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Elimination of chemical products in the pre-treatment section of Las Palmas III reverse osmosis desalination plant to control fouling

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ABSTRACT

The paper analyses the extrapolation of the results obtained in a pilot plant to a full-scale seawater desalination plant. A technological system was implemented in the pre-treatment line of Las Palmas III seawater reverse osmosis (RO) desalination plant with a capacity of 36,000 m^3/d. This system is aimed to control membrane fouling. It consists in the non-dosing of sodium hypochlorite or another biocide to seawater in order to minimize RO membrane biofouling. The pH regulation at 6.5 controls the scaling and the 12.5 ppm dosage of $FeCl_3$ as a coagulant maximizes the coagulation efficiency of colloidal particles and controls the fouling process.

1. Introduction

The seawater desalination plant "Las Palmas III" (LP3) has been a worldwide reference since its construction and inauguration at the end of 1989 and the start of 1990. The latest advances and state-of-the art technology of the time in the field of reverse osmosis (RO) seawater desalination were incorporated in the project. At that moment, it was one of the most modern and largest plants of its type in the world, and was responsible for supplying potable water to around 500,000 people in the town of Santa Brigida and Las Palmas de GC, the capital city of Gran Canaria (Spain) [1–3,5,6].

The LP3 full scale plant collects the seawater for desalination using an 'open intake' type system, and since it was first put into service began to suffer a series of technical problems which over the years took on a critical status. The worst problems included accelerated membrane fouling, persistent bad smells, a rapid increase of pressure loss in the modules and a rapid decrease in water product quantity and quality, etc. Consequently, the membranes had to be cleaned each 15 or 20 days with serious consequences for plant production and operating costs [2–6]. Granted the opportunity to participate in the search for solutions to these problems, a research project was accepted and funded by EMALSA which obtained highly satisfactory results. The recommendations that were made and implemented have resulted in the LP3 full scale plant being able to operate with almost no need for the application of chemical products and under very stable conditions. This research work served as the basis for the doctoral thesis of A. Muñoz Elguera.

Though the design capacity of the LP3 full scale plant was 36,000 m^3/d, at the start of the research study in 1997 it was only producing an average of 29,000 m^3/d, using a traditional pre-treatment system and operating conditions characterised by use of the following [1]:

- Open intake collection system, through a chamber situated in the cooling water sedimentation basin of the UNELCO thermal power plant; comprising 7 pump houses with an average delivery of 80,000 m^3/d or 3300 m^3/h seawater (each pump delivers around 550 m^3/h, at a pressure of 1.75 kg/cm^2).
- Chemical pre-treatment system, comprising application of the following:

i. Sodium hypochlorite (NaClO): shock dosing during the first 2 h directly in the collection chamber (100 l/h, 50 ppm of NaClO), followed by continuous application in the seawater pressure line (100 l/h, 50 ppm of NaClO). This oxidising biocide was used to control RO stack membrane biofouling (viruses, bacteria, fungi, moulds, etc.), the presence of algae and molluscs in the seawater and to avoid clogging of the screens through which the seawater passes on its way to each collection chamber.
ii. Sulphuric acid (H_2SO_4): to enhance the biocidic action of the NaClO, to regulate the process water pH at 7.1, and to strengthen the action of the sodium hexametaphosphate as scale inhibitor. A dosage of 35 l/h was applied of pure sulphuric acid (20 ppm to the process water).

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iii. Iron chloride ($FeCl_3$): coagulant applied proportionally to the raw water flow rate using two dosing pumps for approximately 15 l/h of pure ($FeCl_3$) (around 6 ppm in the process water), to control RO stack membrane fouling.
iv. Sodium metabisulphite ($NaHSO_3$): applied to fully eliminate residual chlorine from the NaClO, (applied to control membrane biofouling). Application of $NaHSO_3$ was made to the filtrate of the candle filters and just before the safety filters, as the active polyamide layer of the membranes used in LP3 full scale plant was highly sensitive to the oxidising action of the NaClO and any residual chlorine that might be present in the water entering into contact with them. The $NaHSO_3$ was applied as a 20% w/w solution using two dosing pumps proportional to the concentration of residual chlorine present in the water at a rate of approximately 15 l/h (about 15 ppm in the process water).
v. Sodium hexametaphosphate: applied just before the safety filters, as a 25% solution, proportionally to the raw water flow rate and at approximately 30 l/h (about 6 ppm in the process water). This chemical reagent was used to prevent the precipitation of any dissolved salts that might be present in the water entering into contact with the membranes when saturation concentrations were exceeded: mainly carbonates, sulphates and/or fluorides of alkaline-earth metals (Ca, Mg, Ba, Mn, etc.); iron, silica, etc. [5,9,11].
vi. As is well known, sand filters do not retain soluble oils (unlike anthracite and activated carbon filters). Filtration of suspended particles is limited to around 10 to 20 μm, and even at the end of the filter run (clogged filter) the filters are unable to retain particles below 5 μm. Such circumstances meant it was necessary to use a second filtering stage to remove the particles (as microfloccules and dispersed particles) that could not be removed by the gravity filters, comprising a booster pump room, precoat filters and safety filters.

2. Aims of the research project

As described above, the main aims of the research project were firstly to undertake a detailed study of the accelerated and drastic fouling process suffered by the RO membranes of the stacks of the LP3 full scale plant which uses open intake type collection [1–4,6], and secondly to determine the most appropriate technological procedure that would allow to minimize the fouling process, reduce the chemical cleanings to levels recommended by the membrane manufacturers (a maximum of 1 or 2 chemical cleanings per year) and resolve the technical problems of LP3 full scale plant [2–8].

At the same time, and with a view to attaining the main aim of the project as described above, the following partial aims were defined which were sequentially attained:

1. To identify, prioritise and study the main causes of the technical problems affecting operation of the LP3 full scale plant [9–12,14–17]
2. To formulate and test, at pilot plant level, the technological procedures that would allow an adequate control of the main causes of the technical problems [2,3,6,13]
3. To extrapolate to the LP3 full scale plant the most important results obtained in tests at pilot plant level

3. Experimental procedure

The following actions summarized in Table 1 were carried out to identify, prioritise and study the main causes of the technical problems of accelerated fouling of the LP3 membranes.

3.1. Membrane autopsies

These were performed to identify the types of matter which were causing membrane fouling [4]:

Table 1
Chronology of the evolution of pretreatment carried out.

Year	Actions
1990–1997	Dosage of all chemical products summarized in Fig. 1.
1997–1998	Optimization of the different chemical dosages in the LP3 full scale plant
1999	Pilot level research (elimination of chemical products)
2000	Extrapolation to the LP3 full scale plant (elimination of chemical products)

- A total of 47% was comprised of material of organic nature (the amount of the sample lost or burnt when heated to a temperature of up to 550 °C).
- A total of 50% was comprised of material of inorganic nature consisting principally of: 30% silica (SiO_2), 1.4% iron oxide (Fe_2O_3), 0.8% calcium oxide (CaO), 1.3% magnesium oxide (MgO), 2.7% magnesium carbonate ($MgCO_3$), 1.3% aluminium oxide (Al_2O_3), 6.4% carbon dioxide (CO_2), 2.1% sulphur trioxide (SO_3), and 0.3% phosphorus pentoxide (P_2O_5).

The microbiological analysis of the material deposited on the membrane surface, in the feed channel spacer and the internal spacer which carries the permeate water, gave the following results:

- Viable bacteria (non-enteric): Staphylococcus, Arthrobacter, sulphate reducers, etc.
- Fungi: Genus Aspergillus, and other unusual unidentifiable fungi
- Various humic acids were also identified in the raw seawater

3.2. Optimization of the different chemical dosages

The original schematic flow diagram of the LP3 seawater reverse osmosis desalination plant is shown in Fig. 1. From 1997 to 1998 various studies were carried out to optimize the pre-treatment line chemical product applications, and their effect on RO membrane performance was evaluated. The most significant were:

- Sodium hypochlorite (NaClO): both in the seawater collection chamber (shock dosage, initially 50 ppm), and in the pressure line to the pre-treatment section (initially 50 ppm); dosages which were ultimately eliminated in the pre-treatment line
- Sodium metabisulphite ($NaHSO_3$): initially applied as a 20% w/w solution (200 kg for each 1000 l of water), and finally eliminated after removing the NaClO dosage in the pre-treatment line
- The dosages were also optimised of the iron chloride ($FeCl_3$), sulphuric acid (H_2SO_4), etc.

3.3. Pilot level research study

Taking as reference the results of the partial questions previously investigated and related to the technical problems affecting LP3 plant operation [2,3,6], the basis of the research study was established and tested using two pilot plants made available for this purpose. This basically comprised of:

- Control of scaling through the application of H_2SO_4 to regulate the seawater feeding the RO membranes at an appropriate pH value, instead of using as scale inhibitor the hexametaphosphate employed in LP3 full scale plant.
- Control of fouling through optimization of the coagulation-flocculation process and the plant's filter units.
- Control of biofouling testing two hypotheses based on preliminary studies [2,3,6]:
  i. Continuous application of sodium hypochlorite (0.5 ppm) to the seawater, without its neutralisation by applying sodium

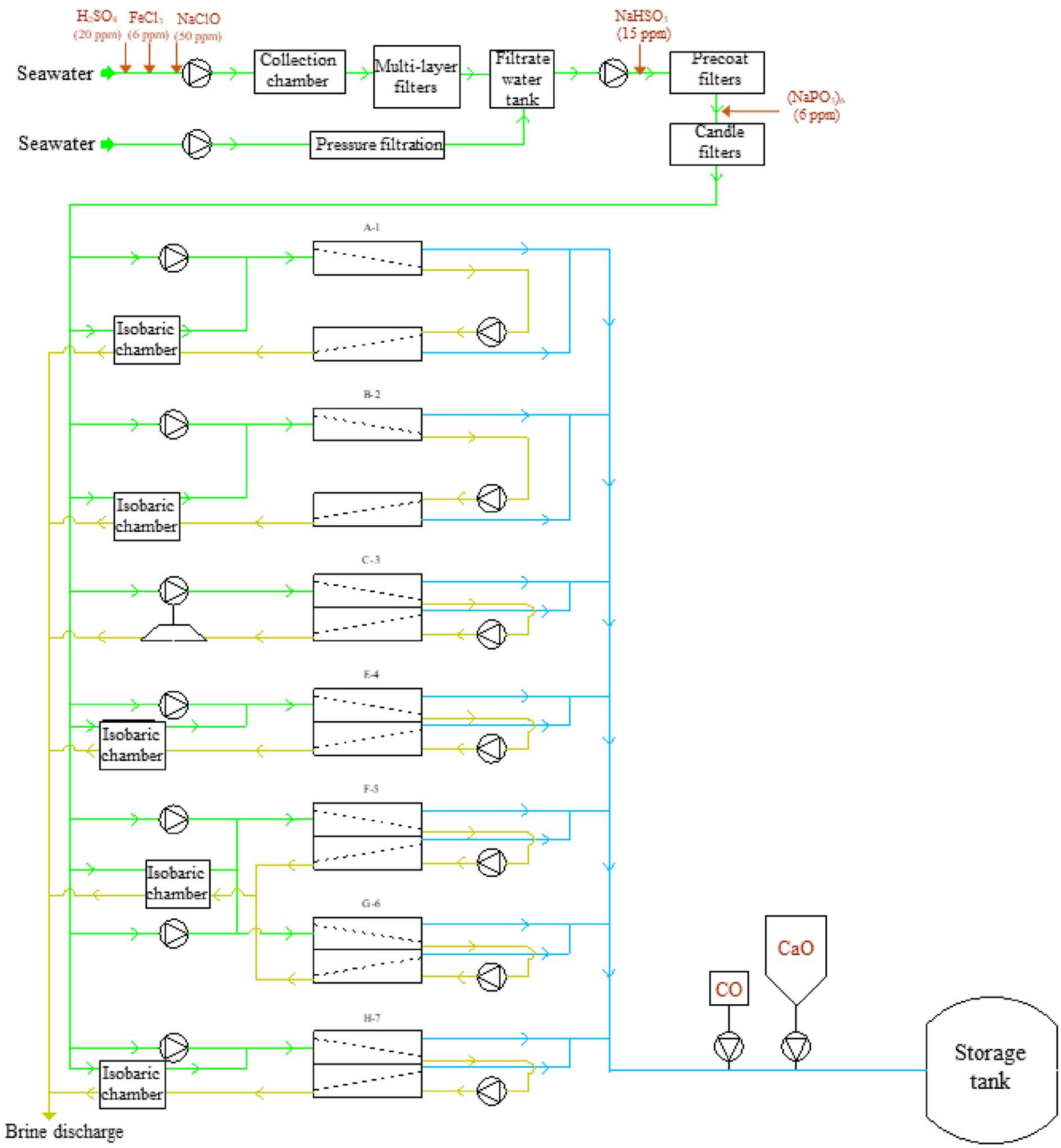

Fig. 1. Schematic flow diagram of LP3 full scale plant (1990–1997).

metabisulphite, thereby allowing continuous contact of biocide and membrane (which necessarily requires a high tolerance to this biocide). These tests were performed with the Toyobo test plant, equipped with cellulose triacetate membranes with hollow fibre configuration [2,3].

ii. No application of sodium hypochlorite (or any other biocide) to the seawater in the pre-treatment stage. This was tested at the "EMALSA" pilot plant built to replicate the LP3 full scale plant and using polyamide membranes with a spiral configuration, highly sensitive to oxidising biocides (NaClO, $Ca(ClO)_2$, O_3, H_2O_2, etc.). This entails a novel technological procedure, with a daring and radical modification of the traditional "philosophy" employed in RO desalination plant operation based on the application of NaClO and its subsequent neutralisation through the application of $NaHSO_3$ prior to feeding the seawater to the membranes.

As mentioned, in view of the results obtained in the preliminary studies [1,2] carried out at LP3 full scale plant, the basis of the research study was determined [3], tested at two pilot plants made available for the purpose and the results were presented at the EDS Congress in Barcelona (Spain) in 2012.

3.4. Extrapolation of results obtained at pilot plant level to the LP3 full scale plant

When EMALSA deemed the results obtained in the pilot plant research studies to be satisfactory and reliable, it was decided to extrapolate these results to the LP3 full scale plant.

3.4.1. Extrapolation results

Taking as reference all the preliminary research studies (membrane autopsies, chemical dosage optimization, etc.), a protocol was designed to undertake a further research study using the "EMALSA" pilot plant (designed to replicate the LP3 full scale plant). The most notable results to be extrapolated were as follows:

- Elimination of the both the shock and continuous application in the pre-treatment line of sodium hypochlorite (NaClO).
- Elimination of sodium metabisulphite ($NaHSO_4$) from the pre-treatment line due to the elimination of the application in that line of NaClO.
- Application of sulphuric acid (H_2SO_4) to regulate at around 6.5 the pH of the pre-treated seawater, used to feed the RO membrane modules, and thereby eliminate application of sodium hexametaphosphate as scale inhibitor.
- Application of the coagulant ($FeCl_3$), at an optimum dosage of 12.5 ppm, to the raw seawater which then needs to be very efficiently flocculated and filtered.
- Optimization of the efficiency and time in service of each filtering unit (sand, precoat and safety), and evaluation of their respective operation.
- Identification of water sampling points along the pre-treatment line and physical, chemical and microbiological analyses to allow an overall evaluation in quantitative terms of pre-treatment efficiency and operation.
- Definition of the operating parameters to quantitatively evaluate the efficiency of each pilot plant pre-treatment processing unit and operation.
- Elaboration of the formats for data collection (parameters, analyses, etc.) required to evaluate the results of the tests.

3.4.2. Procedure for extrapolation of the pilot plant results to the LP3 full scale plant

Though EMALSA considered the results obtained in the pilot plant research studies to be satisfactory and reliable, and after deciding to extrapolate them to the LP3 full scale plant, it was realised that the heavy contamination of the facilities at the full scale plant would be problematic. To ensure results in the extrapolation process at the LP3 full scale plant as satisfactory as the pilot plant results, a protocol was designed which comprised the following preliminary actions:

3.4.2.1. Thorough and complete disinfection of the whole plant. Based on the certainty that the technical problems, particularly the biofouling, which were affecting the LP3 full scale plant membranes, were caused by high levels of seawater microbiological contamination, the first obvious step was to thoroughly disinfect all the units of the pre-treatment section. This task was carried out as follows:

1. Plant operation was ceased, as per the procedure described in the operations manual. All the pre-treatment units were maintained with maximum possible water level (homogenisation tank, settling chambers, sand filter basins and filtrate water tank).
2. A commercial product was added to each filtration basin to act as biodispersant and surfactant at the dosages recommended by the corresponding supplier. The mixture was then subjected to air-stirring for a similar time to that of a normal cleaning (about 5 min), to detach all the organic matter stuck to the basins, sand and delivery lines. Finally, the solution was completely discharged (water and chemical products) from the 6 sand filters to the filtrate tank.
3. Two seawater pumps were started and the same chemical products (biodispersant and surfactant) added to the sand filters were used in the collection chamber at the dosages recommended by the suppliers. All the corresponding valves were then closed to isolate the stacks to ensure the water and chemical products circulated only through the delivery lines and exit through the reject line of the turbopumps. Two filtrate water pumps were then started. When water was observed exiting through the reject channel outlet (when necessary foam inhibitor was added), the filtrate water pumps were stopped, the discharge valves of the turbopumps closed and, finally, the two seawater pumps were stopped. Once all the pre-treatment section, supply lines and turbopumps had been filled with the cleaning solution, the whole system was maintained like this for a suitable time to soften and detach all the adhered organic matter.
4. The reject discharge valves of the turbopumps were opened and the two seawater pumps were started as well as the two filtrate water pumps (applying foam inhibitor at the general reject outlet and wherever necessary). A specially selected biocide based on quaternary ammonium, at the dosage recommended by the supplier, was then applied as well as a high dosage of hypochlorite (such that there were around 6 ppm of residual chlorine at the general reject outlet of the plant) from the seawater collection chamber to the start of the 800 mm plant pipe. The purpose here was to undertake an in-depth disinfection of the whole pre-treatment section and the supply lines as well as the turbopumps.
5. Finally, an exhaustive rinsing was carried out with seawater of all the disinfected line. The biocide was then neutralised with a strong reducing reagent, as is metabisulphite, which must be applied (at the dosage established in the chemical laboratory) at the general reject outlet of the plant.

3.4.2.2. Chemical cleaning of the six membrane stacks of the plant. The chemical cleaning which gave the best results of those tested at the full scale plant was then used, consisting of the following general steps:

1. The stack was taken out of service and a rinsing was performed with permeate water to eliminate the brine from the interior of the membrane modules of the first and/or second stage.
2. An acid cleaning was performed with a metabisulphite solution (100 kg in 25 m^3 of permeate water), with emphasis on the need to alternate periods of steeping and recirculation. The chemical cleaning was concluded when the parameters used of the chemical cleaning solution ($[Ca^{+2}]$ and $[Mg^{+2}]$) to measure the evolution of membrane cleaning remained constant (generally after 10–12 h).
3. A new rinsing was then made of the stack with permeate water for some 20 or 30 min (pump flow rate of 240 m^3/h) until the acid cleaning solution was eliminated.
4. An alkaline cleaning was then performed with an Ultrasil P-10 (detergent) solution (75 kg in 25 m^3 of permeate water), also with alternate periods of steeping and recirculation. The chemical cleaning was concluded when the parameter used of the chemical cleaning solution (turbidity) to measure the evolution of membrane cleaning remained constant (generally after 6–10 h).
5. A third rinsing was performed of the membrane modules for 40–60 min before the stack was put into service again.

3.4.2.3. Appropriate conditioning of the filter units. As one of the premises (on which the new technological procedure which was being extrapolated to the full scale plant was based) was the need to optimize the coagulation and flocculation processes, as well as the processes of the filter unit operations to ensure maximum removal of both colloidal particles and microorganisms, the following considerations were given to the filter units:

- Sand filters required a suitable thickness of each layer of filtering material, especially the LP3 filters which had only gravel and sand (at the time the anthracite layer described in the operating manual was absent). It was therefore necessary to confirm that the sand layer had a minimum thickness of 1 m, as with high filtering rates (the rate at which the water passes through the filter bed) the level of efficiency decreases considerably with the thickness of the bed.
- The filter cartridges, both the precoat and safety filters, must be in perfect condition. That is, they must not be compacted or irreversibly clogged, and certainly not broken (as was observed in some cases on first inspection). If possible, given the lack of space for new

units), attempts were made to augment the filter surface area (or the number of filter cartridges) inside each of these filter units.

3.4.2.4. Adjustment of chemical dosages in the pre-treatment section. It should be recalled that the new technological process being extrapolated to the LP3 full scale plant only retained the following applications:

- Of sulphuric acid (H_2SO_4), to regulate the pH of the seawater fed to the membrane modules at an approximate value of 6.5, with a view to controlling the precipitation processes of inorganic salts, in the form of microcrystalline solids, deposited on the active layer of the membranes (scaling) and causing inefficient membrane operation (decrease in flow rate and permeate water quality).
- Of iron chloride ($FeCl_3$), at an optimum dosage of 12.5 ppm (previously determined in the laboratory using jar tests, and satisfactorily evaluated in the tests performed with the LP3 pilot plant). The function of this chemical reagent is to act as coagulant in the coagulation of both the colloidal particles and the microorganisms of colloidal nature with positive surface charges which will subsequently take part in the complementary flocculation process and be separated from the water in the filtration process.

4. Experimental results

To quantitatively evaluate the effects of the new extrapolated technological procedure (basically in the pre-treatment sections of the full scale plant) on the quality of the seawater to be fed to the LP3 membrane stacks, stack "F" was chosen to obtain the necessary experimental data to analyse the following:

- The physical, chemical and microbiological parameters associated with the evolution of the quality of the seawater in the collection chamber, comparing them with the quality of the water leaving the pre-treatment section and which is processed in the LP3 membrane stacks.
- The operating parameters of the membrane stacks and their evolution over time to determine whether the new technological procedure extrapolated to the pre-treatment section resolved the problem of accelerated fouling of the LP3 membranes.

4.1. Evaluation of the performance of the pre-treatment sections after extrapolation

The analysis of the evolution of the seawater quality parameters, from its collection and passage through each of the pre-treatment section processes to its exit as effluent from the safety filter, allowed evaluation of the effects of the extrapolation. The water quality parameters which were considered useful for this purpose are as follows:

- Physical parameters: temperature, turbidity and the silt density index (SDI)
- Chemical parameters: pH, electrical conductivity and total organic carbon (TOC).
- Microbiological: total and fecal coliforms, spp Bacillus, total count and MPN

All the experimental and analytical data obtained in the tests in this extrapolation process can be seen in Figs. 2, 3, 4 and 5.

4.2. Evaluation of stack "F" operation after the extrapolation process

To quantitatively evaluate the effects of the new technological procedure extrapolated to the pre-treatment section on the new operation of the membrane modules of the LP3 full scale plant, stack "F" was chosen to obtain the necessary data. This analysis was centred on four basic aspects:

- Determination of the initial operating conditions of the stacks
- Evolution of the physical, chemical and microbiological quality of the seawater as it passes through the stack membrane modules
- Pilot plant stack operating parameters
- Evolution of the performance of the stack membranes

4.2.1. Initial operating conditions of the "F" stack

To evaluate the effects of the new technological procedure on the operation of the LP3 stack "F" membranes, there was a clear need to establish:

- The initial quality of the pre-treatment seawater outflow
- The intial operating conditions of the stack

This information would serve as reference to evaluate the evolution over time of the new operating parameters of the modules and the new performance of the stack "F" membranes. They were as follows:

4.2.1.1. Characteristics of the seawater fed to the membrane modules of the stack. The most important initial characteristics of the water leaving the safety filters of the pre-treatment section and which is fed to the LP3 stacks, and in particular stack "F", were:

- Temperature around 22 °C and pH around 6.5
- Turbidity ranging between 0.18 and 0.22 NTU
- Variable SDI around 1.5 units
- Electrical conductivity, around 55,000 μS/cm.
- Average sand filter service of 8–10 h
- Average precoat filter service of 2–3 h
  Microbiological proliferation was initially uncontrolled (subsequently controlled), even when the operating requirements established in the pilot plant tests were being employed (disinfection with $KMnO_4$ of the sand and precoat filters).

4.2.1.2. Initial operating conditions of the stack "F" modules. The initial operating conditions of the membrane modules were as follows:

- Flow rate of the appropriately pre-treated feedwater of around 620 m^3/h
- Feedwater (or operating) pressure of around 62 bar
- First stage pressure loss of around ΔP = 1.6 bar
- Second stage pressure loss of around ΔP = 2.2 bar
- Permeate or product flow rate of around 265 m^3/h
- Average conversion rate in the modules of around 43%
- First stage permeate water electrical conductivity of around 730 μS/cm
- Second stage product water electrical conductivity of around 2000 μS/cm
- Stack product water electrical conductivity of around 1100 μS/cm

4.2.2. Evolution of the water quality parameters

As is evident, the quality of the stack feedwater will be a determinant factor with respect to the correct or otherwise operation of the membrane modules. We therefore analysed the evolution over time of the feedwater quality parameters during its passage through stack "F", considering it would enable a better understanding of the evolution of the operaing parameters of this stack and the performance of the membranes. The most important quality parameters that were analysed for this purpose were as follows:

- Chemical parameters: pH, electrical conductivity and TOC
- Microbiological: total and fecal coliforms, spp Bacillus, total count and MPN.

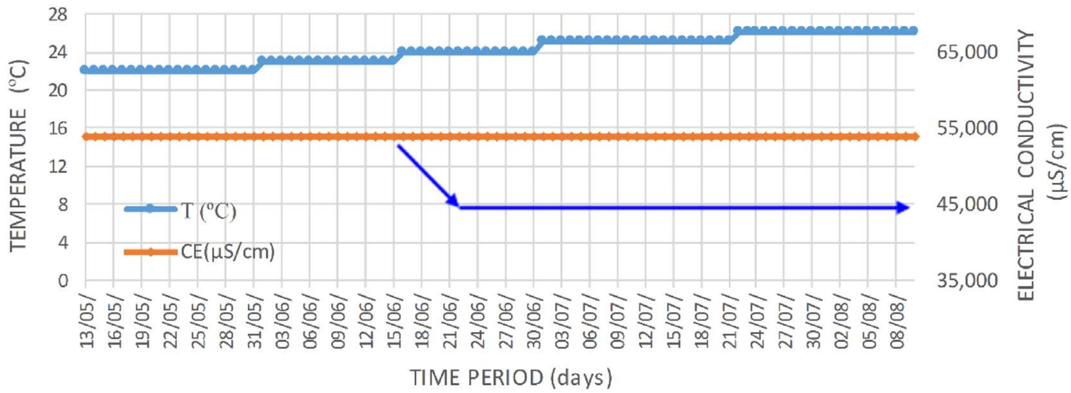

Fig. 2. Plant/Stack feedwater temperature and electrical conductivity (estimated values) during the study period may-august 2000.

The chemical and microbiological parameters allowed a quantitative appreciation of the effects of the new technological procedure extrapolated to the pre-treatment section, amnd in reference principally to the stack feedwater and reject water. The most important and relevant test data referring to stack "F" of the LP3 full scale plant are shown in Figs. 6, 7, 8, 9 and 10.

4.2.3. Evolution of stack operating parameters

While the analysis of the evolution of the operating parameters of each section of the LP3 full scale plant was important, those corresponding specifically to stack operation allowed us to quantitatively evaluate the effects of the new technological procedure extrapolated to the pre-treatment section of the LP3 full scale plant on control of the accelerated fouling process of the membranes. The most important operating parameters in this respect were as follows:

- Flow rates: of feedwater to the plant (Q_F), of feedwater to the stack (Q_B), of permeate or product water of the 1st stage (Q_{P1}), of the 2nd stage (Q_{P2}), of the mix or total (Q_{PM}), and of reject brine (Q_R)
- Pressure: stack operating pressure – 1st stage (P_{IN-1}), 2nd stage (P_{IN-2}), differential pressure of precoat filter (ΔP_{PC}), of safety filter (ΔP_{FS}), differential pressure of the 1st stage of the stack ($\Delta P1$), and the 2nd stage ($\Delta P2$)

4.2.4. Evolution of the performance of the membranes

The performance of the membranes basically involved an analysis of the evolution over time of the "quantity" or flow rate of the permeate water produced and its "quality" (expressed as the amount of total dissolved solids (TDS) or indirectly through electrical conductivity).

In this particular case, the performance of the LP3 "F" stack membrane modules was used to determine the extent of the effect of the new technology implemented in the pre-treatment sections, as the problem of RO membrane fouling and clogging depends primarily on feedwater quality and this quality is a direct consequence of the adequacy, efficiency and effectiveness of its conditioning (or pre-treatment).

The most important data, analysed over time, of the operating parameters of stack "F", as well as the quantity and quality of the permeate water produced by the membrane modules under the studied operating conditions, can be seen in Figs. 11, 12, 13, 14 and 15.

5. Conclusions

After a full, exhaustive and objective analysis of all the test results analytically obtained in the LP3 full scale plant laboratory, and of the operating parameters at pilot plant level and very similarly with stack "F" as a valid representative of the other LP3 stacks, various conclusions can be drawn with respect to the primary aim of this extrapolation stage of examining the effects of a new technological procedure for the control of biofouling, fouling and scaling of RO membranes. These contributions not only benefit the company EMALSA in its running of the LP3 full scale plant, but can also contribute to benefitting RO seawater desalination in terms of significant reductions in investment and operating costs. The following conclusions with respect to RO technology and its impact on the environment are consequently made:

5.1. Scientific/technological contributions to RO seawater desalination technology

- The definitive suspension of the application of sodium hypochlorite

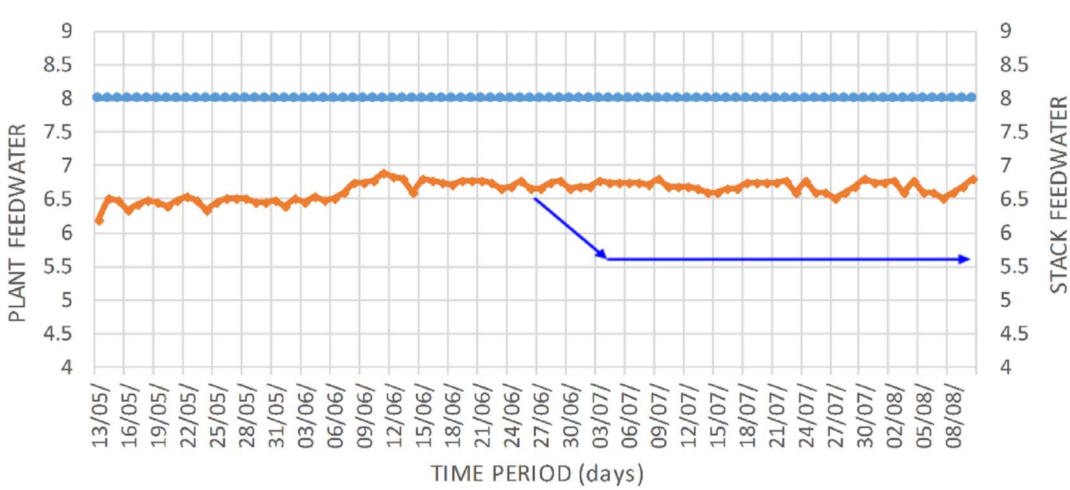

Fig. 3. Plant/Stack feedwater pH during the study period may-august 2000.

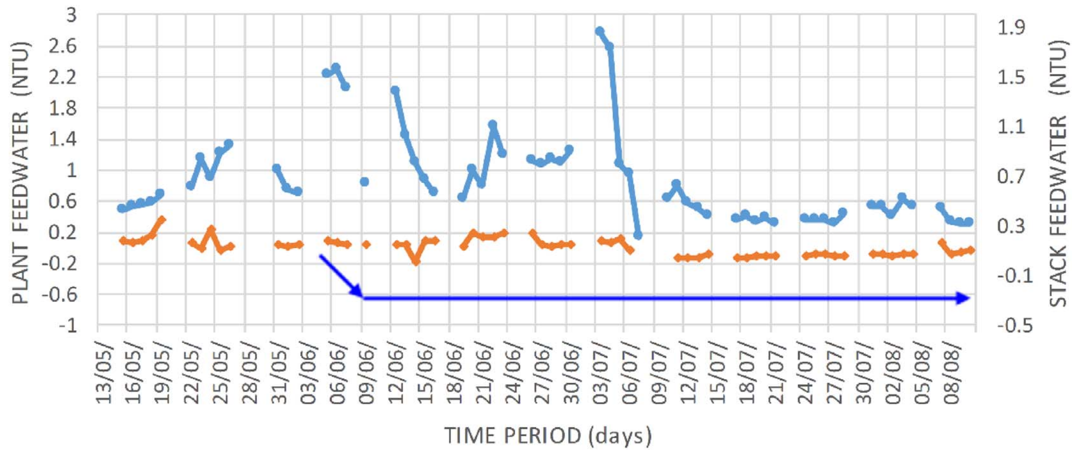

Fig. 4. Plant/Stack feedwater turbidity during the study period may-august 2000.

(NaClO) or any other biocide to the seawater fed to RO membrane modules, while appropriately controlling microbiological proliferations in the process water and drastically minimizing the RO membrane biofouling process. Also the organic fouling control hinders this possible proliferation of microorganisms

- Control of the pH of the seawater fed to the RO membrane modules at around 6.5, enabling an appropriate control of the membrane scaling process.
- Implementation of an optimum dosage of coagulant of around 12.5 ppm of ppm de $FeCl_3$ (iron chloride), even when not complemented with an appropriate point of application, determination of optimum gradient or optimum pH (which normally enable maximum efficiency of the coagulation processes). It was possible to maximize removal of colloidal particles and even of microorganisms present in the process water, significantly improving the quality of the seawater fed to the membranes and confirming an appropriate control of the fouling process.

These conclusions are fully supported by the test results obtained in the research study undertaken at the LP3 full scale plant.

5.2. Economic-type contributions to RO seawater desalination technology

- The definitive suspension of the application of sodium hypochlorite (NaClO) or any other biocide, as well as of the application of sodium metabisulphite ($NaHSO_4$) and the scale inhibitor sodium hexametaphosphate to the seawater fed to RO membrane modules, represent an important reduction in terms of:

i. Investment costs: due to the reduction in the number of dosage application systems (pumps, tanks), chemical product storage deposits, control elements, chemical product delivery lines, etc.
ii. Operating costs: product applications (year 1997, 8,624,726.40 kg/year at a total cost of 2,938,933.55 euros), electrical consumption of the chemical product dispensers, cost of chemical cleanings (chemical products, electrical energy, permeate used, production fall of 6000 m^3/d for each stack cleaning, labour, etc.). In the specific case of EMALSA, these represented in 2001, when operating with the new pre-treatment process, savings of approximately 3 million Euros/year.

- Previously, chemical cleanings of each stack were required each 15 or 20 days (more than 200 chemical cleanings/year). After the successful extrapolation of the new technological procedure, only 1 or 2 chemical cleanings each year are required, with a consequent longer useful membrane life and a significant reduction in the need for their replacement (15% annually, according to the manufacturers).
- Due to the stable and continuous operation over time of the membrane stacks, a significant increase in mean monthly production can be obtained. In the specific case of EMALSA and the LP3 full scale plant, before extrapolation of the new technological procedure production was around 29,000 m^3/d (1997), compared to a design capacity of 36,000 m^3/d, and increased to around 39,000 m^3/d (2001).

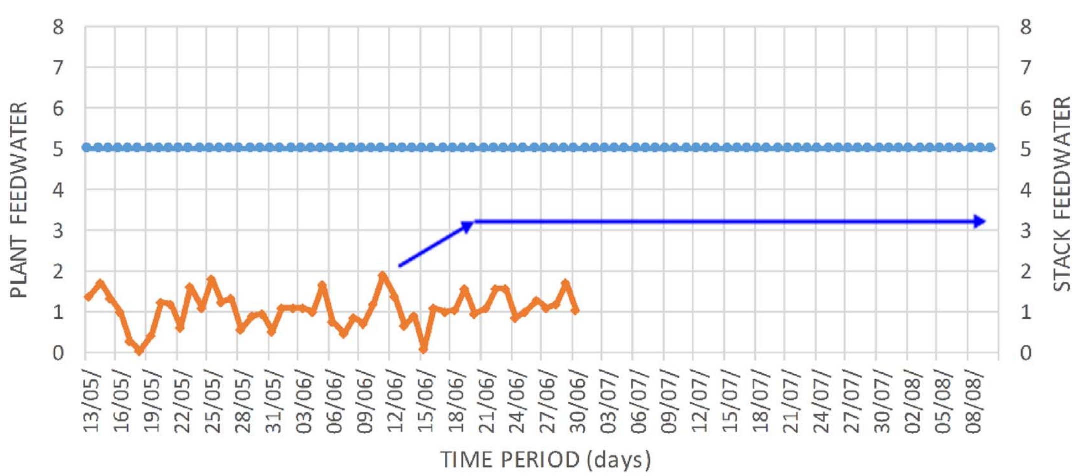

Fig. 5. Plant/Stack feedwater SDI during the study period may-august 2000.

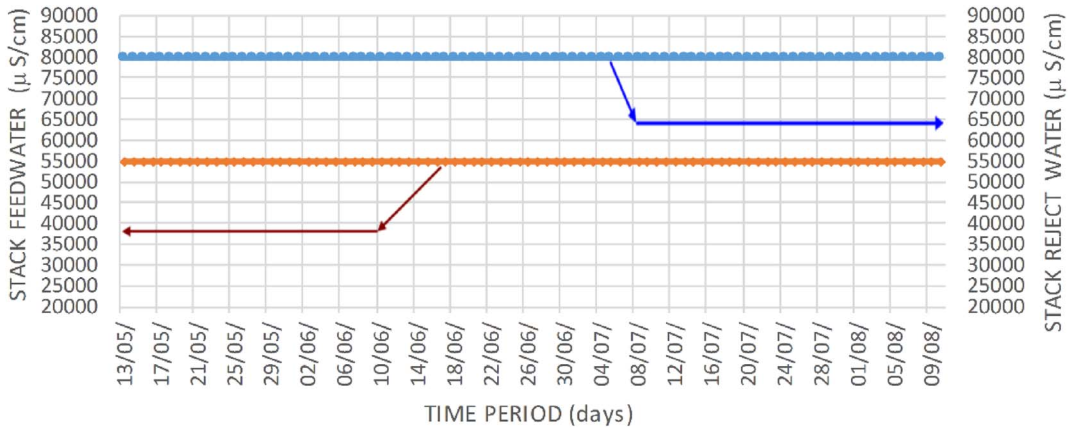

Fig. 6. Stack Feed/Reject Water electrical conductivity during the study period may-august 2000.

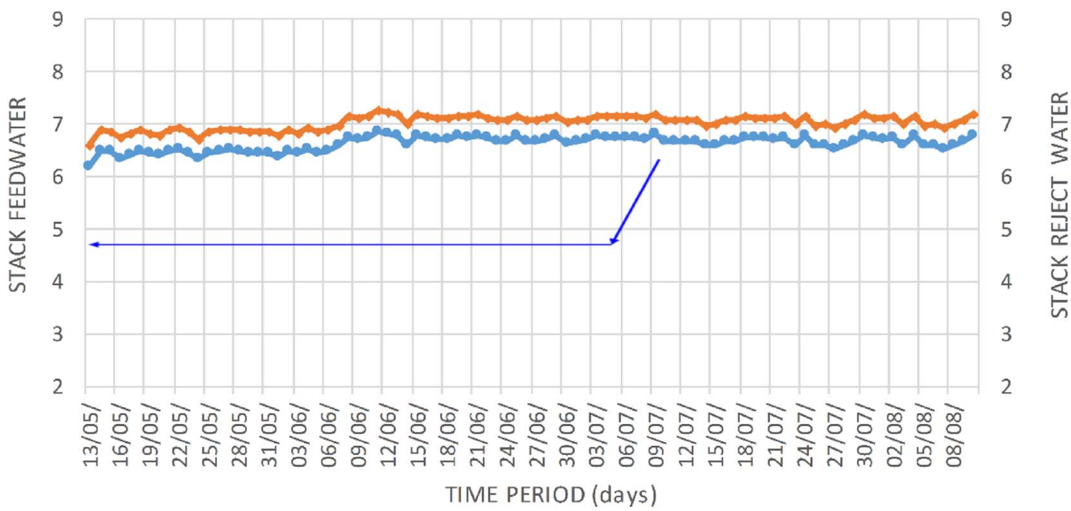

Fig. 7. Stack Feed/Reject Water pH during the study period may-august 2000.

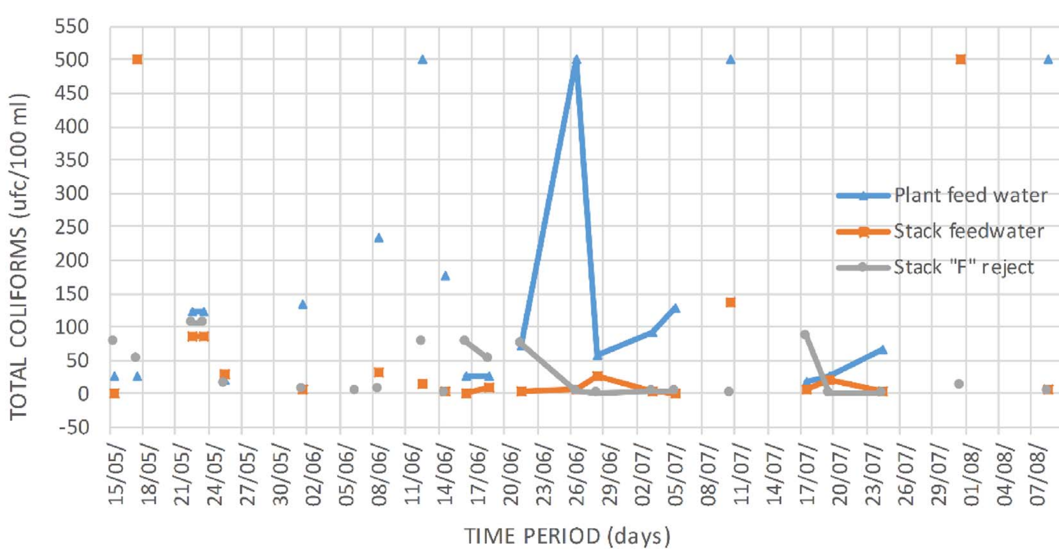

Fig. 8. Total coliforms: plant feedwater/stack "F" reject/stack feedwater during the study period may-august 2000.

5.3. Contributions to environmental protection and conservation

- A significant and important reduction in the typical direct and constant dumping in the sea or other bodies of water in the form of 'reject water' or highly concentrated brine in the so-called 'traditional operation' of desalination plants of thousands of tonnes of chemical products (biocides, scale inhibitors, detergents, foam inhibitors, various acid and alkaline products, etc.). The consequent contamination inexorably and often irreversibly affects the various ecosystems present there, as well as any soils that may be in contact

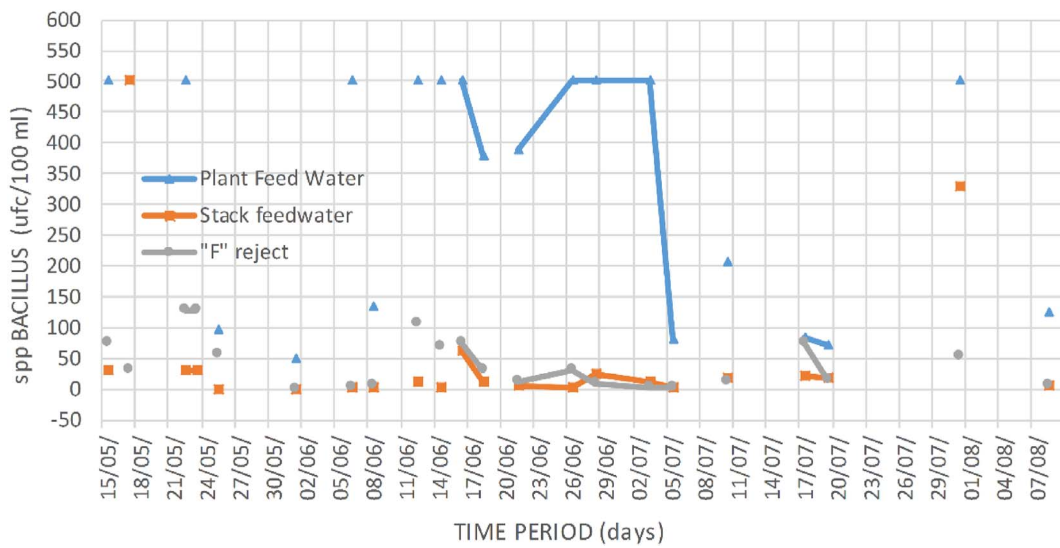

Fig. 9. spp. *Bacillus*: plant feedwater/stack feedwater/"F" reject" during the study period May–August 2000.

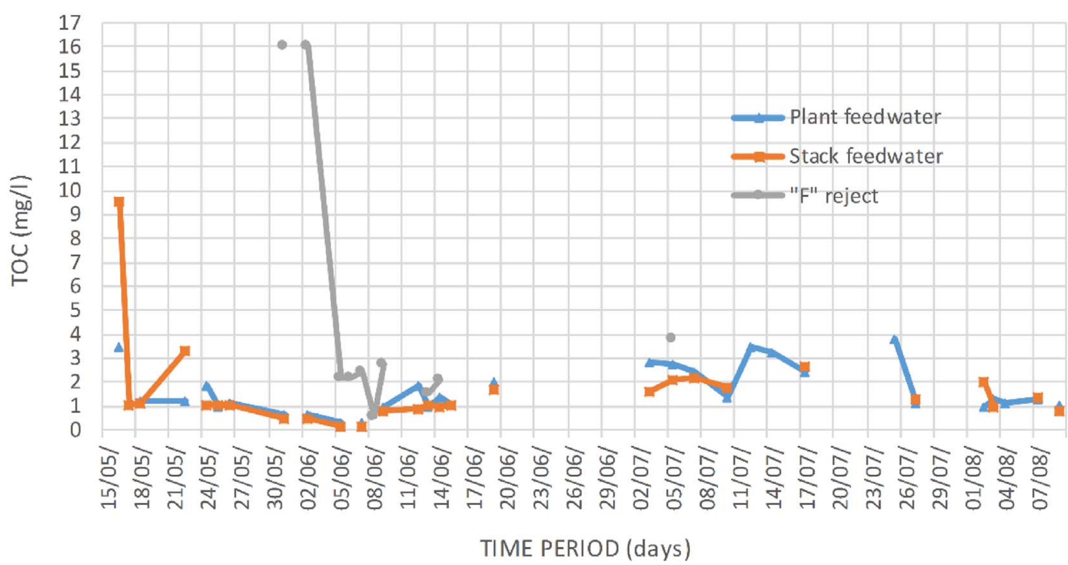

Fig. 10. TOC (mg/l): plant feedwater/stack feedwater/"F" reject during the study period May–August 2000.

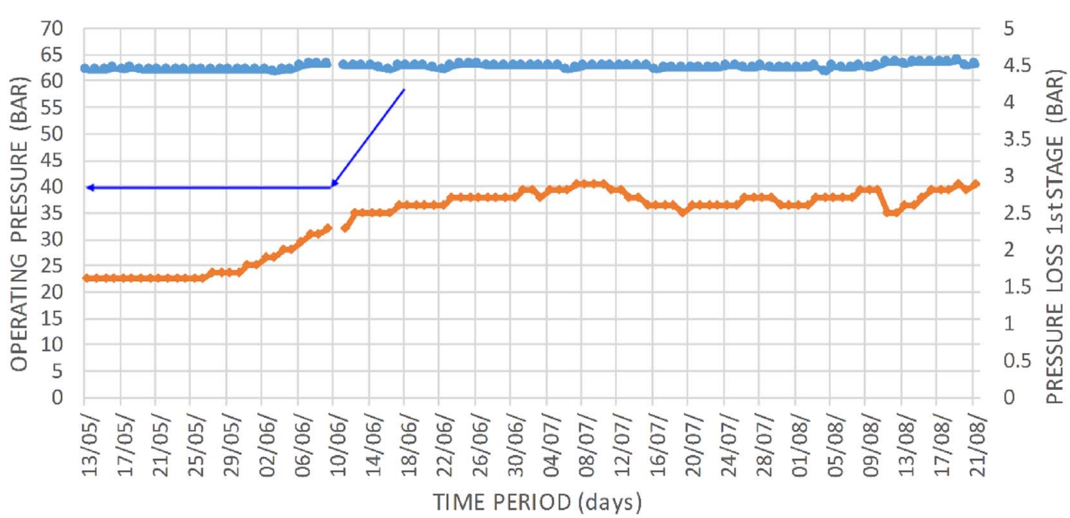

Fig. 11. Operating pressure/Pressure loss: 1st stage during the study period May–August 2000.

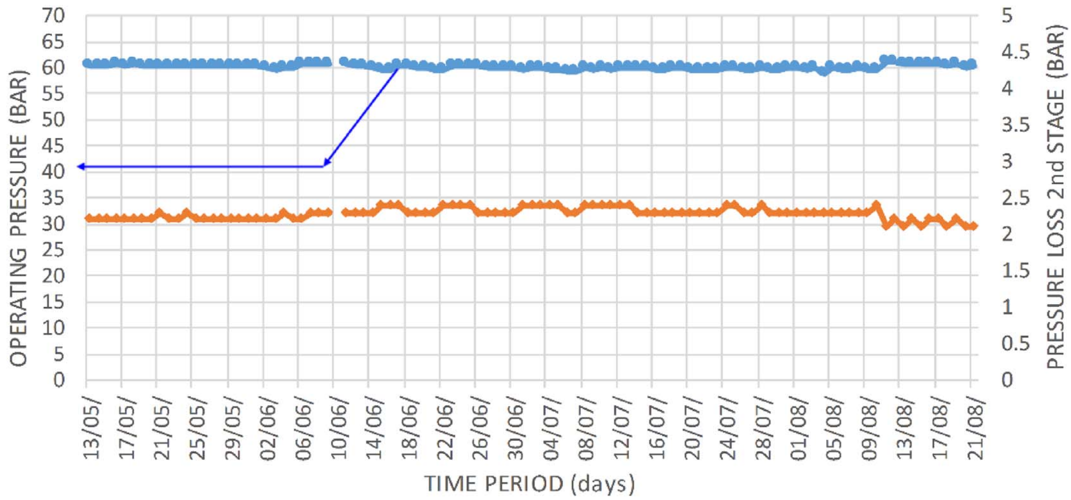

Fig. 12. Operating pressure/Pressure loss: 2nd stage during the study period May–August 2000.

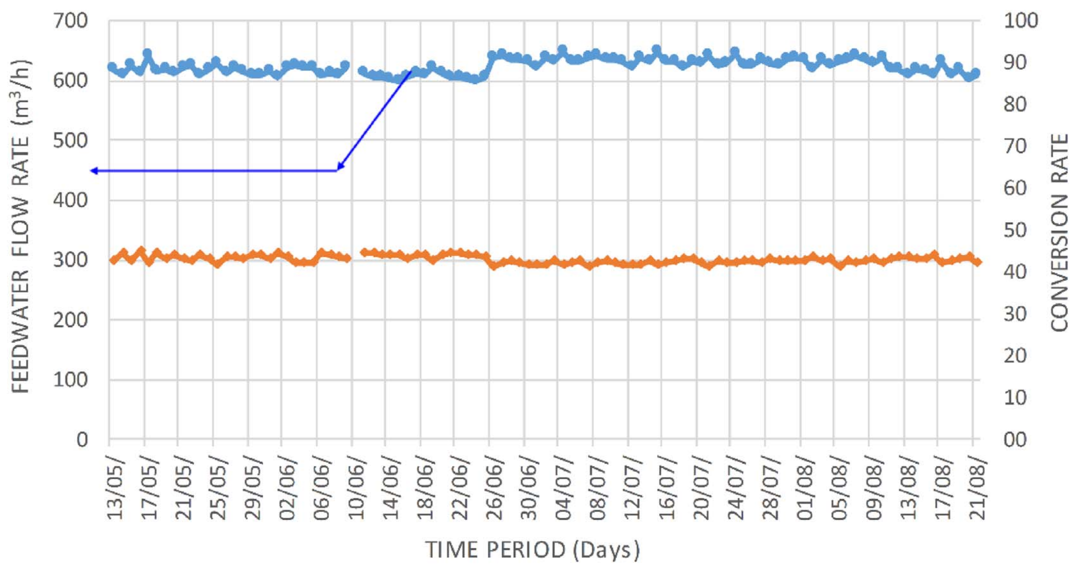

Fig. 13. Feedwater flow rate/Conversion rate during the study period May–August 2000.

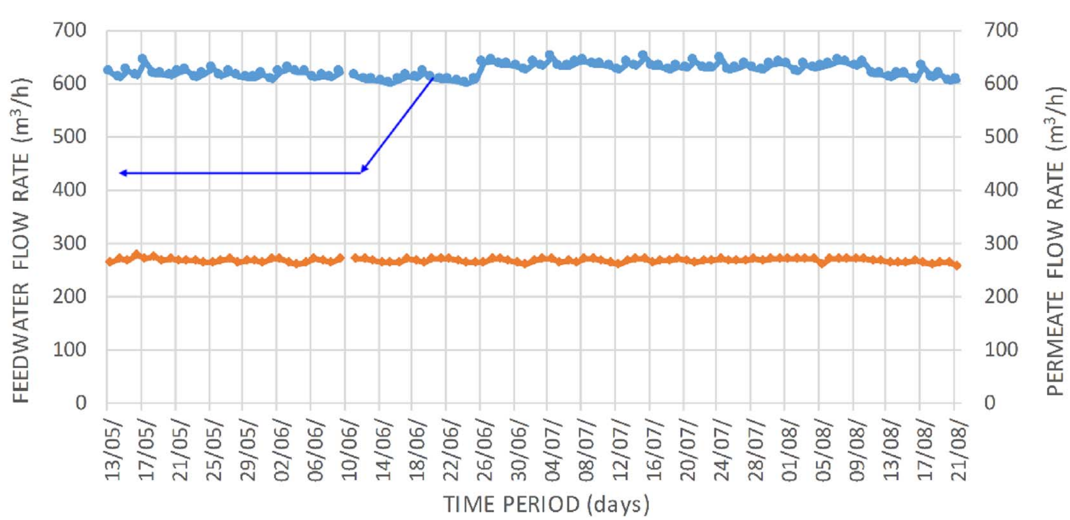

Fig. 14. Flow rate: feedwater/permeate during the study period May–August 2000.

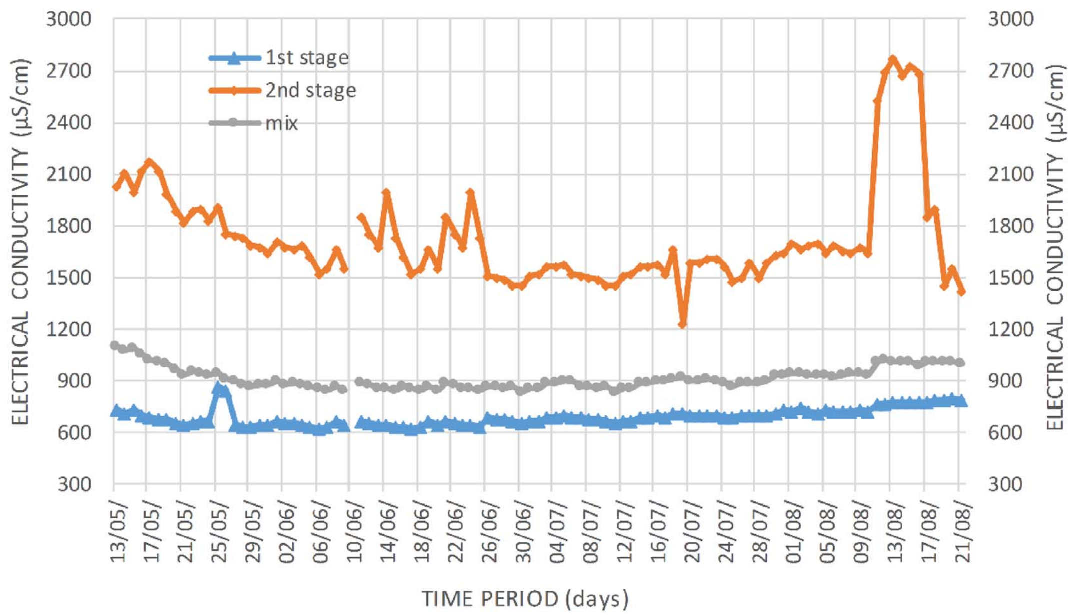

Fig. 15. Electrical conductivity: 1st stage/2nd stage/mix during the study period May–August 2000.

with them.

- The specific elimination of the application of sodium hypochlorite (NaClO) or any other similar biocide to the raw water subsequently subjected to the desalination process in the RO membrane modules fully prevented the possibility of the formation of so-called trihalomethanes, considered dangerous carcinogenic compounds. These compounds are formed through chemical reactions between the chlorine and a series of organic compounds (principally humic and tannic acids, as well as other compounds, which constitute the 'organic' colour of water) which are generally present in surface water bodies (sea/ocean/river/lake water).
- Solution to the worldwide problem of the scarcity of potable water: the contributions of this work (significant reduction in the use of chemical products, excellent control of biofouling, fouling and scaling) simplify the use of RO seawater desalination technology, with lower investment and operating costs and stable operation over time. Consequently, RO technology can be a more economically viable and competitive alternative to other desalination technologies (of river/lake, etc., water), enabling a definitive resolution of the problems of potable water scarcity in many regions of the world, including the Canary Archipelago and other arid areas in Africa, the Middle East, Arabian countries, etc.

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