.62	534.37	CO_3H^-	156.29	2.56
K^+	487.89	12.48	F^-	1.37	0.07
Ba^{++}	0.01	0.00	Br^-	0.00	0.00
Sr^{++}	5.12	0.12	I^-	0.00	0.00
Fe^{++}	0.00	0.00	NO_2^-	0.00	0.00
NH_4^+	0.01	0.00	NO_3^-	0.00	0.00
Ag^+	0.00	0.00	$CO_3^{=}$	16.70	0.56
Mn^{++}	0.00	0.00	$PO_4^{=}$	0.00	0.00
Zn^{++}	0.00	0.00	$S^{=}$	0.00	0.00
Cu^{++}	0.00	0.00	SiO_2 colloidal	25.42	0.42
Al^{+++}	1.00	0.11	SiO_2 soluble	0.26	0.00
Fe^{+++}	0.00	0.00	CO_2	0.94	0.02
H^+	0.00		OH^-	0.00	
Total	14,522.80	675.45	Total	24,806.36	675.45
Other components					
Arsenic, ppm	0.00		DBO_5, ppm	10.00	
Cadmium, ppm	0.00		DQO, ppm	20.00	
Boron, ppm	4.22		Proteinic nitrogen, ppm	17.50	
Mercury, ppm	0.00		Phenolic compounds, ppm	0.00	
Lead, ppm	0.00		Detergents, ppm	0.05	
Selenium, ppm	0.00		Oils and grease, ppm	0.00	
Cromiun (total) , ppm	0.00		Hydrocarbons, ppm	0.50	
Cromium VI, ppm	0.00		Total suspended solids, ppm	18.50	

Table 3
Plant design conditions and other requirements

Plant capacity, m^3/d	100.000
Number of RO lines	5
Recovery rate, %	47.0
Guaranteed specific power consumption, kWh/m^3	3.56
Daily hours of operation, h	24
Operating days per year, d	355
Type of water	Seawater (open intake)
Water withdrawn from ocean, m^3/d	216.000
Brine rejection	To the sea with diffusers at the outfall
Maximum temperature, °C	27
Minimum temperature, °C	18
Plant site level, m	12
Product water head required pressure at delivery, bar	12

4. Process description

As a brief introduction, SWDP design, as it has already been mentioned above, is based on a traditional pretreatment process line mainly relying on a double stage filtration, dual media each, is considered appropriate and robust for the open intake seawater characteristics and followed after by a single RO pass at 47% of recovery rate. The permeate is then conditioned to the final quality by disinfection and taking advantage of the low permeate pH that dissolves calcium and magnesium when flows through the dolomite filter beds before being pumped for final delivery. Fig. 3 shows schematically the plant process.

In what follows a description of each process unit will be included with more detail.

4.1. Marine intake and brine rejection pipes

As it can be observed in Fig. 4, seawater enters the process through an offshore hexagonal tower placed at –18.0 m bellow sea surface and at 1,000 m north from the coast line. Tower dimensions are 3.8 m in diameter and 6.85 in height.

From the tower the water flows through a 1.8 m diameter HPDE pipe to the pumping station located in the coast.

Water velocities close to 1 m/s ensure minimal head losses so that the intake pump station is not deep bellow the ground level, static and dynamic levels of the pit prior to the pump are acceptable, and at the same time not significant matter settling is expected in the pipe.

The intake pipe is partially leaned on the seabed and anchored with ballasts and when it approaches the level –10 m (nearly 400 m offshore), it is buried under the sea ground until reaching the pumping pit at –5 m bellow the sea level.

Brine rejection HDPE pipe, 1.6 m in diameter, follows the same track as the intake one but ends up earlier at a level of –10 m, precisely in the transition between the buried and leaned pipes. A diffuser at the end of the brine pipe ensures a rapid and proper dilution according to the environmental requirements.

The difficulties of the marine works carried out because of the sea conditions especially during autumn, winter and spring should be mentioned, which limited most of the works to a few days during the summer season where anchoring of the pipe could be done easier.

Either because of this reason, most underground marine works were carried out from land by digging a trench and protecting it from flooding by means of earth dams in the perimeter erected mainly with rocks and soil excavated from the trench, which will be used later on to refill it. This way, most of these tasks could be completed without dependence on the weather conditions as it would have been if this task would rely on dredging boats.

4.2. Seawater intake pumping station

As soon as raw seawater flows through an isolating floodgate to the intake piping station, it is first screened by means of two Beaudry type rotating screens, with a mesh size of 1,000 microns. The election of this system was based on the minor civil work requirements compared to a drum filter system. Materials of the screens are all seawater corrosion resistant, metal parts are duplex steel 1-4462 and meshes are plastic made. Total wetted surface is 12.5 m^2 which provides a filtering velocity through the mesh of 0.2 m/s. Screens are equipped with an automatic cleaning system and can be isolated by means of floodgates for maintenance purposes.

After being screened, water enters the pumping station pit from which water is pumped to the pre-treatment. At the pit and inlet channels, up to 5 ppm of hypochloride as free chlorine can be dosed for disinfection purposes and bacterial and organic growth inhibition.

The pumping station which must supply up to 9,000 m^3/h of seawater to the pre-treatment is designed to operate in 5 different flow steps according to the same number of RO lines considered, that is with 5 seawater pumps plus one on stand-by. This way, flow regulation is simplified since there is a total correspondence between the numbers of seawater pumps, high pressure pumps and RO skids.

Fig. 4. Marine works.

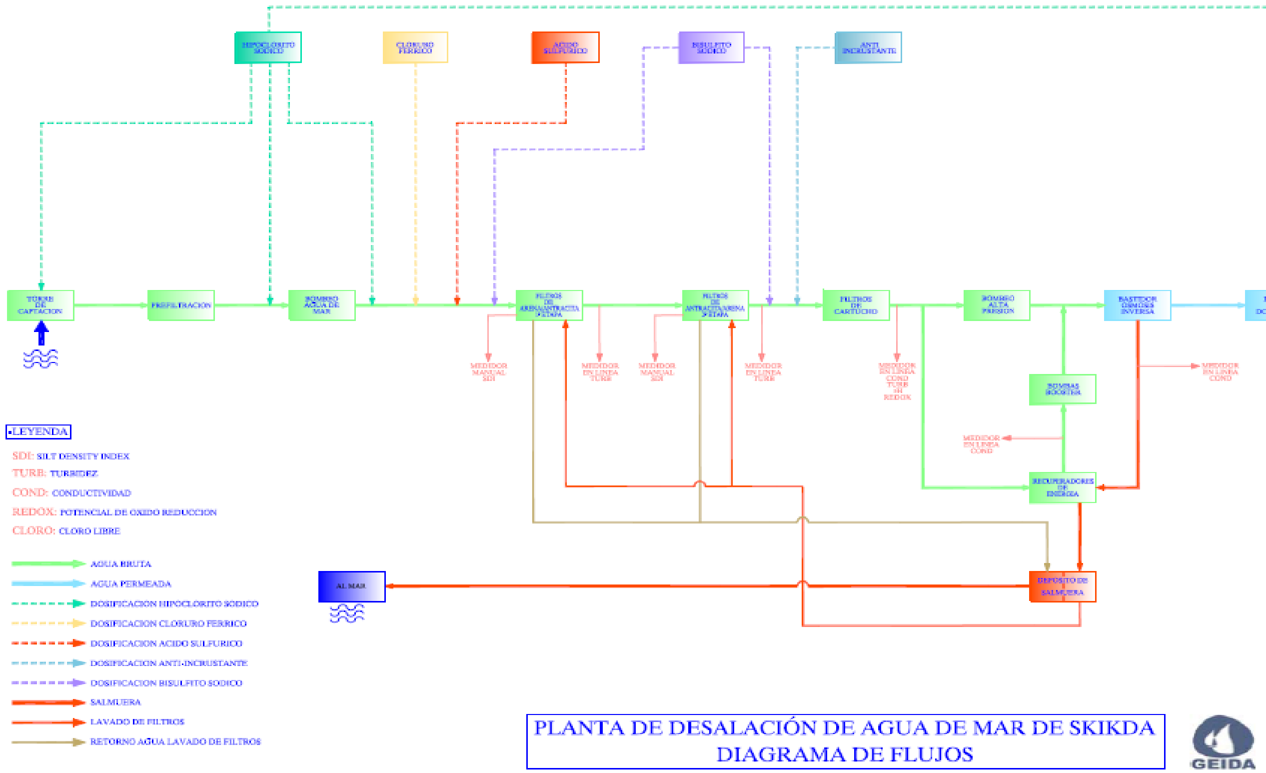

Fig. 3. General process diagram of Skikda SWDP.

Pit levels are expected to range between +2.3 m above sea level, maximum expected tide when the pump station is not in operation and maximum expected water hammer from the inflow pipe if a sudden total pumping failure happen, and –0.8 m bellow sea level which is the level expected under full dynamic operation of the pumping station and low tide conditions.

Pumps are located at 3 m above sea level so that they need a vacuum system to feed them with water prior to every start-up and are centrifugal, split case, type with a capacity of 1800 m^3/h and 6 bar. The absorbed power during operation is 316 kW each, and motors are fed at high voltage current to avoid transformation losses and lighten the motor weight. Flow and pressure can be regulated at the discharge butterfly valves.

All pumps, although running in coordination with the number of RO skids in operation, discharge to a common manifold (DN1300) that will lead the water to the filters. It is in the manifold where it is possible again to add hypochloride, adjust the pH and favour matter coagulation by ferric chloride addition.

4.3. Chemical treatment

The most remarkable fact of the chemical treatment process is the use of pH adjustment by sulphuric acid not only to achieve an acceptable acidic level for optimal coagulation and precipitation inhibition at membrane modules, but to achieve a sufficient lower pH at RO permeate so that no need of further CO_2 addition is required for dissolving the dolomite at the pos-treatment.

pH is expected to be low down up to a value of 6.5 where CO_2 concentration is about 30 ppm that since it is not rejected by the RO membranes will be kept in the permeate and therefore react with calcium and manganese carbonate in the dolomite filter beds.

Additionally, as it has been indicated abov,e hypochloride and ferric chloride can also be dosed in line.

After chemical and physical treatment and at the security micro-filtration stage, remaining free chlorine and oxidizing elements are reduced by sodium metabisulphite addition and antiscalant also if required.

4.4. Filtration treatment

After disinfection, pH adjustment up to 6.5 and ferric chloride dosed according to seawater quality requirements, the dual stage dual media filtration takes places.

Both filtration stages are done in horizontal pressure vessels at respective average velocities of 8.8 and 14.5 m/h.

Up to date, the selection of the velocities and filter media have shown to be appropriate by achieving SDI_5 values after each stage below 4 and 3, respectively, from immeasurable SDI_5 at raw water when 5 ppm of ferric are dosed.

Filter pressure vessels (Fig. 5) dimensions are the same regardless the stage at which they operate, owing to a filtration surface area of 40 m^2 each. 25 units are installed at the first filtration step and 15 at the second.

Fig. 5. Pressure filters.

Piping design allows by-passing any (or both) of the filtering stages and drains for the whole flow of the filters to ease start-up of the filters or in the case the flow is needed to be taken out of the process line because no minimum required water quality at the membranes is reached.

Maximum expected water head loss at each stage is 10 m.w.c depending on filter fouling. The selected operating mode of the filters is based on achieving such operative washing frequency that water losses are kept safely below that maximum loss but without regulating a constant flow through each independent unit as other plants do. However the flow at each unit is monitored, and when it falls below a certain value, the unit is put in the washing queue to recover functionality. In Table 5 the media filters selected can be observed.

4.5. Filter washing system

Brine is used as the fluid for backwashing 1st and 2nd stage filtration. Prior to rejection, brine flows to a tank that overflows through a splitway to a homogenization de-

Table 5
Media filters in Skikda SWDP

Layers	Media type	Effective size (mm)	Layer height (mm)
1st stage			
Support layer	Sand	2	100
Lower filter media	Sand	0.9	500
Upper filter media	Anthracite	1.5	700
2nd stage			
Support layer	Sand	2	100
Lower filter media	Sand	0.5	500
Upper filter media	Anthracite	0.9	700

gritting channel where it is mixed with return backwash waters as membrane cleaning rejections.

From the brine tanks, two pumps (1 on standby) are installed to perform backwash at a flowrate of 1,000 m^3/h (25 $m^3/m^2/h$).

Air is also used at the backwash stage by means of air blowers (one in operation, one standby) at a rate of 2,000 Nm^3/h (50 $Nm^3/m^2/h$)

Backwashing stages include filter partial drain, air swelling, water and air backwash, water backwash and filter rinse. After the backwashing cycle, brine is displaced with seawater being reincorporated to the end process in order to not produce salinity peaks at the inlet of the membranes every time that a washed filter is re-started. Total filter backwash cycle takes about 40 min, and the expected frequency under worst condition is above 1.5 days between two consecutive cycles per filter.

4.6. Micro-filtration

After strictly speaking physico-chemical pre-treatment and once the antiscalant and bisulphite have been dosed, seawater undergoes a security microfiltration stage at 15 absolute microns prior to the RO process.

The selected microfiltration type is that of polypropylene cartridge filters (15 absolute microns as already mentioned) with a filtration velocity of about 13 m/h and with head losses ranging between 0.3 and 2 bar depending on the fouling state of the cartridges. Pressure control at the outlet of this stage is vital to ensure proper high pressure pump (HPP) and energy recovery device (ERD) operation since it cannot be below 2 bar so as not to feed both types of equipment under pressure inlet requirements.

Cartridges are grouped in 10 GRP pressure vessels, containing 280 units each, 2 inch in diameter and 60 inch length. They are expected to be replaced every 3–4 months.

It is up to this microfiltration system that all the process is carried out through common manifolds thus easing the flexibility and readability of the process although readers can understand that all units are 5 or multiple of five so regulation of the 5 RO lines is in coordination with the number of units in operation in the pre-treatment (specially pumps), as it has been said several times.

4.7. RO process

4.7.1. Feed manifold to the process

Feed manifold is common to the 5 RO lines and it feeds indistinctly ERD's and HPP. This way hydraulic circuits are simplified, and since inlet pressure at both types of devices is similar (2 bar) there are no significant sacrificed pressures.

At the end of the manifold (DN1300) there is a butterfly valve that connects it with the brine loop to regulate (through a PID loop) the flow and pressure through the feed manifold, especially during the progressive start-up of each RO line.

From the feed manifold different independent lines to the 5 RO devices come up at DN400. All of these branches can be isolated through butterfly valves.

4.7.2. Description of each single RO line

As has already been stated, each RO producing line is designed with a nominal capacity of 20,300 m^3/d in a single pass. Each line is fed by one independent HPP and rack of EDR's. The recovery rate is 47%.

All metal parts are seawater corrosion resistant made in superduplex steel Sch40s, and low pressure (LP) parts (LP inlets, permeate and LP outlet of ERD's) are made of plastic (mainly PP, PVDF and GRP) rated at PN6, 10 and 16 depending on the service demand.

4.7.3. High pressure pumps

Each HP pump has a capacity of 863 m^3/h at 70 bar. Flow pumping capacity slightly overpasses the permeate flow to come up with flow leakage losses at ERD's.

The nominal pump motor power is 2 MW at 6 kV, and it runs at fixed speed. Regulation of the RO system, if required, is achieved by a permeate regulation valve and ERD's recirculation pump and brine outlet valve.

This way, it is intended to operate the HP pump, the highest power consumer of the process at its best efficiency point (BEP) is 84.5%, and it takes an advantage of the lower transformation electrical losses of the motor operated at high voltage.

4.7.4. Energy recovery device system (ERD's)

As it is well known, this system has to provide pressurized seawater equivalent to the flow of brine produced to the RO inlet by profiting the residual pressure of the brine at the outlet of the RO vessels.

These systems lose efficiency since they have hydraulic and saline mixing losses within the currents they handle. In order to reduce mixing losses, they can be run at seawater overflow conditions (more seawater than brine is injected in the process), however this is not the expected case, and the system is expected to be run at zero overflow conditions assuming that the savings in pumping less seawater to the system will compensate for slightly higher saline increment at the RO feed.

Head efficiency losses and increase in required inlet pressures because of the mixing are overcome by means of a booster pump between the ERD's and the inlet to osmosis membranes. This booster pump is also equipped with a variable speed driver (VSD) so that the osmosis process can be regulated as well as the operating mode of the ERD's.

ERD's are ERI 220 type grouped in 5 racks (one for each membrane rack). Each ERD's rack is comprised of

22 ERI 220 units running at a mid-high flow of 47 m^3/h of brine each. Expected hydraulic efficiency is above 95% so that only approximately 1.2 bar are lost in the exchange of pressure between brine and seawater. Saline increase at the HP seawater ERD's outlet is 6% maximum (3% roughly speaking at the membrane inlet). The LP brine valve is of vital importance for controlling the ERD's performance, in this case a DN300 automated flow regulating valve is installed.

Hydraulic losses, as it has already been mentioned, are overcome by the booster pump which has a nominal capacity of 950 m^3/h, a TDH 69 m.w.c and hydraulic efficiency of 86%. Consumed power is 205 kW, and motor is run at a low voltage current through a VSD.

4.7.5. Membrane racks

Membranes are fed with the mix of the two currents coming from the HP pump and the ERD's. The inlet flow is 1800 m^3/h at a required pressure rating between 61 and 66 bar depending on membrane fouling and temperature.

The design foresees 245, 7 membrane capacity pressure vessels, that is 1715 RO membranes. The elements are seawater spirally wounded polyamide low pressure membranes, Hydranautics SWC5 with a Unitarian surface of 400 ft^2 operating at a flux of 13.2 lmh. Permeate TDS content is about 330 ppm at pH of 5 (30 ppm CO_2).

Membrane racks can be cleaned at once with the membrane cleaning system at a flow of 9 m^3/h per vessel and at 6 bar. Cleaning solutions are prepared in a 100 m^3 tank equipped with water heater resistances and mixing pumps to prepare the solution.

4.8. Post-treatment

After the RO process, permeate from all units is gathered in a product water manifold that leads the water to the dolomite filter beds.

No CO_2 addition is required since pH and CO_2 contents are enough to dilute the dolomite (50% $CaCO_3$ and 50% $MgCO_3$) to re-conditioning the water to required parameters:

Maximum TDS after post-treatment: <500 ppm
Alkalinity: max. 65 ppm as $CaCO_3$
Total hardness: 50–65 ppm as $CaCO_3$
pH: 8–8.5
Langelier index: 0–0.4

Retention time at filter beds is 10 min at a flow of 15 m/h. About 65 ppm of dolomite will be dissolved in the permeate reaching the final quality shown above. About 2,500 ton will be consumed yearly.

There is a possibility of dosing hypochloride (up to 2 ppm) at filters inlet to leave residual free chlorine in the water to be supplied.

Ten filter beds in total have been installed for treating full plant capacity and even with one out of operation for maintenance purposes.

Once final water quality is achieved, it overflows to a 2500 m^3 tank from which it is pumped to a 5000 m^3 tank, 6 km away from the SWDP at a height of 115 m.a.s.l.

The pumping station is compounded by 3+1, 600 kW pumps at 6 kV.

5. Conclusion

Skikda SWDP design is conceptualized in what be called a conservative design where the main governing design philosophy is to ensure a robust process, flexible enough for its needs (at steps of one fifth basically) and where the advantages of the use of big size RO lines and associated equipment have been traduced on a competitive water cost in terms of energy and other operational costs.

The use of dual media filters at two stages and with the selected media size has proved to be very appropriate.

Execution of marine works has shown to be the most challenging task and should give way to rethinking the difficulties that it brings compared to the benefits of better seawater quality that with the pre-treatment design can be easily achieve by far the required membrane water quality that membrane manufacturers are ready to accept.

Nevertheless and once execution has been completed, the plant as a whole is a tool for the economic development of the region that up to date lacks this basic resource, bringing a high quality potable source to its population and industries.