Desalination and Water Treatment
www.deswater.com

51 (2013) 307–317
January

Taylor & Francis
Taylor & Francis Group

doi: 10.1080/19443994.2012.713565

More efficient production line with Desalination plants using reverse osmosis

José Feo[a,*], J. Jaime Sadhwani[b], Luis Alvarez[c]

[a] *Electronic and Automatic Engineer Department, University of Las Palmas de Gran Canaria, Spain*
Tel. +34 928451963; Fax: +34 928457319; email: jfeo@diea.ulpgc.es
[b] *Process Engineer Department, University of Las Palmas de Gran Canaria, Spain*
[c] *Physics Department, University of Las Palmas de Gran Canaria, Spain*

Received 14 March 2012; Accepted 15 July 2012

ABSTRACT

We introduce the present article with the intention to define the most efficient production line for reverse osmosis seawater desalination plants. We show the relationship between the cost of desalinated water per cubic meter according to the production capacity, verifying a scale economy as the production rises significantly. The destination of this article is within the reach of small desalination plants in the range between 500 and 15,000 m^3/day in the Canary Islands Autonomous Community. Specified range is the most established in the Autonomous Community. Approximately, more than about the 90% of the desalination plants have a production capacity corresponding to the selected range. The methodology used consists of calculating each one of the costs involved in the seawater desalination process, applying actual prices, and obtaining a graphic serial according to prices tolerance, from −5% to a value of +5%. Concerning staff costs, we have recovered data from the iron and steel industrial sector collective agreement of the Autonomous Community. In our article, we present all the elements that directly affect each one of the costs, equations, and formula based on factors affecting each one of them, with actual market prices in the Autonomous Community of Canary Islands, making all calculations and obtaining a family of costs graphics for each one. As an innovative and original article, we present the real costs for small desalination plants, in between the said range. We also present a new cost, to bear in mind, according to current regulations, which is the environmental cost, based, among other things, in solving the problem of brine spills directly into the sea. Cost has been calculated based on the introduction of a new machinery and canalization to reduce the before mentioned environmental impact. Lastly, this article, as a final result, presents the total value of the cost in €/m^3 with the results and graphics for each plant between the before established range in the Canary Islands, obtaining according to them, the most efficient production line. We present the results based on a small fluctuating scale economy. Our article presents costs results in order to be able to select the most convenient production line in each case, based on the production capacity and on the several own factors of each individual cost. The aim of our work is to study the influence of the fouling factor and temperature according to the desired production (500–15,000 m^3/day) on the cost in €/m^3. Based on it, we study the operational and functional costs searching for the production line with the best efficiency.

Keywords: Reverse osmosis; Unit costs; Canary Islands; Desalination; Operating parameters

---

*Corresponding author.

Presented at the International Conference on Desalination for the Environment, Clean Water and Energy, European Desalination Society, April 23–26, 2012, Barcelona, Spain

1. Reverse osmosis seawater desalination in Canary Islands

Canary Islands is pioneers in desalination process in Spain. In fact, the first seawater desalination plant in Canary Islands and Spain was installed in Lanzarote in 1964. The plant produced 2.500 m^3/day of drinking water, although it used the technological process M.S.F.

Canary Islands is the Autonomous Community with the biggest water production capacity by using reverse osmosis desalination, absorbing in 2004 the 38% of the totally installed capacity of the country, far ahead of the capacity in Andalucia, which is close to 14.5%. After that they follow the communities of Valencia and Murcia with a 14 and 13.5%, respectively, while the plants existing in Balearic Islands cover less than 10% of the total desalination capacity [1].

It was precisely in this decade when, thanks to the development of technology, great steps forwards were obtained and, as a result of it, were never known before boom. The reverse osmosis technology has been greatly developed during this time. Particularly, in Canary Islands, which have served as a model for the rest of the Spanish territory, more than 95% of the desalinated water uses the reverse osmosis process (Fig. 1).

2. M^3 desalinated water cost analysis by reverse osmosis

In this section, we go through all events happened during the last years in relationship with the reverse osmosis water desalination and the impact in the m^3 cost due to the installation design factors.

In 2001, in Spain, the government of Aragon publishes an article stating the Desalination as an alternative to the National Hydrological Plan. In the said article it is commented that, for 2010, the cost of reverse osmosis desalinated water could be around 0.36–0.39 €/m^3 [3].

In 2001, Andreas Poullikkas concludes an article by estimating a worldwide cost of 0.44 €/m^3 [4].

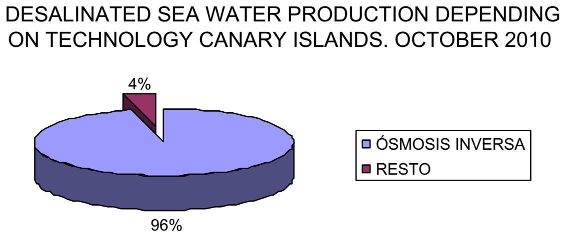

Fig. 1. Desalinated seawater production in Canary Islands [2].

Also in the same year, D. Prats Rico and M.F.Chillón reveal that the cost of the electric part could be around 0.19–0.22 €/m^3 [5].

In 2002, the magazine "Agricultura" presents an article by María Amparo Melián Navarro and José María Cámara Zapata about the desalination techniques and costs, stating that during 2001 the cost of reverse osmosis desalinated seawater was around 0.42 and 0.84 €/m^3 [6].

In 2002, the magazine Desalination, in its number 142, publishes an article by S.A. Avlomitis, with a study of the costs of reverse osmosis desalinated seawater in small plants of the Greek Islands and four different places elsewhere. He reaches the conclusion that, in the best case, the cost is of 0.6 \$/m^3 and refers slightly to the Canary Islands where the cost for a plant of 36,000 m^3/day is said to be around 1.62 \$/m^3 [7–10].

In 2002, the magazine Desalination publishes an article by Azza Hafez and Samir El-Manharawy in which they study an approximation to the costs of desalinated seawater for the region of the Red Sea in Egypt. In the best case, their estimation results in a value of 0.86 \$/m^3 [11–16].

It was during the year of 2002 when costs studies are finally presented through a Doctoral Thesis done by Mr. David Martinez Vicente. In that thesis, he studies the costs of desalination with reverse osmosis in big plants, from 10.000 to 140.000 m^3 of desalinated water production, considering an energy consumption of 4.4 kWh/m^3 and a cost of 4 cents€/kW. The author, based on data of different desalination plants in Spain and on his own investigation proved in his thesis which shows us that total costs for plants producing 10.000 m^3 could be around 0.5576–0.6276 €/m^3 depending on the source of water (well or direct source) [17].

For the plants with productions of 140,000 m^3 of desalinated waters, the values fluctuate between 0.4095 and 0.4678 €/m^3 depending on the source of water (well or direct source).

In 2004, during the Water Management and Planning Iberian Congress comments talk about the cost of desalinated water in Spain near the 0.53 €/m^3 [18].

In 2005, the magazine Desalination publishes an article by Wilf M. And Bartels C. in which it is shown that the boosting pumps efficiency has to be around 88%, the Pelton turbines and interchangers should be around 94%, and electrical engines near the 96% [19].

In November 2006, the company Acciona publishes an article by Luis Catilla, General Manager of Acciona Agua, in which he presents a graphics serial related to the cost of desalination, reaching the conclusion that the costs of desalinated water are around 0.4–0.8 €/m^3 [20].

In 2008, the magazine Desalination publishes an article by Akili D. Khawaji, Ibrahim K. Kutubkanah, and Jong-Mihn Wie talking about the advances in new technologies in seawater desalination. More specifically, they comment on the improvement in the membranes production technologies and the introduction of energy recovery systems. For them, the cost of seawater desalination by reverse osmosis is around 0.53 €/m^3 [21].

Also in 2008, the same magazine publishes an article by Salah Friouri and Rabah Oumeddour in which it is stated that the cost can reach 1.81 €/m^3 in the case of the reverse osmosis technology [22].

In 2009, the magazine Desalination publishes an article by Catherine Charcosset based on a revision of the desalination process membranes using renewable energy. In the said article, it is commented that the reverse osmosis requires, in particular, between 3 and 10 kWh/m^3 of electrical energy for drinking water production and that the conversion factor fluctuates between 25 and 45% [23].

In the last two years, 2010 and 2011, the realized studies show a cost of 0.4 €/m^3 for big desalinating plants.

As we may have analyzed, all studies carried out up to now refer to big desalinating plants. Therefore we have presented this work, in which we have studied plants within a production range from 500 to 15,000 m^3/day, the range to which more than 90% of the reverse osmosis desalinating plants in the Canary Islands belongs to. It is important to state that the tendency in the Canary Islands of building up small sized desalinating plants is due to the fact of the existence of many gullies in the landscape, spreading many small population areas quite far from each other.

3. Methodology and calculation hypothesis

3.1. Applied methodology

The used methodology is based on the costs distribution in fixed and variables costs. By making an initial study of the said costs, we considered as fundamental for the study the influence of the energetic factor in the total cost, which is why we decided to study the energetic cost separated from the other costs. We divided the variables into two groups attending to the fact that they were part of the plant design conditions or part of the different combinations used in the study. The first group correspond to the pressure and salinity. The second group correspond to temperature, fouling factor, percentage of conversion, and production. Herewith, we show Fig. 2, which served as basis for the study

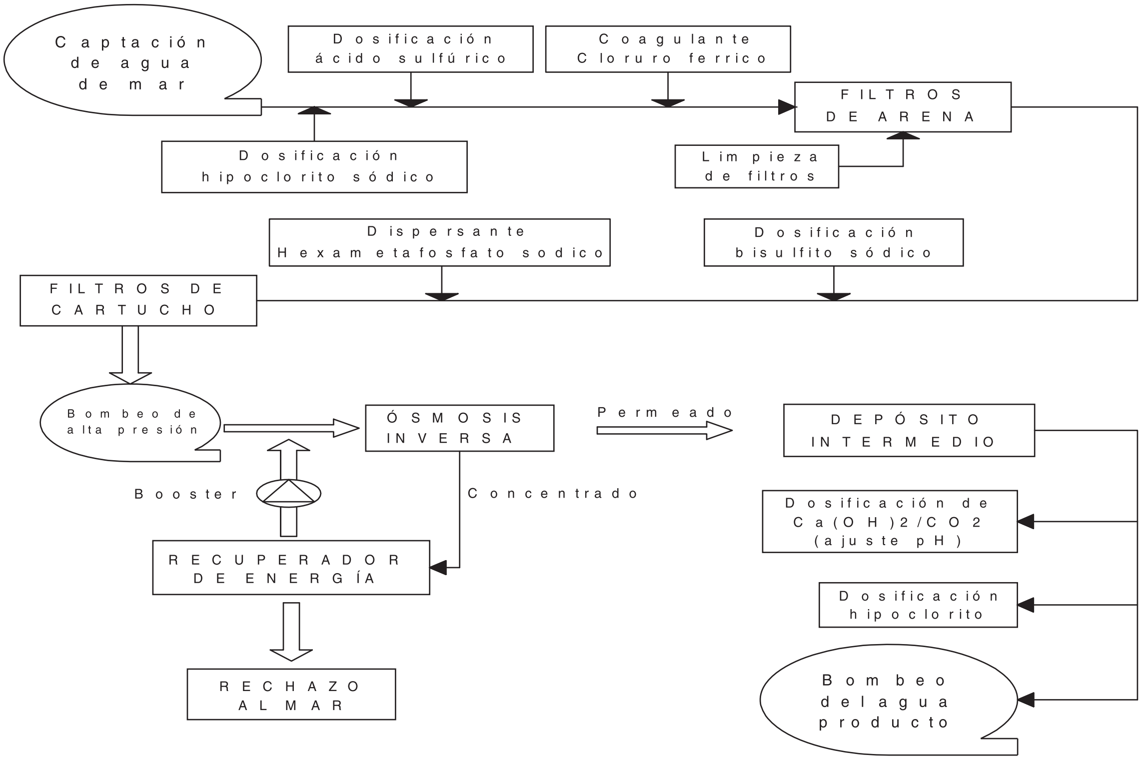

Fig. 2. Basic scheme of the desalinating plant.

of the costs of seawater desalination by reverse osmosis.

3.2. Calculation hypothesis

As stated, the calculation hypothesis is based on two well-differentiated studies, considering their influence in the total cost per m^3. On that basis, we comment on the hypothesis.

3.2.1. Energetic cost

From all the phases involved in energetic consumption, the reverse osmosis process is the one showing a bigger consumption. For the calculation of the high pressure pump and the boost pump and both consumptions, we have used two software programs, ROSA version 7.2.1 [24] and Excel spreadsheet of the manufacturer ERI-PX. Based on the software and several steps depending on the different combinations, we have obtained the values for power and consumption for each one of them.

With the help of the software program ROSA, we obtain the results for pressure, salinity, energetic consumption without ERI, etc. which will allow us to define the right point for each production.

It is important to comment that this software has allowed us to work, maximum, with eight membranes for each pressure box. The different alternatives studied affect the fouling factor value (0.85–1), the temperature (19, 20, or 21 ˚C), the conversion factor (42 or 45%), and the production (500, 1,000, 2,000, 5,000, 7,500, 10,000, 12,000, or 15,000 m^3/day).

We have obtained an average of 20 different options depending on the quantity of membranes per each combination, throwing a result of 1920 different options in the work.

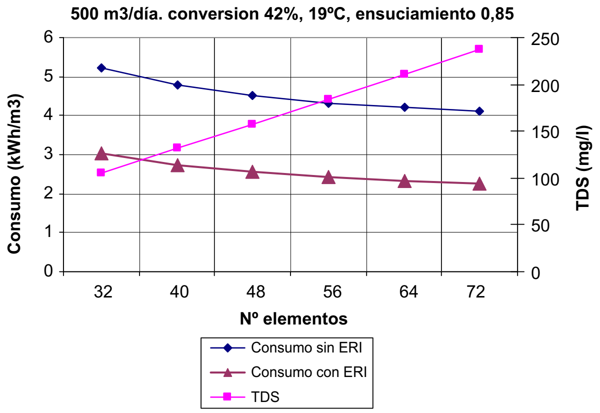

Fig. 3. Energetic consumption against TDS.

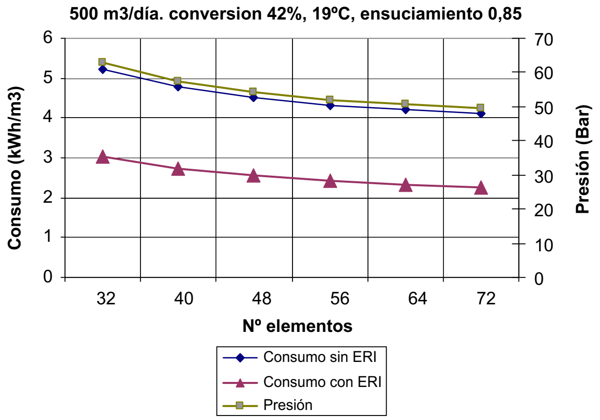

Fig. 4. Energetic consumption against pressure.

For each of the 96 combinations, we have obtained the following results showed in the graphics of salinity TDS and pressure against energetic consumption, not introducing and introducing the energy recovery system, which shows a total of 192 graphics. As an example, we present two types of graphics for a better explanation of it (Figs. 3 and 4).

For each of the different options, which correspond to a specified number of elements or membranes, we have introduced in each case an energy recovery system adopting a value of 80% of the output of all the machineries.

3.2.2. Rest of costs

Costs affecting this section are amortization, reagents consumption, cartridge filters replacement, membranes replacement, staff, maintenance, and environmental costs.

For said costs, hypothesis is based on calculating each one of the costs for each one of the combinations.

For each one of the combinations we have studied the total costs so that we can obtain throughout this investigation the most efficient production line.

3.3. Costs description

3.3.1. Investment cost/amortization

To begin with the study of the investment cost, we have divided the cost of the process of the reverse osmosis seawater desalination into 10 sections, corresponding to six phases of the desalination process, with one phase of different components, one phase of electrical installation which include the low voltage and the high voltage installations, one phase for the water pumping to consumers installation, and one phase dedicated to permits, terrain obtaining and civil works. We have included all what is necessary in order to put the plant into working conditions. All these phases include the calculations of all the pumps, canalizations, tanks, pressure groups, filters, high pressure group, membranes, energy recovery system, as well as a small amount of components such as different gages for measuring flow, pressure, and temperature.

All equipments, strictly calculated in this section, meet the requirements and performances of pressure, salinity, flow, temperature, conversion, and fouling factor based on the different combinations made in this study.

Once we have obtained, for each of the combinations, the total cost of investment, we studied the amortization cost, for an interest rate of 4.5% and 15 years as amortization period, according to banks in the Canary Islands Autonomic Community.

3.3.2. Reagents consumption cost

The methodology used to calculate the cost of reagents, for the pretreatment and the posttreatment, is based on an initial calculation of the average dosage and price per kilo of each reagent, actualized to January 2012, and on a second calculation to obtain the needed quantity of each product and, finally, we make the initial analysis of the cost in €/m^3.

Let us have a look at Table 1, which shows the average dosage in mg/l of each chemical reagent and its price in €/kg.

Secondly, we present Table 2 with the detailed quantities per year, in kilograms, of each of the reagents. For this calculation we have considered a 97.5% yearly working time, i.e. 356 days.

Based on the above figures, we will calculate the cost of each chemical reagent per m^3 and for each of the combinations flow—conversion factor.

3.3.3. Cartridge filters replacement cost

In order to calculate the cost of replacement of the cartridge filters, we calculate the flow, Q, in m^3/day, obtained depending on the initial flow of production of the plant and the conversion factor, all expressed in m^3/h.

Once defined the flow Q to work with, we define the normal operating flow, design factor given by the cartridge model (for each simple cartridge of 250 mm corresponds 10 l/min), which corresponds to 0.6 m^3/h.

For this work we have considered a cartridge filter to be divided in five simple cartridges. The main cartridge is 1,250 mm long incorporating five simple cartridges of 250 mm each.

Based on it, we calculate the number of cartridges of 1,250 mm and, therefore, the replacement cost of cartridge filters.

3.3.4. Membranes replacement cost

For our work we have chosen the membranes manufacturer DOW, who supplies membranes under the trade mark FILMTEC and with the following characteristics:

Membrane type	SW30HR LE-400
Material	Aromatic polyamide (TFC)
Configuration	Spiral winding
Nominal production flow (m^3/day)	28
Minimum salt rejection	99.6%
Maximum operational pressure (bar)	83
Maximum operational temperature	45°C

To calculate this cost we have estimated in all cases a yearly membranes replacement percentage of 7%, according to the manufacturer.

To select the number of membranes, we based our calculations on the membrane nominal production which, as we stated, is 28 m^3/day.

Table 1
Reagents dosages

Chemical reagents in pretreatment	mg/l	Average value (mg/l)	Price (€/kg)
Sulfuric acid (H_2SO_4)	20–30	25	0.13
Ferric chloride—coagulant (Cl_3Fe)	3–7	5	0.24
Sodium hypochlorite (NaOCl)	2–6	4	0.19
Sodium bisulfite ($NaHSO_3$)	2–7	4.5	0.6
Sodium hexa meta phosphate—disperser $(NaPO_3)_6$	3–6	4.5	0.45
		Average value (mg/l)	
Sodium hypochlorite (NaOCl)	0.4–0.6	0.5	0.19
Carbon dioxide (CO_2)	30–40	35	0.14
Lime $Ca(OH)_2$	22–42	32	0.05

Table 2
Total reagents quantities

Yearly quantities in kilos for each product									
Caudal (m^3/día)	F.C. (%)	Pretreatment					Posttreatment		
		H_2SO_4	Cl_3Fe	NaOCl	$NaHSO_3$	$(NaPO3)_6$	NaOCl	CO_2	$Ca(OH)_2$
500	42	10,595.24	2,119.05	1,695.24	1,907.14	1,907.14	89.00	6,230.00	5,696.00
500	45	9,888.89	1,977.78	1,582.22	1,780.00	1,780.00	89.00	6,230.00	5,696.00
1,000	42	21,190.48	4,238.10	3,390.48	3,814.29	3,814.29	178.00	12,460.00	11,392.00
1,000	45	19,777.78	3,955.56	3,164.44	3,560.00	3,560.00	178.00	12,460.00	11,392.00
2,000	42	42,380.95	8,476.19	6,780.95	7,628.57	7,628.57	356.00	24,920.00	22,784.00
2,000	45	39,555.56	7,911.11	6,328.89	7,120.00	7,120.00	356.00	24,920.00	22,784.00
5,000	42	105,952.38	21,190.48	16,952.38	19,071.43	19,071.43	890.00	62,300.00	56,960.00
5,000	45	98,888.89	19,777.78	15,822.22	17,800.00	17,800.00	890.00	62,300.00	56,960.00
7,500	42	158,928.57	31,785.71	25,428.57	28,607.14	28,607.14	1,335.00	93,450.00	85,440.00
7,500	45	148,333.33	29,666.67	23,733.33	26,700.00	26,700.00	1,335.00	93,450.00	85,440.00
10,000	42	211,904.76	42,380.95	33,904.76	38,142.86	38,142.86	1,780.00	124,600.00	113,920.00
10,000	45	197,777.78	39,555.56	31,644.44	35,600.00	35,600.00	1,780.00	124,600.00	113,920.00
12,000	42	254,285.71	50,857.14	40,685.71	45,771.43	45,771.43	2,136.00	149,520.00	136,704.00
12,000	45	237,333.33	47,466.67	37,973.33	42,720.00	42,720.00	2,136.00	149,520.00	136,704.00
15,000	42	317,857.14	63,571.43	50,857.14	57,214.29	57,214.29	2,670.00	186,900.00	170,880.00
15,000	45	296,666.67	59,333.33	47,466.67	53,400.00	53,400.00	2,670.00	186,900.00	170,880.00

3.3.5. Staff cost

The staffs needed for the maintenance of a reverse osmosis desalination plant depend clearly on its daily production and on its automation degree.

We, for the purpose of our article, will consider that the plant has no automation in order to study the staff cost based on the worst possible case.

We calculate the minimal number of staff needed to attend the plant during the whole year, 365 days, and 24 h a day. It is important to notice that, although we have estimated that the plant will stop for 9 days, working 356 days a year, the staff will continue working the whole year around.

The minimum needed staff can be calculated by two different systems, choosing the less favorable, complying with the "Iron and Steel Collective Agreement of the Province of Las Palmas" of the regional Employment, Industry and Commerce Ministry, signed in the Province of Las Palmas on 26 June 2009 [25].

Based on the weekly working days, by taking into consideration that from 7 days of a week a person works for 5 days, so that we need four persons to attend the morning hours and the evening hours and two for the night hours. Based on it, we present the following formula:

$$\frac{\text{Persons needed daily (4)} \times \text{days of the week (7)}}{\text{Days worked weekly by a person (5)}} \approx 6 \text{ employees}$$

Based on reducing the holidays from the working days, according to the Collective Agreement the employees will count on 48 free days as holiday, as they will work on nonworking days, weekends, etc. so we need more employees to cover the holidays. Based on it we will calculate once again the number of employees, based on the following formula:

$$\frac{\text{Holidays (48)}}{\text{Days per year (365)}} = 0.1315 \Rightarrow 1 - 0.1315 = 0.86$$

$$\frac{\text{Minimum num. of employees (6)}}{0.86} = 6.97 \approx 7 \text{ Employees}$$

Based on the calculations, we can conclude that a desalination plant needs a minimum quantity of seven employees to be attended the whole year around for a production of 500 m^3/day.

The seventh employee is the one responsible to cover during the whole year round the holidays of the other employees.

Herewith, we present the distribution and timetable of the staff based on the daily production of this type of plant (500 m^3/day) (Table 3).

3.3.6. Maintenance cost

For the cost of the maintenance of the whole desalination plant, we have based our study on the Manual for Implementation of Treatment Systems in small towns, written jointly by CENTA and CEDEX [26], from which we have taken the necessary data, as well as on the estimated values of the average life of each item and the percentage of deterioration based on the initial investment.

We attach a basic table with the necessary data to elaborate the maintenance cost (Table 4).

Based on this table and knowing that the working limit is of 15 years, we have applied the said coefficients to each one of the parties of the investment affected by the maintenance.

3.3.7. Environmental cost

The environmental cost is a type of cost obtained as a result of the environmental impact generated by the desalination plants into the sea. As it is well known, the rejected water (brine) is discharged into the sea. It is our intention for this work to calculate this cost which is theoretically new and it is based on reducing the environmental impact generated in the sea by the dumping of the desalination plants.

The said cost is based on mixing the brine with seawater with the help of the corresponding pipe line and pump, in sending the said mixture back in to the sea and with similar characteristics as the seawater, in controlling to avoid any suspension particles and to keep an adequate pH.

In order to realize it, we shall need the following materials:

(a) Seawater boost pipe to the brine pipe.
(b) Seawater boost pump to the brine pipe.
(c) Decantation tank for separating floating particles.
(d) pH meter for the water to be pumped back into the sea.
(e) Mixed water expulsion pipe.

Theoretically, the said cost could be included into the investment costs, as it is initially required.

Table 3
Work weekly distribution for a type plant

	Q m³/día						
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Oficial 1ª	M	M	M	M	M	L	L
Oficial 1ª	L	L	T	T	T	T	T
Oficial 1ª	L	L	M	N	M	M	M
Oficial 3ª	N	N	L	L	N	N	N
Oficial 3ª	T	T	N	N	N	L	L
Oficial 3ª	V	V	V	V	V	V	V
Laborer	N	N	N	L	L	N	N

where M = morning shift, from 6 to 14 h;
T = evening shift, from 14 to 22 h; N = night shift, from 22 to 6 h;
L = free day; and
V = holidays.

Table 4
Average life of items

Item	Average life (years)	(%) Annual inversion
Recipients and Tanks	25	0.8
Rotary mechanical equipments	17	4.3
Machines driving equipments	25	1.5
Instrumentation	25	4.5
Pipes, valves, and accessories	25	3.0
Centrifugal pumps	17	4.2
Electricity	25	4.3
Civil work (construction)	75	0.3

Although we have considered that for the function of the desalination plant is not a basic step, we have included it here as a cost arising from the functioning of the said plant.

To calculate this cost, we focus on the brine expulsion and on the control of chemical reagents needed to clean the equipment.

It could be harmful for the wildlife to throw into the sea the brine, as expressed before, due to its great salt content.

The pipe and pump that we shall use to boost the seawater up to the expulsion pipe will cost half of the nominal value of the pipes used to boost the water to the plant, due to the fact that only a 45% of the water is converted into drinking water, meaning that a mixture of the 50% is the adequate one. The brine expulsion pipe will have the same cost as the seawater boost pipe (up to the plant).

As a design factor, we note that the boost speed can be in between the range of 0.4 to 1.2 m/s, although it is recommended to keep a speed of 1 m/s in order to guarantee the right functioning of the design. This value has been taken into consideration in all calculations of the present article.

After calculating the boost and expulsion environmental pipes, we calculate the cost of the seawater boost environmental pump. As expressed before, the nominal cost will be the half of the nominal value of the pump to boost the seawater into the plant. We have estimated a length of 150 m to extract the seawater to the plant.

To control the chemical reagents and the floating particles on the brine we shall use, as mentioned before, a pH meter and a decanter for the said floating particles.

3.3.8. Energetic consumption cost

To end with the costs analysis involved in the reverse osmosis desalination plants, we study the cost of the energy consumption, which we will see is the most influential parameter in the total cost.

From the moment the water is pumped off the sea into the plant up to the moment the consumer receives it at home, the energetic consumption is involved in different phases, to be described further on.

Each of the said phases is represented by the necessary generated power in kW and by the generated consumption in kWh/m^3.

Energetic consumption of the boost pump. Taking into account the data of the cost of investment, Section 1, we get the power corresponding to the seawater boost pump.

Energetic consumption of the reverse osmosis process. From all the phases involved in energetic consumption, the reverse osmosis process is the one showing a bigger consumption and therefore, we study it in Section 3.2.1.

Energetic consumption of the intermediate processes of the plant. Once the water is in the desalination plant, several small power pumps are used in the intermediate processes to boost the water from the feeding tanks to the reverse osmosis process as well as the different dosage pumps with their corresponding shakers for the different chemical reagents. To calculate the whole energetic cost, we have taken into consideration the energetic costs of the said small pumps as well as their consumption, which, according to calculations, vary between 8 kW for plants producing 500–1,000 m^3/day and 14 kW for plants producing 12,000–15,000 m^3/day.

Energetic consumption corresponding to the environmental cost. As we discussed in the section of the seawater pumping, we use the data of the power corresponding to the seawater boost pump which is corresponding to the environmental cost and calculate the consumption in accordance with the used formula.

Energetic consumption corresponding to the boost for consumers. As in other sections, we use the data corresponding to the calculation of the pump that boosts water for the consumers and calculate its consumption with the already described formula.

Once we have done all the calculations and obtained all the data for each one of the phases, referred to pumps power and consumption, we just add together all the calculated data to know the energetic consumption of each desalination plant.

Once we have the data of the power to contract the electrical hook up, which we call power term, and the total consumption, which we call from now on the energy term, herewith we show the tariff conditions for the peak periods (P1), flat (P2), and off-peak (P3), corresponding to the terms of power and energy (Table 5).

Table 5
Power and energy terms prices in AT [27]

	Tariff Period 1	Tariff Period 2	Tariff Period 3
Tp €/kWh año	24.493,015	15.104,184	3.463,562
Te en DH3 €/kWh	0.134,025	0.116,987	0.081,679

After this, we explain the process for the calculation of the energy cost based on the terms expressed below:

(a) Power term:
PYearly cost $= (P \times 24.493015 + P \times 15.104184 + P \times 3.463562)$

(b) Energy term:
EYearly cost $= (C \times 0.134025 \times 4 \times 365 + C \times 0.116987 \times 12 \times 365 + C \times 0.081679 \times 8 \times 365)$

(c) Electricity Tax:
TYearly cost $= (C_e + C_p) \times 1.05113 \times 0.04864$

(d) Measure equipment hiring cost: This is a fix amount costing 48.11 €/month

(e) Local tax I.G.I.C. 2%: Local tax I.G.I.C. reduced to 2% is applied to power term, energy term and electricity taxes term

(f) Local tax I.G.I.C. 5%: Normal type of I.G.I.C. is applied to the measure equipment hiring

4. Results

As a result of the realized work, we present the two obtained graphics in our study. In the first graphics, we have obtained the energetic cost for temperatures of 19, 20, and 21 ℃ and a fouling factor of 0.85 and 1. The said graphics are represented by a conversion factor of 42 and 45% (Figs. 5 and 6).

In the second graphics, we have obtained the values for the rest of the costs for the same conversion factors.

5. Conclusions

(1) The graphics show that there is a stabilization in the energetic consumption after a production of 5,000 m^3/day and that best values correspond to a temperature of 21 ℃ with a fouling factor of 1.

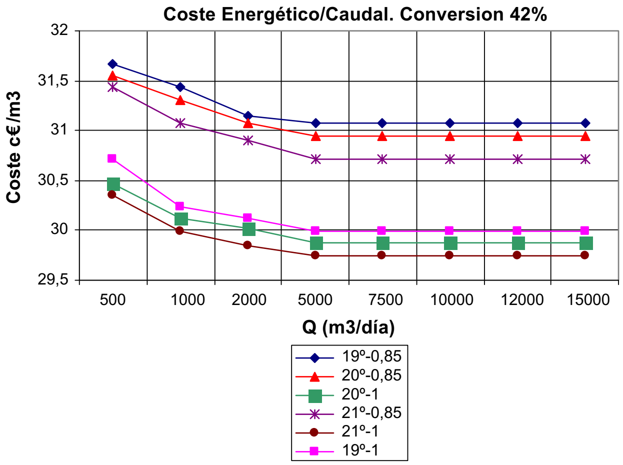

Fig. 5. Energetic cost influenced by temperature and fouling factor 42%.

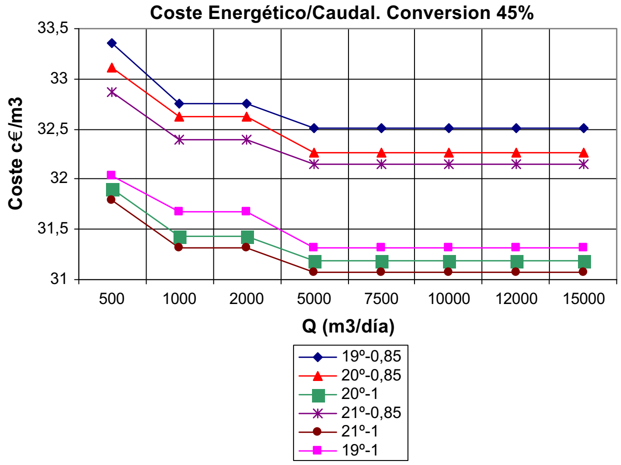

Fig. 6. Energetic cost influenced by temperature and fouling factor 45%.

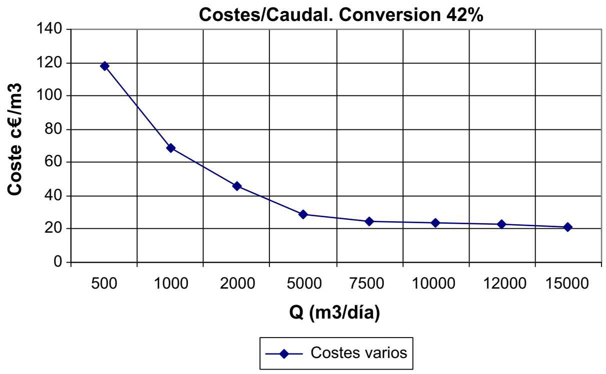

Fig. 7. Different costs for conversion factor of 42%.

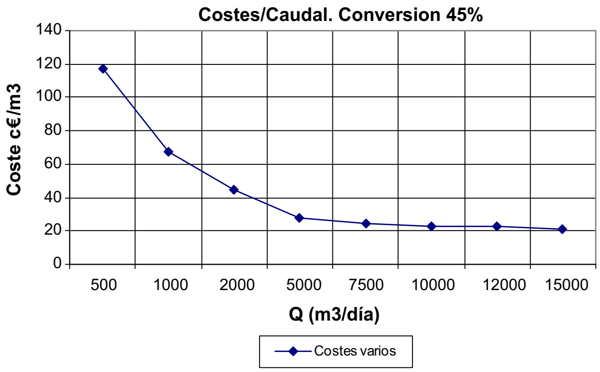

Fig. 8. Different costs for conversion factor of 45%.

(2) As a result of the graphics, we may observe that the value of the different costs begin to stabilize for a flow of 5,000 m^3/day and that the differences based on conversion factor are minimal.

(3) The temperature and the fouling factor are fundamental, observing that there is a saving of 0.3 €/m3.

(4) In the graphics, in the initial study, the values up to 2,000 m^3/day were high due to the amortization of the initial capital and staff cost. There from arises the need for these plants with the initial capital investment support as well as the automation of the plant in order to reduce the staff costs.

(5) We may conclude that the most efficient production line for reverse osmosis desalination plants in the range of 500–15,000 m^3/day correspond to a production of 5,000 m^3/day, with a conversion factor of 45% at 21 ℃ of temperature and with a fouling factor of 1 (Figs. 7 and 8).

References

[1] S.L. Milliarium Aureum, Desalinizadoras y desalobradoras. Ingeniería Civil y medio Ambiente, 2004.
[2] Manuel Hernández Suárez, Datos estadísticos sobre el agua en Canarias, Centro Canario del Agua, 2007.
[3] Antonio Valero, Uche Javier, Serra Luis, "La desalinización como alternativa al PHM" Gobierno de Aragón, 2001.
[4] A. Poullikkas, Optimization algorithm for reverse osmosis desalination economics, Desalination 133 (2001) 75–81.
[5] D. Prats Rico, M.F. Chillón Arias, A reverse osmosis potable water plant at Alicante University: First years of operation, Desalination 137 (2001) 91–102.
[6] J.M. Cámara, M.A. Melián, Las técnicas de desalación y sus costes, Agricultura (2002).
[7] S.A. Avlonitis, Operational water cost and productivity improvements for small-size RO desalination plants, Desalination 142 (2002) 295–304.
[8] G.F. Leitner, Water cost analysis … we need to do better, Desalination and water reuse, 5 (1995) 24–27.
[9] A. Malek, M.N.A. Hawlader, J.C. Ho, Design and economics of RO seawater desalination, Desalinaton 105 (1996) 245–261.
[10] M. Pappas, K. Moutesidis, Remote Operation and automation for RO plants, Final year project, TEI Halkidas, 2001.

[11] A. Hafez, S. El-Manharawy, Economics of seawater RO desalination in the Red Sea region, Egypt. Part 1. A case study, Desalination 153(1–3) (2003) 335–347.

[12] S. El-Manharawy, A. Hafez, Molar ratios as a useful tool for prediction of scaling potential inside RO system, Desalination 136 (2000) 243–254.

[13] S. El-Manharawy, A. Hafez, Technical management of RO system, Desalination 131 (2000) 173–188.

[14] S. El-Manharawy, A. Hafez, Water type and guidelines for RO system design, Desalination 139 (2001) 97–113.

[15] O. Sallangos, E. Kantilaftis, Operating experience of the Dhekelia seawater desalination plant, Desalination 139 (2001) 115–123.

[16] M. Faigon, Process control of Larnaca seawater RO plant, Desalination 138 (2001) 297–298.

[17] David Martínez Vicente, Studio de la viabilidad técnico-económica de la desalación de agua de mar por ósmosis inversa, Tesis Doctoral, Universidad de Murcia, 2002.

[18] Manuel Latorre, Costes económicos y medioambientales de la desalinización de agua de mar. IV Congreso Ibérico de Gestión y Planificación del Agua, 2004.

[19] M. Wilf, C. Bartels, Optimization of seawater RO systems design, Desalination 173 (2005) 1–12.

[20] Luis Castilla, Viabilidad económica y uso sostenible de las nuevas fuentes de agua, Acciona (2006).

[21] Akili D. Khawaji, Ibrahim K. Kutubkhanah, Jong-Mihn Wie, Advances in seawater desalination technologies, Desalination 221 (2008) 47–69.

[22] Salah Frioui, Rabah Oumeddour, Investment and production costs of desalination plants by semi-empirical method, Desalination 223 (2008) 457–463.

[23] Catherine Charcosset, A review of membrane processes and renewable energies for desalination, Desalination 245 (2009) 214–231.

[24] Software ROSA, versión 7.2.1, Reverse Osmosis System Analysis for FILMTECTM Membranes.

[25] Convenio Colectivo del sector "Siderometalurgia en la Provincia de Las Palmas" de la Consejería de Empleo, Industria y Comercio, firmado el 26 de junio de 2009 en la Provincia de Las Palmas.

[26] Manual para la implantación de Sistemas de depuración en pequeñas poblaciones, CENTA y CEDEX del 3 de marzo de, 2011.

[27] BOE, número 77, Orden ITC/688/2011, de 30 de marzo de 2011, 2011.