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Performances analysis of the reverse osmosis desalination plant of brackish water used for irrigation: Case study

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Abstract: Desalinated brackish water is becoming an important water source for agricultural irrigation. In Brackish water desalination, pretreatment of reverse osmosis is the key step in designing the plants to avoid membrane fouling and scaling. It is enormously important to carry out a study designed at ensuring the optimization of the pretreatment system for brackish desalination plant in order to optimize the quality of the water fed through the reverse osmosis membranes, to guarantee the highest performance and to minimize the number of shutdowns for chemical cleaning. In this paper, performance evaluation carried out for a brackish water reverse osmosis plant for agricultural application, located in Dokkala Region in Morocco. This plant showed poor performances after few months of operating and frequent shutdown. The operating pressure increased significantly and the permeate conductivity decreased surprisingly. To identify the causes for the poor performance, different investigations were carried out. Thus, the pretreatment scheme was thoroughly reviewed to find out the causes of anomalies. The problem was resolved by removing chlorination and sodium bisulfate steps from the pretreatment.

Keywords: Reverse Osmosis, Desalination, Agriculture, Performances, Chemical Pretreatment, Cost

1. Introduction

Desalination is becoming an important source of drinking and agricultural irrigation water [1,2]. Desalination of brackish groundwater in some countries has a high potential in increasing the availability of water for agriculture, such as in Spain 22,4 % of the total desalinated water is used for agriculture, because it offers a solution to the problem for long distance water transportation [3,4]. The cost of brackish water (BW) desalination is considerably lower about 35% comparing with the cost of seawater (SW) desalination [2,5,6], making it more suitable for agriculture [3]. In addition, the use of desalinated BW in agriculture can potentially lead to increasing total biomass production [7] and also enables shifting from some types of crops to others, more salt sensitive and often more profitable [8].

The use of water for agriculture represents 70% of the global use of water and in developing countries the consumption of water in the agricultural sector exceeds 80% [9].The volume of desalinated water used for agricultural irrigation in countries such as Spain, Israel and the United Arab Emirates has dramatically increased in the last years [9,10,11].

In Morocco, the percentage of the used water in agriculture exceeds the 75% [12]. The use of underground water in agriculture becomes frequently facing to the dryness of last the last decades. The use of underground water becomes frequent. This is the case in some regions in Morocco. However the salinity of much underground water exceeds the standards for irrigation of many crops and the use of this water resource without treatment decreases the yield of agricultural crops.

In this field, the big progress in Morocco in the water management since the beginning of the last decade is the use of desalination of brackish water, seawater, and water reuse for, irrigation, potable water and industrial units. Today the national desalination production capacity exceeds 50.000 m^3/day. The market of RO desalination was 43% in 2004 and is forecasted to increase up to 61% in 2015 [14,15].

Many studies were carried out on the use of membranes process to treat the saline waters as sources of water for irrigation such as reverse osmosis, nanofiltration and electrodialysis. Table 1 gives the some investigations.

Table 1: *Membranes process used for agricultural irrigation*

Authors	Membrane process
EL malki et al [12], Goodman et al [16]	Electrodialysis
Soliz et al [17], Shaffer et al [18], Mrayeda[19]	Reverse osmosis
Mrayeda et al [19], Yan et al [20]	Nanofiltration

In this study case, Doukkala is a plain stretching from the Atlantic Ocean south of Oum Er-Rbia River in Morocco, It is mainly an agricultural region, this activity occupies about 56,6% of the economy of this region. Doukkala region has a large capacity of groundwater, but the water quality is deteriorating due particularly to the saline intrusion. For this, the reverse osmosis is the used process to minimize the salinity of the saline water.

In this paper, performances analysis was carried out of desalination plant by reverse osmosis for irrigation, of a geranium flower kind, which is sensitive to saline water. The main objective is to identify the causes for the disorder of performances of the plant after one year of operation. For this aim, different investigations were proposed. In addition, the cost associated with the examined chemicals pretreatment options was evaluated.

2. Methods and Materials

2.1. Raw Water Characterization

The raw water coming from three wells (located at about 6 Km from the sea) contains 2 g/l of total dissolved solid predominantly chloride and sodium ions. The feed salinity varies during the seasons but never exceeds 4 g/l. The characteristics of raw water are given in table 2.

Table 2: *Characteristics of the raw water*

	Well 1	Well 2	Well 3	Limits for irrigation
Sodium (Na^+), mg/l	406,25	261,73	338,45	<54,116
Potassium (K^+), mg/l	2,24	1,30	2,53	-
Magnesium (Mg^{2+}), mg/l	144,6	131,43	226,32	-
Calcium (Ca^{2+}), mg/l	237,24	149,99	242,71	-
Chlorides (Cl^-), mg/l	1136,2	624,47	1134,91	<391,02
Sulfates (SO_4^{2-}), mg/l	184,47	174,12	197,61	114,95
Bicarbonate (HCO_3^-), mg/l	192,20	255,64	214,16	-
Nitrates (NO_3^-), mg/l	200,08	237,53	241,65	103,32
pH	7,07	7,15	7,11	155,01
Temperature, °C	25	25	25	-
TDS, mg/l	2180	1515	2210	<1000

2.2. Description of the Reverse Osmosis plant

The proposed design of the reverse osmosis unit is shown in figure 1.The main treatment unit is composed of:

- Pre-treatment post,
- Reverse osmosis group,
- Post-treatment.

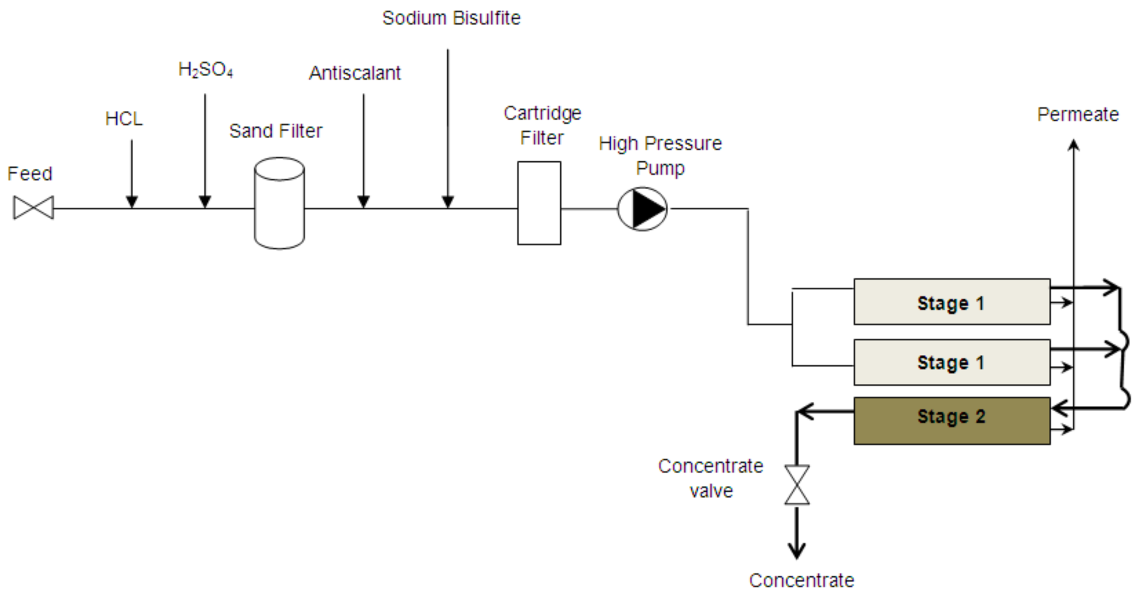


Figure1: *Schematic diagram of RO desalination process*

Pre-Treatment:

The pre-treatment was designed to improve the raw water quality, to remove the undesirable materials in raw water, to provide a final protection and to adapt the pre-treated water to the reverse osmosis membranes requirements [11]. Figure 1 shown the main steps of pre-treatment, it includes**:**

- Dosage of 6-9 ppm of Sodium hypochlorite in order to control the membrane biofouling.
- Injection of Sulphuric acid (H_2SO_4), in order to regulate the water pH, about 62 ppm of Sodium

Metabisulfit ($NaHSO_3$) (reducing agent) to neutralize completely the residual active chlorine [21].

- Injection of a commercial scale inhibitor (antiscalant) with a dosage level at 9 ppm in order to attenuate the risk of salt precipitations.
- The water undergoes a single sand filtration, in order to remove the solid particles and to protect the RO membranes from breakthrough particles.
- In the last step, a filtration with a cartridge filter is used for pretreatment sequence to remove particles larger than 5µm [22].

Reverse Osmosis Unit:

Table 3 gives the characteristics of Doukkala desalination plant.

Table 3: *RO characteristics*

Permeate Flow	20 (m^3/h)
Concentrate flow	12 (m^3/h)
Recovery rate	63 - 65 (%)
High pressure	13 (bar)
Concentrate pressure	8 (bar)
Number stage	2
Number pressure vessel	3
Number membrane/vessel	6

Post-Treatment:

The Post-treatment step is limited to use the sodium hydroxide at level 6-9 ppm, in order to adjust the pH at value of 7.

2.3. Cleaning of Membrane

The fouling of reverse osmosis elements is unavoidable with long-term operation. They can be fouled by biological matter, colloidal particles and mineral scale, element should be cleaned [20]. The protocol of membrane cleaning consisted of washing the membrane with several chemical solutions, it includes two steps:

Step 1: Alkaline solution, extremely effective against organic compounds.

Step 2: Acid solution, remove metal hydroxides, calcium carbonate, and other similar scales.

The consequence was the very high frequency of cleaning, as often as twice per month.

3. Results and Discussion

3.1. Performances of Raw Water

Figures 2, 3, and 4 present the daily variations of the Total Dissolved solids (TDS) collected from the tree RO feed well, during the year of 2011- 2012.

The results show that the Total Dissolved Solid (TDS) survey indicates that brackish water used to feed the RO plant, has a TDS approximately 1,20- 2,20 g/l, with a significant difference between all the seasons especially in the case of well 1 .

As showed in figure 2, in winter 2011 the feed water TDS was about 1,20 g/l, and gradually increased during the same year. Comparing with the same season but in 2012, the TDS of feed water from well 1, was the double value comparing with 2011. Moreover, there was no difference of reverse osmosis plant feed water TDS variation from 2011 to 2012, in the case of wells 2 and 3.

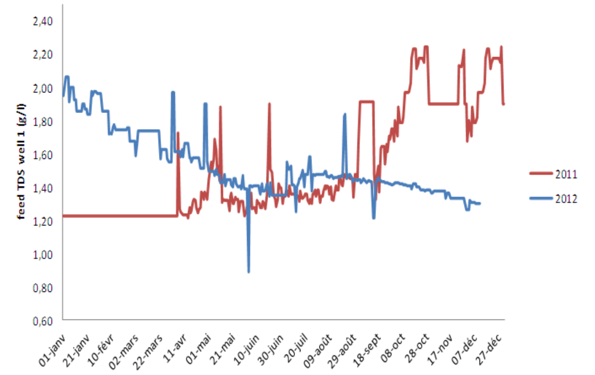


Figure 2: *TDS well 1*

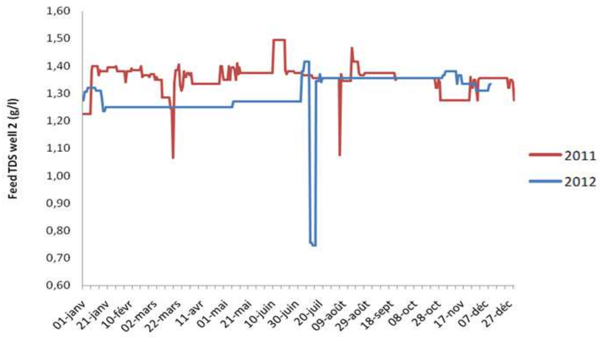


Figure 3: *TDS well 2*

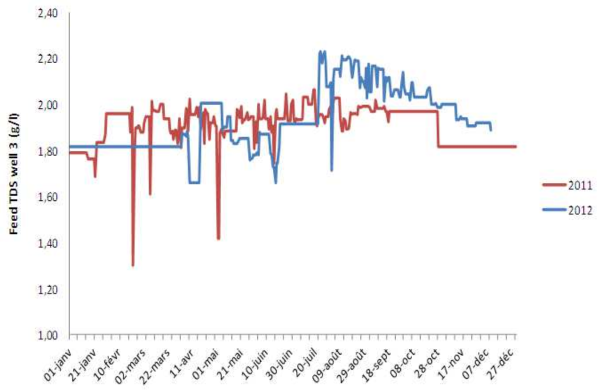
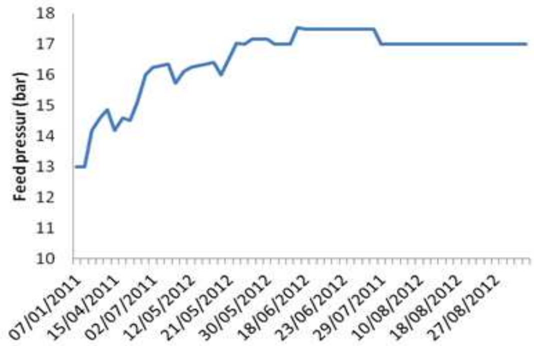


Figure 4: *TDS well 3*

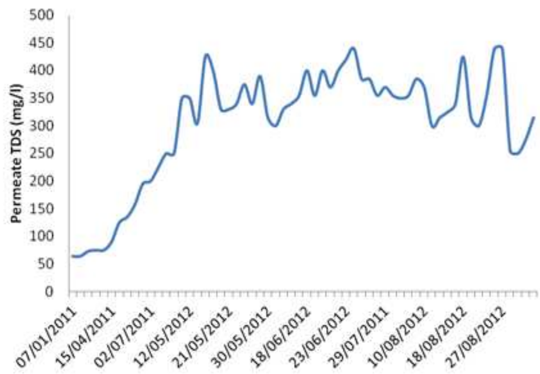
3.2. Performances of Reverse Osmosis Plant

To optimize the reverse osmosis plant performances of brackish water desalination for irrigation. The TDS of producer water, the permeate flow, and feed pressure were controlled continuously. Figure 5 (a, b and c) shows the variation of these parameters versus time.

a. The permeate variation



b. The Feed pressure variation



c. The permeate TDS variation

***Figure 5:** Performances of reverse osmosis plant versus time*

The analysis of the results shows that the permeate flow decreases progressively with the increase of the feed pressure, and the produced water TDS increases from 70 to 350 mg/l, the increases of the feed pressure was more significant from 13 to 17 bars.

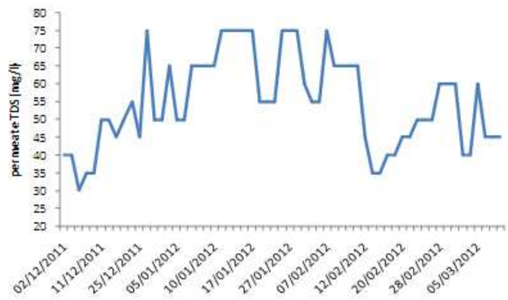
The first investigation, indicated that it might be a seriously membranes fooling. For this reason it was appropriate to establish a cleaning protocol of the membranes, to remove the fouling aspect. The disfunctioning noticed was linked to biological activity as well as the presence of oxidizing agents in raw water. Furthermore, the use of prechlorination would have caused an increased oxidizing power of water by adding the residual chlorine.

In order to overcome the abnormal dysfunction of the RO plant and to remedy definitely the origin of this disorder, three actions were undertaken:

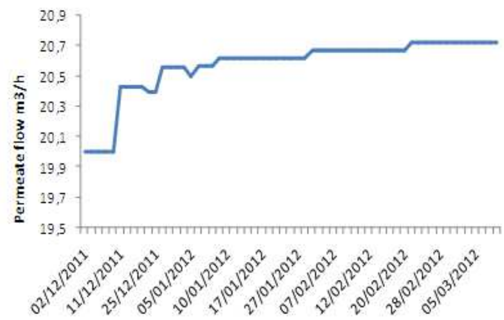
- Change the fouled membrane by osminics membranes AG8040F.
- Eliminate the chlorination step in pretreatment, to avoid the oxidation problem.
- Eliminate the sodium bisulfate from the pretreatment step, because it is used for the reduction of residual chlorine.

Figure 6 (a, b and c) groups together the evolution versus time of measured parameters such as permeate TDS, feed pressure and product flow.

a. Feed pressure variation



b. Permeate TDS variation



c. Product flow variation

***Figure 6:** Performances of reverse osmosis plant versus time*

The results show that the evolution of the permeate TDS have been remained above the required values 75 mg/l, with a feed pressure of 15 bar as recommended by the manufacturer of membranes. Also, the variation of the product flow was improved conforming to the characteristics of operation of the Doukkala desalination plant.

3.3. Economic Evaluation

Several factors affect the cost of reverse osmosis desalination plant [23]. The total cost of the plant consists of two terms: capital cost and operation/maintenance cost [24]. The Capital Cost includes all expenditures associated with the implementation for construction (equipment, piping, service utilities, etc.), engineering efforts, and administrative/financing activities.

The Operation and maintenance (O&M) costs consist of plant operation costs (energy, chemicals, replacement of consumables, and labor) and maintenance costs for plant equipment, buildings, and utilities. The O&M costs are typically expressed as either all operational expenditures per year (e.g., \$/y) or operational costs for desalinated product water per volume (e.g., \$/m^3) [25].

In this study case and in terms of the economic point of view, economical evaluation was done concerning the chemicals cost. Table 4 gives the cost of chemical pretreatment. The remove of Sodium hypochlorite and sodium metabisulfite from pretreatment step, cause the saving cost of 54 800 \$/year in operation unit cost.

Table 4: *Cost of chemical pretreatment*

Product	Cost \$/m^3	Cost \$/ yr
Sodium hypochlorite- NaCl	0.30	50 274
Sodium Metabisulfit- $NaHSO_3$	0.03	4 570
Antiscalant	0.57	95 297

4. Conclusion

In reverse osmosis desalination technology, the steep of pretreatment of feed water is very important issue and is the key of the RO plants operation success. The operations of the pretreatment phase are more complicated when raw water quantity and quality changes during seasons. Thus the designed pretreatment became improper and not enough to secure RO membrane.

In this paper, the performance evaluation of a brackish water desalination plant used for irrigation was carried out. The poor performances of the plant were mainly due to the risk of membranes damage, by the effect of chlorine injection. After modification of chemical pretreatment steps by canceling the chlorine and sodium bisulfate, the plant showed stable performances. A new control system is applied in the plant to predict any futures anomalies.

Furthermore, it is also important to investigate the influence of this water on the soil and its effects on the crop yields.

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