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Evaluation of the first seven years operating data of a RO brackish water desalination plant in Las Palmas, Canary Islands, Spain

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ABSTRACT

The present research describes the graphical evolution of the operating information of the first seven years. A study of the normalization and standardization of the information about the seven years of evolution of the plant for fixed feedwater conditions, operating pressure, and system recovery are also shown, so that the performance evaluation of the plan can be indicated correctly. From these results, it has been deduced that the compaction and fouling factor values and the average ionic permeability coefficients of the reverse osmosis (RO) membrane were utilized. Likewise, this paper describes the graphic evolution of the brine Langelier saturation index and Stiff and Davis stability index (actual and theoric values). The conclusions of this work and the operating experience are intended to get a practical and optimum design of RO brackish water desalination plants without using acid in the pretreatment and having a reasonable operating life between 7 and 8 years.

Keywords: Brackish water; Reverse osmosis; Desalination plants; Operating data; Normalization

1. Introduction

The Canary islands suffer a serious lack of water resources which is aggravated with time and includes cyclical drought periods. Even some farmers irrigate their crops with their own water produced either by brackish or seawater desalination. Then, in this case, the farmers have assumed in their production costs the price of this water coming from desalination. It is very important to know the performance in a long-term experience in the desalination plants in order to know the proper operating condition. This article constitutes a continuation of different works carried out by the authors [1–3].

The objectives of this work were:

(1) To indicate the graphical evolution of the operating data of this reverse osmosis (RO) brackish water (BW) desalination plant. Details of the evolution about the first seven years.

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(2) To show the evolution of the product flow and the salt rejection normalized by application of the American Society for Testing and Materials (ASTM) method [7]. The operating data of the 46 different samples of the feed, product, and reject water were used in this study (Table 1). To obtain the most accurate standardization, the standard conditions were closed to the average actual conditions (Sample 32).

Table 1
Operating conditions of the samples

Sample	Operating time (h)	Recovery (%)	SDI_a	pH_f	pH_r	Antiscalant type	Antiscalant dose (mg/l)
1	20.00	58.00	2.60	7.68	7.91	Vitec 3000	6
2	889.00	56.00	2.70	7.77	7.95	Vitec 3000	6
3	987.00	56.00	2.40	7.65	7.87	Vitec 3000	6
4	2,142.00	58.00	2.30	7.68	7.91	Vitec 3000	6
5	3,455.00	58.00	2.30	7.68	7.90	Vitec 3000	6
6	4,815.00	56.00	2.40	7.64	7.87	Osmotech1141	6
7	6,071.00	57.00	2.40	7.55	7.80	Osmotech1141	6
8	6,527.00	57.00	2.20	7.30	7.52	Osmotech1141	6
9	7,103.00	65.00	2.20	7.40	7.66	Osmotech1141	6
10	8,555.00	58.00	2.40	7.63	7.85	Osmotech1141	6
11	8,940.00	58.00	2.60	7.55	7.78	Osmotech1141	6
12	9,084.00	59.00	2.70	7.42	7.61	Osmotech1141	6
13	10,506.00	58.00	2.40	7.35	7.53	Osmotech1141	6
14	11,836.00	57.00	2.30	7.63	7.81	Osmotech1141	6
15	13,715.00	58.00	2.30	7.50	7.74	Osmotech1141	6
16	15,626.00	60.00	2.40	7.72	7.91	Osmotech1141	6
17	16,976.00	59.00	2.50	7.76	7.97	Osmotech1141	6
18	18,319.00	59.00	2.30	7.80	7.98	Osmotech1141	6
19	19,160.00	60.00	2.60	7.71	7.90	Osmotech1141	6
20	20,286.00	60.00	2.70	7.26	7.44	Osmotech1141	6
21	22,310.00	58.00	2.50	7.78	7.99	Osmotech1141	6
22	24,066.00	61.00	2.40	7.63	7.85	Osmotech1141	6
23	25,621.00	60.00	2.40	7.74	7.96	Osmotech1141	6
24	26,852.00	63.00	2.50	7.63	7.90	Osmotech1141	6
25	28,813.00	64.00	2.30	7.55	7.78	Osmotech1141	6
26	29,665.00	60.00	2.50	7.30	7.54	Osmotech1141	6
27	30,999.00	59.00	2.50	7.40	7.62	Osmotech1141	6
28	32,016.00	59.00	2.40	7.82	8.07	Osmotech1141	6
29	32,951.00	60.00	2.30	7.37	7.63	Osmotech1141	6
30	34,101.00	61.00	2.30	7.80	8.06	Osmotech1141	6
31	35,719.00	61.00	2.30	7.10	7.24	Osmotech1141	6
32	37,113.00	60.00	2.40	7.58	7.79	Osmotech1141	6
33	37,847.00	60.00	2.30	7.80	8.06	Osmotech1141	6
34	39,889.00	60.00	2.40	7.85	8.10	Osmotech1141	6
35	41,329.00	60.00	2.50	7.70	7.93	Osmotech1141	6
36	42,590.00	60.00	2.40	7.73	7.95	Osmotech1141	6
37	43,678.00	60.00	2.50	7.87	8.10	Osmotech1141	6
38	45,203.00	60.00	2.50	7.54	7.76	Osmotech1141	6
39	46,604.00	60.00	2.40	7.49	7.66	Osmotech1141	6
40	48,000.00	60.00	2.40	7.67	7.87	Osmotech1141	6
41	49,253.00	60.00	2.40	7.60	7.85	Osmotech1141	6
42	50,468.00	60.00	2.40	7.70	7.93	Osmotech1141	6
43	51,964.00	60.00	2.40	7.71	7.91	Osmotech1141	6
44	52,939.00	61.00	2.50	7.67	7.90	Osmotech1141	6
45	54,897.00	60.00	2.30	7.57	7.82	Osmotech1141	6
46	56,178.00	59.00	2.30	7.80	8.04	Osmotech1141	6

(3) Through the analysis of these samples, the real and theoric brine Langelier saturation index (LSI) and Stiff and Davis stability index (S&DSI) were computed to compare the different values (Figs. 7 and 8).

2. Procedure

The capacity of this RO BW desalination plant (Fig. 1) was 360 m^3/day and from June 2004 to April 2013, it was in operation with a LSI and S&DSI of about 2.3 and 1.7, respectively, without using acid in the pretreatment and only using Vitec 3000 [4] and Osmotech 1141 [5] antiscalant products. The RO system (1 pass 2 stages) was equipped with five pressure vessels. The arrangement was 3 + 2 and the number of elements by pressure vessels was 6. A total of 30 (18 + 12) Filmtec BW30-400 RO elements [6] were placed.

The present work describes the evolution and evaluation of the first seven years of operation. The operating conditions of any RO desalination plant such as

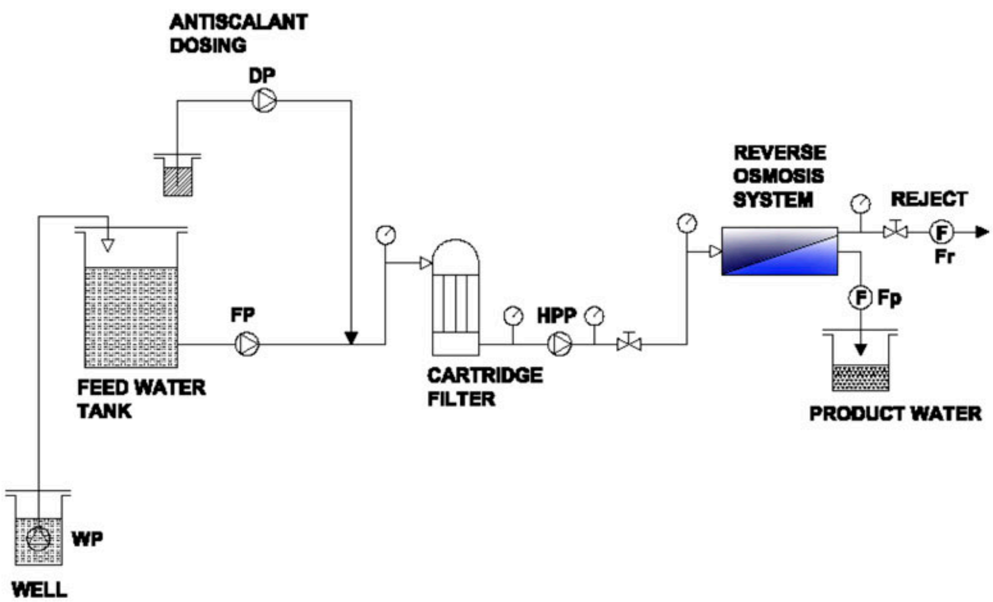

Fig. 1. Desalination plant diagram, where WP: well pump, FP: feed pump, DP: dosing pump, HPP: high pressure pump, F: flowmeter, Fr: rejection flow, and Fp: product flow.

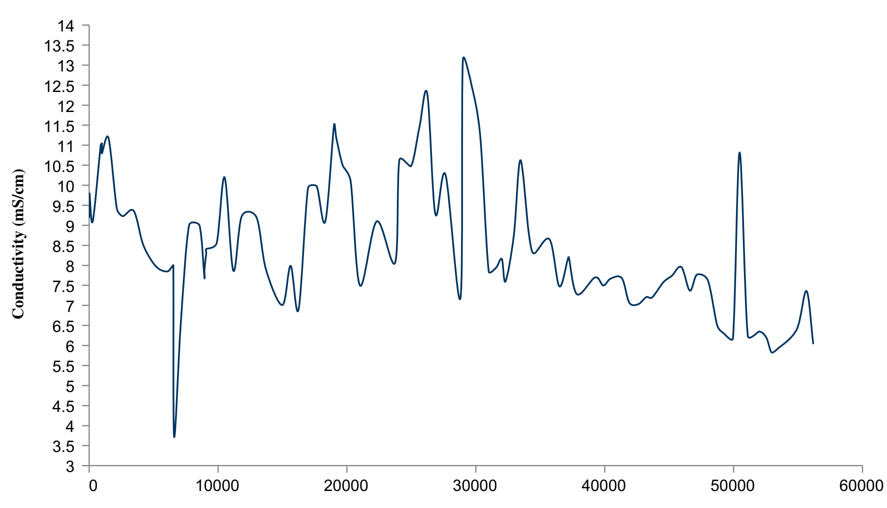

Fig. 2. Feedwater conductivity.

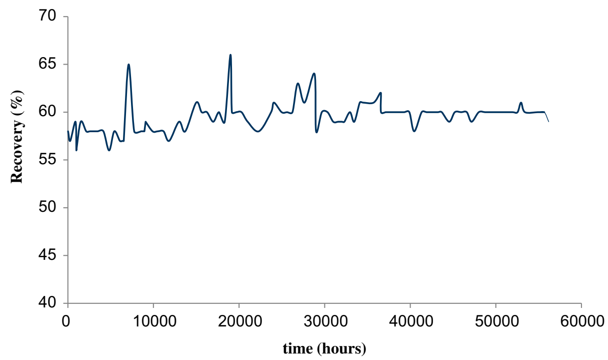

Fig. 3. System recovery.

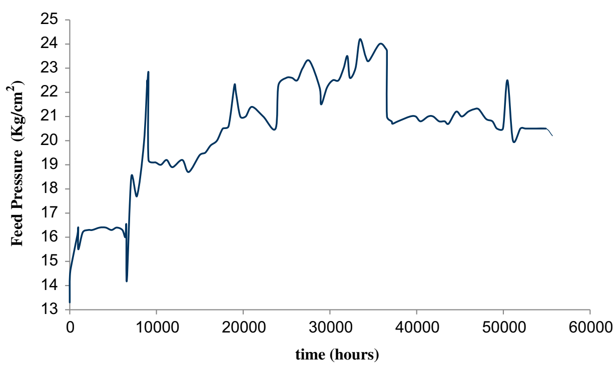

Fig. 4. Feed pressure.

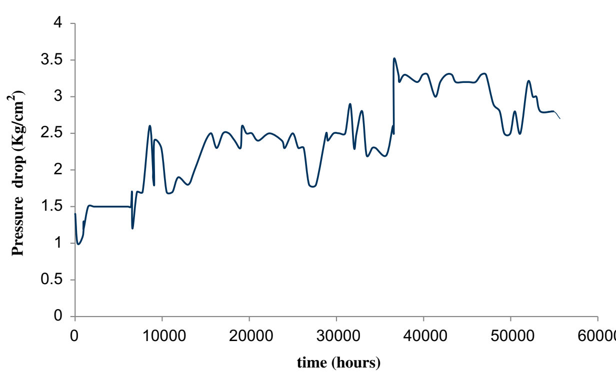

Fig. 5. Pressure drop.

pressure, recovery and feedwater can vary, causing permeate flow and salt rejection to change. Normally, the actual operating data are generated at different conditions (Figs. 2–5). To evaluate plant performance, it is necessary to compare permeate flow and salt rejection data at the same operating conditions (Figs. 6 and 7).

3. Results and discussions

All the information on which the graphs of the evolution of the operating parameters are based was obtained every month. Four graphs of the evolution of the plant through the first seven operating years are shown to indicate operating time (hours) vs. the performance of the following parameters:

- Fig. 2: Feedwater conductivity.
- Fig. 3: System recovery.
- Fig. 4: Feed pressure.
- Fig. 5: Pressure drop.

The method used for the standardizing RO performance data was the ASTM [7]. The main equations incorporated with this method are:

- Standardization of permeate flow

$$A = P_{fs} - \frac{\Delta P_{fbs}}{2} - P_{ps} - \mathrm{OP}_{fbs} + \mathrm{OP}_{ps} \tag{1}$$

$$B = P_{fa} - \frac{\Delta P_{fba}}{2} - P_{pa} - \pi_{fba} + \pi_{pa} \tag{2}$$

$$Q_{ps} = \frac{A \cdot \mathrm{TCF}_s}{B \cdot \mathrm{TCF}_a} \cdot Q_{pa} \tag{3}$$

- Standardizing salt passage

$$\%\mathrm{SP}_s = \left[\frac{\mathrm{EPF}_a}{\mathrm{EPF}_s}\right] \cdot \left[\frac{\mathrm{STCF}_a}{\mathrm{STCF}_s}\right] \cdot \left(\frac{C_{fbs}}{C_{fba}}\right) \cdot \left(\frac{C_{fa}}{C_{fs}}\right) \cdot \%\mathrm{SP}_a \tag{4}$$

As it can be seen from the corresponding graphs, the cycles of chemicals cleaning depended on the pressure increase or production decrease (5–10%). According to the membranes' manufacturer instructions [8], the following chemical products in solution with product water ($T = 22°C$) were used:

- Bioclean 511 (Alkaline) and Bioclean 103A (Acid).
- Osmotech 2691 (Alkaline) and Osmotech 2575 (Acid) [9].

The time used for chemical cleanings was 40 min in both cases. It was decided that to change the products which causes the performance of the chemical cleaning.

Forty-six representative samples of the plant evolution have been taken. The dose of antiscalant was same for both of the product utilized, 6 mg/l. The results obtained are shown in Figs. 6–9.

If we take into account the concentration polarization over the membrane surface, we will deduce that the brine LSI values of the last RO elements are between 2 and 2.7 as S&DSI is between 1 and 2.

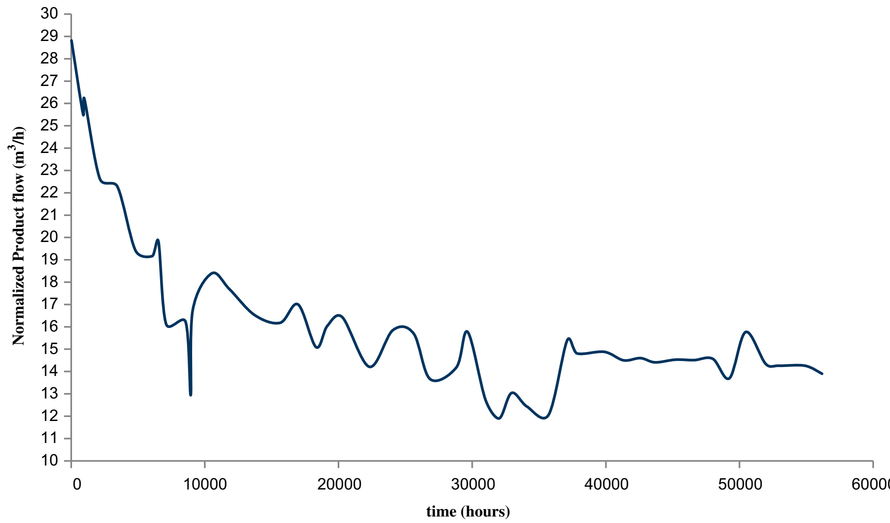

Fig. 6. Normalized product flow.

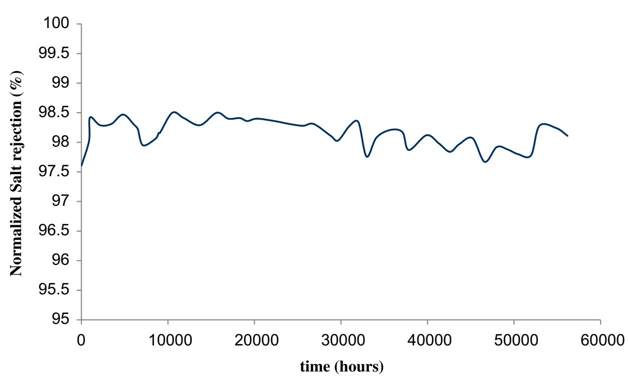

Fig. 7. Normalized salt rejection.

The results (Fig. 8) indicate a relation between theoric and real brine LSI and S&DSI values of about 5–13%. This relation is quite conservative to appear that the application of the theoric LSI and S&DSI values to design RO BW desalination plants will be a good practice [10,11].

From the results of the normalized product flow (Fig. 5), the following practical values of the compaction and fouling correction factor (CFCF) or fouling factor (FF) [8] or operating time factor F_t (Table 2) have been deduced.

Likewise, from the normalized salt rejection graph (Fig. 7), we can deduce that if some kind of physical or chemical degradation of the RO membranes or the RO modules does not exists, the salt rejection is almost constant along the operating time. From this

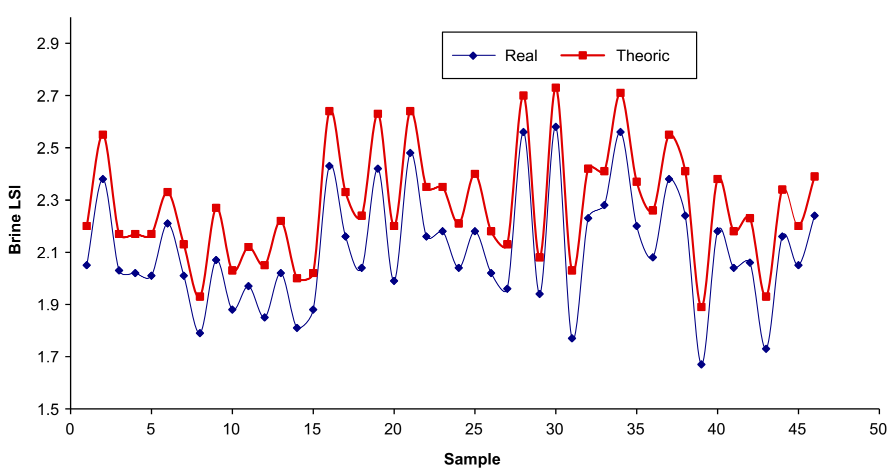

Fig. 8. Brine LSI.

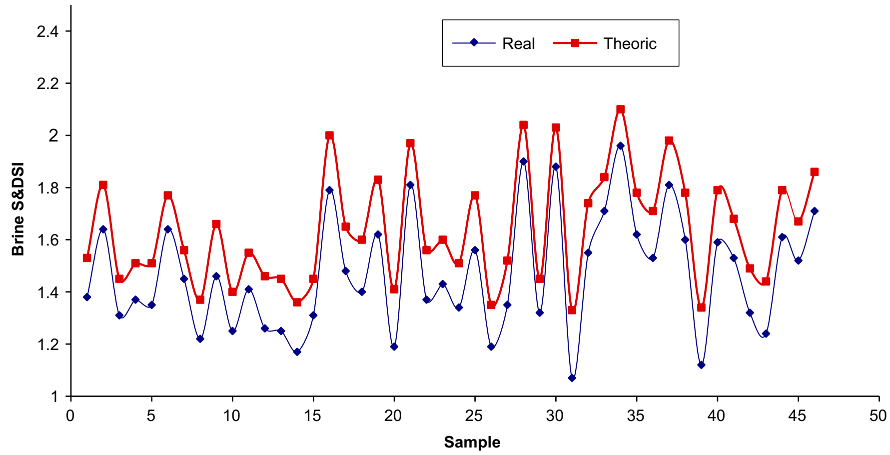

Fig. 9. Brine S&DSI.

Table 2
Operating time factor

Operating life	F_t
1	0.9
3	0.8
5	0.7
7	0.6

Table 3
Average ionic permeability coefficients at 25°C

Ion	Salt rejection (%)	Salt pass (%)	K_j (m/day)
Ca^{2+}	99.28	0.72	0.00275
Mg^{2+}	99.67	0.33	0.00123
Na^{2+}	97.39	2.61	0.00989
K^+	95.49	4.51	0.01701
HCO_3^-	98.64	1.36	0.00517
SO_4^{2-}	99.82	0.18	0.00068
NO_3^-	90.57	9.43	0.03585
Cl^-	98.18	1.82	0.00689
SiO_2	99.33	0.67	0.00254

work, we have deducted the average ionic permeability coefficients at 25°C (K_j) [8] from the RO membrane utilized (Table 3).

The previous values (Tables 2 and 3) will be useful to design the RO system using spiral wound RO elements similar to the type FT 30 considered.

4. Conclusions

The normalized product flow and salt rejection of the plant appear to indicate a normal level of compaction and a stability of the membrane performance vs. time. It seems clear that a more than seven years operating life is a reasonable projection for these operating conditions and for this BW30-400 RO element. These RO systems with little maintenance can offer the guarantee of a continuous operation with a long-time limit and with a minimum deterioration of its operational characteristics.

Symbols

BW, bw	—	brackish water
C_f	—	feed concentration (mg/l NaCl)
C_{fb}	—	feed-brine concentration (mg/l NaCl)
CFCF	—	compaction and fouling correction factor
FF	—	fouling factor (idem CFCF)
F_t	—	operating time factor (idem CFCF)
K_j	—	average ionic permeability coefficients at 25°C
LSI	—	Langelier saturation index
OP_{fb}	—	feed-brine osmotic pressure (kPa)
OP_p	—	permeate osmotic pressure (kPa)
P_f	—	feed pressure (kPa)
P_p	—	permeate pressure (kPa)
PD_{fb}	—	feed-brine pressure drop (kPa)
Q_p	—	permeate flow
RO, ro	—	reverse osmosis
SDI	—	silt density index
SP	—	salt passage
T	—	feed water temperature (°C)
TCF	—	temperature correction factor

Subscripts

a	—	actual (real) conditions
b	—	brine
f	—	feed
p	—	product, permeate
r	—	reject
s	—	standard conditions
i,j	—	ion/component

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