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

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ABSTRACT

The RO brackish water desalination plant described in this paper has been operating from June 2004 without using acid in the pretreatment and only using antiscalants during 75.000 h with the same RO elements. The present research describes the graphical evolution of the operating information of the first nine years. A study of the normalization and standardization of the information about the nine 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 plant can be indicated correctly. From these results it has been deduced the compaction and fouling factor values, and the average ionic permeability coefficients of the RO membrane 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 study 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 9 and 10 years.

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

1. Introduction

Reverse osmosis (RO) is a widely accepted and applied process for the purification of a variety of raw water sources, especially when there is a need for removing the bulk of the dissolved salts and other impurities present in the feed streams. The long-term success of a small RO brackish water (BW) desalination plant depends, among other factors, on proper operation and maintenance of the system. Usually in Canary Islands the risk of silica fouling is the limiting factor in maximizing recovery on systems with high silica concentrations in the feed waters. Darton [1] published RO plant experiences with high silica water

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Table 1
Operating conditions of the samples

Sample	Operating time (h)	Recovery (%)	SDI_f	pH_f	pH_r	Antiscalant type	Antiscalant dose (mg/l)
1	20.00	58.00	2.60	7.68	7.91	Vitec 3,000	6
2	889.00	56.00	2.70	7.77	7.95	Vitec 3,000	6
3	987.00	56.00	2.40	7.65	7.87	Vitec 3,000	6
4	2,142.00	58.00	2.30	7.68	7.91	Vitec 3,000	6
5	3,455.00	58.00	2.30	7.68	7.90	Vitec 3,000	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
47	57,576.00	63.00	2.50	7.75	8.18	Osmotech1141	6
48	60,571.00	61.00	2.60	7.31	7.72	Osmotech1141	6
49	62,228.00	62.00	2.50	7.87	8.29	Osmotech1141	6
50	63,677.00	61.00	2.60	7.74	8.15	Osmotech1141	6
51	65,265.00	62.00	2.50	7.73	8.14	Osmotech1141	6

(*Continued*)

Table 1 (*Continued*)

Sample	Operating time (h)	Recovery (%)	SDI_f	pH_f	pH_r	Antiscalant type	Antiscalant dose (mg/l)
52	66,080.00	60.00	2.30	7.56	7.96	Osmotech1141	6
53	66,852.00	60.00	2.30	7.62	8.02	Osmotech1141	6
54	67,751.00	60.00	2.40	7.55	7.94	Osmotech1141	6
55	68,063.00	61.00	2.50	7.63	8.03	Osmotech1141	6
56	69,144.00	60.00	2.50	7.66	8.05	Osmotech1141	6
57	69,702.00	60.00	2.30	7.72	8.12	Osmotech1141	6
58	71,261.00	59.00	2.50	7.71	8.10	Osmotech1141	6
59	72,221.00	60.00	2.30	7.64	8.03	Osmotech1141	6
60	73,048.00	60.00	2.40	7.67	8.06	Osmotech1141	6
61	73,956.00	60.00	2.40	7.82	8.21	Osmotech1141	6
62	74,811.00	60.00	2.30	7.45	7.85	Osmotech1141	6

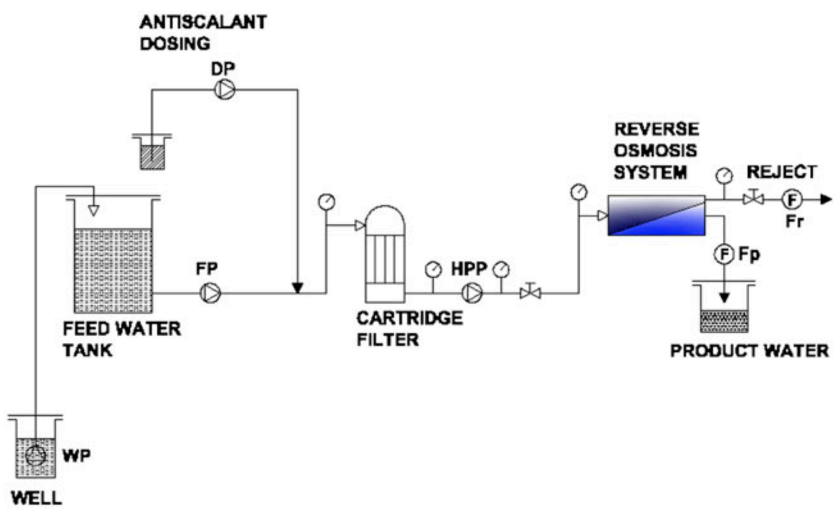

Fig. 1. Desalination plant diagram, where WP, well pump; FP, feed pump, DP, dosing pump; HPP, hight pressure pump; F, flowmeter; Fr, rejection flow; Fp, product flow.

in the Canary Islands but focusing on the silica fouling issue. The following paper will evaluate the 9 years of operating data and membrane performance of elements constituting a continuation of different works carried out by the authors [2–4].

The objectives of this work were:

(1) To indicate the graphical evolution of the operating data of this RO BW desalination plant. Details of the evolution about the first nine years.
(2) To show the evolution of the normalized product flow and the salt rejection by application of the American Society for Testing and Materials (ASTM) method [5]. The operating data of the 62 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 close to the average actual conditions (Sample 32).

Table 2
Feed water composition

	Concentration range (mg/l)
Ca^{2+}	85.17–336.47
Mg^{2+}	111.39–467.43
Na^{+}	635.90–2,319.92
K^{+}	17.99–79.37
HCO_3^-	505.25–1,041.61
SO_4^-	254.11–1,177.82
NO_3^-	30.38–423.46
Cl^-	1,017.35–3,344.94
SiO_2	27.50–44.00
TDS	3,600.02–7,790.76

(3) Through the analysis of these samples the actual and theoric brine LSI and S&DSI were computed to compare the different values (Figs. 7 and 8).

2. Plant description and characteristics

The capacity of this RO BW desalination plant (Fig. 1) was 360 m^3/d and from June 2004 to February 2015 it is in operation with a Langelier saturation index (LSI) and Stiff and Davis stability index (S&DSI) of about 2.3 and 1.5, respectively, without using acid in the pretreatment and only using Vitec 3,000 [6] and Osmotech 1,141 [7] 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 six. The element used was Filmtec BW30–400 RO [5]. The raw water composition is shown in Table 2.

The operating conditions of any RO desalination plant such as pressure, recovery, and feedwater conditions can vary, causing permeate flow and salt rejection to change. Usually the actual operating data are generated at different conditions Figs. 2–6, so that, to evaluate plant performance, it is necessary to compare permeate flow and salt rejection data at the same operating conditions (Figs. 7 and 8).

3. Results and discussion

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

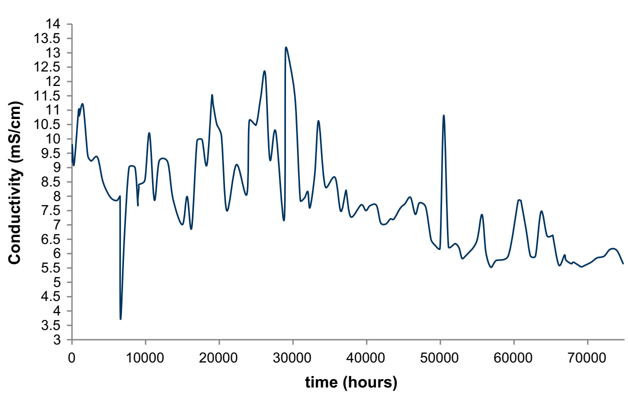

Fig. 2. Feedwater conductivity.

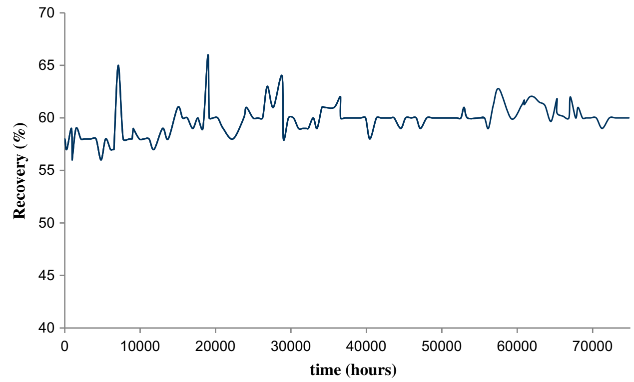

Fig. 3. System recovery.

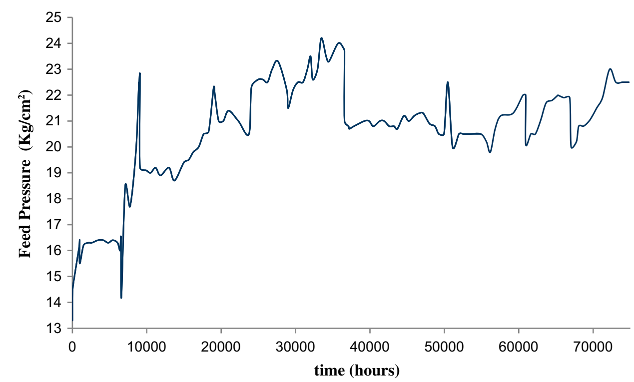

Fig. 4. Feed pressure.

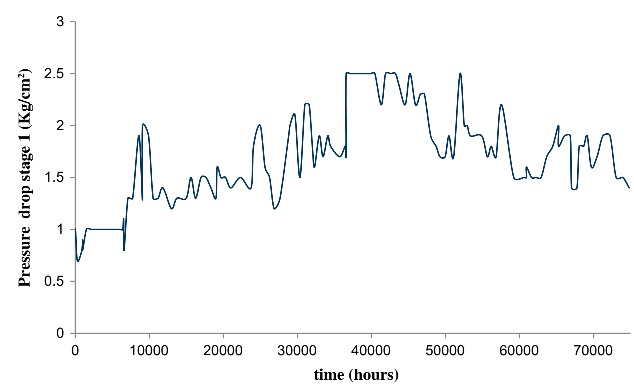

Fig. 5. Pressure drop stage 1.

- Fig. 2: Feedwater conductivity.
- Fig. 3: System recovery.
- Fig. 4: Feed pressure.
- Fig. 5: Pressure drop stage 1.
- Fig. 6: Pressure drop stage 2.

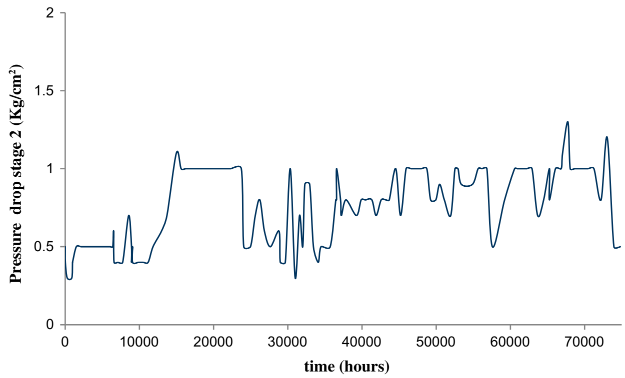

Fig. 6. Pressure drop stage 2.

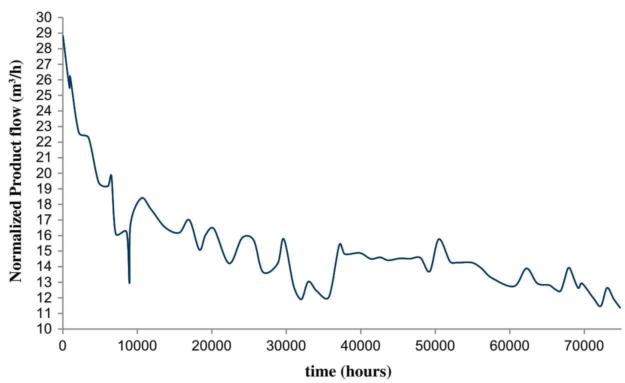

Fig. 7. Normalized product flow.

The method used for the standardizing RO performance data was the ASTM [8]. The main equations incorporated with this method are:

Standardization of Permeate Flow

$$A = P_{fs} - \frac{\Delta P_{fbs}}{2} - P_{ps} - OP_{fbs} + OP_{ps} \qquad (1)$$

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

$$Q_{ps} = \frac{A \cdot TCF_s}{B \cdot TCF_a} \cdot Q_{pa} \qquad (3)$$

Standardizing salt passage

$$\% \, SP_s = \left[\frac{EPF_a}{EPF_s}\right] \cdot \left[\frac{STCF_a}{STCF_s}\right] \cdot \left(\frac{C_{fbs}}{C_{fba}}\right) \cdot \left(\frac{C_{fa}}{C_{fs}}\right) \cdot \% \, SP_a \qquad (4)$$

As it can be seen from the corresponding graphs, the cycles of chemical cleaning depended on the pressure increase or production decrease (5–10%). According to the membranes manufacturer instructions [9], the following chemical products in solution with product water ($T = 22$°C) were used:

- Bioclean 511 (Alkaline) and Bioclean 103A (acid).
- Osmotech 2,691 (Alkaline) and Osmotech 2,575 (Acid) [10].

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

Sixty-two representative samples of the plant evolution have been taken. The dose of antiscalant was the same for both products utilized 6 mg/l. The results obtained are shown in Figs. 7–10.

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 between 1 and 2.

The results (Figs. 9 and 10) 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 [11,12].

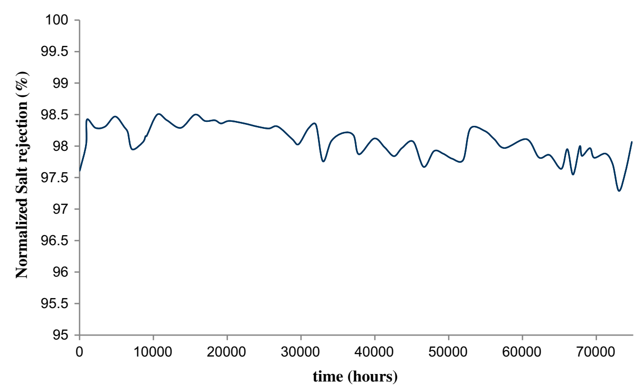

Fig. 8. Normalized salt rejection.

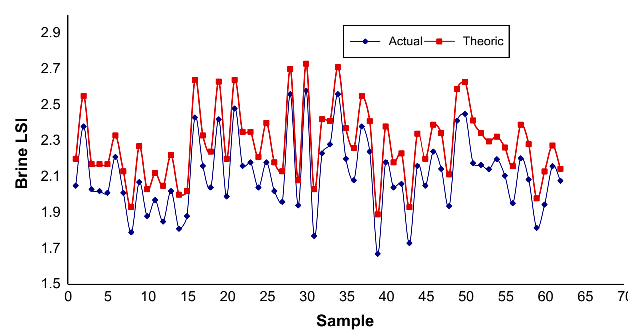

Fig. 9. Brine LSI.

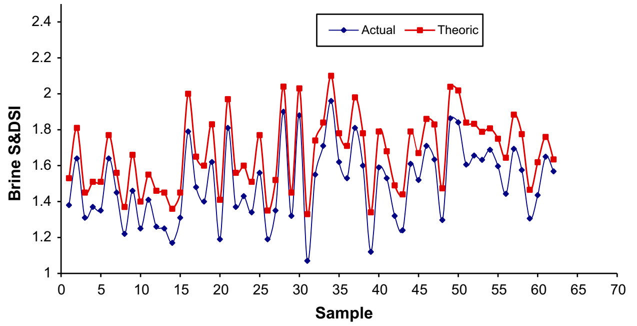

Fig. 10. Brine S&DSI.

From the results of the normalized product flow (Fig. 7), the following practical values of the compaction and fouling correction factor (CFCF) or fouling factor (FF) [5] or operating time factor F_t (Table 3) has been deduced.

Likewise, from the normalized salt rejection graph (Fig. 8), we can deduce that, some kind of physical or chemical degradation of the RO membranes or the RO modules exists or not, the salt rejection is almost constant along the operating time. From this work we have deducted the average ionic permeability coefficients at 25°C (k_j) [9], of the RO membrane utilized (Table 4).

Table 3
Operating time factor

Operating life	F_t
1	0.9
3	0.8
5	0.7
7	0.6
9	0.5

Table 4
Average ionic permeability coefficients at 25°C

Ion	Salt rejection (%)	Salt pass (%)	k_j (m/d)
Ca^{2+}	99.30	0.70	0.00269
Mg^{2+}	99.69	0.31	0.00118
Na^{2+}	97.27	2.73	0.01038
K^{+}	95.52	4.48	0.01696
HCO_3^-	98.64	1.36	0.00518
SO_4^-	99.80	0.20	0.00076
NO_3^-	90.74	9.26	0.03532
Cl^-	98.05	1.95	0.00739
SiO_2	99.32	0.68	0.00259

The previous values (Tables 3 and 4) 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 versus time. It seems clear that more than 9–10 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 of deterioration of its operational characteristics.

Acknowledgments

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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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