Desalination and Water Treatment
www.deswater.com
51 (2013) 1817–1830
February
Taylor & Francis
Taylor & Francis Group
1944-3994/1944-3986 © 2013 Desalination Publications. All rights reserved
doi: 10.1080/19443994.2012.704733

Advantages obtained through the elimination of chemical products in the pre-treatment process of large desalination plants for the control of fouling, biofouling and scaling in reverse osmosis membranes

A. Muñoz Elguera*, S.O. Pérez-Báez, A. Gómez-Gotor

Process Engineering Department, EIIC, University of Las Palmas de Gran Canaria, Las Palmas de Gran Canaria, Las Palmas, Spain
Email: amunoz@dip.ulpgc.es

Received 8 March 2012; Accepted 15 June 2012

ABSTRACT

This paper presents the results of research work conducted as part of a doctoral thesis and undertaken with the aim of resolving the problem of *accelerated fouling* of *reverse osmosis membranes* (made from spiral-wound polyamide), as a result of the deposition of colloidal particles (particulate fouling), the precipitation of inorganic salts (scaling) and the accumulation of living and/or dead biological matter (biofouling). The reverse osmosis modules affected form part of the Las Palmas III (LP3) desalination plant run by the company EMALSA (Spanish initials: Empresa Mixta de Aguas de Las Palmas). This plant is located on the island of Gran Canaria (Spain) and supplies potable water to around half a million people.

Keywords: Scaling; Fouling; Biofouling; Reverse osmosis

1. Background

The seawater desalination plant Las Palmas III (LP3) has been at the vanguard of research osmosis desalination technology since the time of its construction with the latest advances available. At the time it was put into operation between the end of 1989 and the start of 1990, the plant was one of the most modern and the largest of its type in the world. The plant has been run since its inauguration by a company called EMALSA (Empresa Mixta de Aguas de las Palmas SA) and is responsible for the supply of potable water to around 500,000 people in the town of Santa Brígida and the city of Las Palmas de Gran Canaria (Canary Islands, Spain) [1–3,5,6,26].

The LP3 plant draws seawater for desalination through an open intake system and, since its inception, has been affected by a series of technical problems which have been growing steadily worse. These problems include accelerated membrane fouling, the presence of unpleasant odours, rapid increases in module pressure loss, rapid falls in the quantity and quality of the water product, etc. These problems have obliged those responsible for running the plant to wash the membranes each 15–20 days, which has obviously had a direct effect on operating costs [2–6].

A research project was formulated during the search for solutions to the aforementioned problems.

*Corresponding author.

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

The project was accepted and one of the authors of this paper, Aldo Muñoz, hired to carry out the research. The results of the study undertaken were very positive as can be seen in the conclusions of the present paper. This research work also formed the basis of a doctoral thesis written by the same author.

2. Desalination plant LP3: initial operating conditions

The LP3 seawater desalination plant, located on the island of Gran Canaria, has a design capacity of 36,000 m^3/d, but an actual mean production rate of 29,000 m^3/d. There is a pre-treatment system and the operating conditions are based on the following criteria [1]:

2.1. Process water capture system

Surface open intake, via a catchment area located in the cooling water sedimentation basin for the UNELCO power station, comprising seven chambers and seven vertical motor pumps (one on standby) with an average pumping capacity of 80,000 m^3/d or 3,300 m^3/h (each pump handles 550 m^3/h, at a pressure of 1.75 kg/cm^2) of seawater.

2.2. The process water pre-treatment system uses the following chemical reagents

Shock dosage of 100 l/h (50 ppm of NaClO) of sodium hypochlorite applied directly to the intake chamber compartments. This biocide dosage is used for the control of microorganisms (viruses, bacteria, fungi, moulds, etc.), algae and molluscs present in the seawater, thereby preventing clogging up of the grilles through which the seawater enters each intake chamber. The same dosage is also used in the seawater pressure line to the plant in order to control microbiological contamination present in the seawater captured for processing and to impede biofouling of the membrane modules [7,19–23].

Approximately 35 l/h of pure sulphuric acid, H_2SO_4, (20 ppm in the processed seawater) is added to strengthen the biocidal action of the NaClO, regulate the pH of the process water to 7.1, and maximize the action of the sodium hexametaphosphate which is often applied in measured quantities to impede membrane scaling [1,10,13,15,25,26].

The coagulant Cl_3Fe is applied proportionally to the untreated water flow which feeds the plant by means of two metering pumps which convey approximately 15 l/h of pure Cl_3Fe (some 6 ppm in the processed water). This is done to favour the removal of matter in a state of dispersion and/or suspension such as solid inorganic particulate matter (colloidal particles) and emulsified oil particles which may be present in the feed water and whose removal is undertaken through successive and complementary processes of coagulation and flocculation [9,11,12,14,16,18].

It is known that sand filters do not remove soluble oils (unlike anthracite and activated carbon) and that their filtering cut-off point for suspended particulate matter is of the order of 10–20 μm. Even at the end of the filtration run (clogged filter), particles smaller than 5 μm are not removed. These circumstances mean that a secondary filtration stage is required to remove particles that the gravity filters were unable to deal with, like microfloccules and dispersed particles. This stage comprises a booster pump room, precoat filters and safety filters. Also important to note is the dosing in of sodium metabisulphite and sodium hexametaphospate (HMF).

Since in the pre-treatment stage sodium hypochlorite has been dosed into control the microbiological problems affecting the process water, and since the membranes installed in the modules are of polyamide and cannot enter into the slightest contact with any chemical oxidizing agent, the residual chlorine which may still be present in the effluent seawater of the safety filters must be totally neutralized with sodium metabisulphite ($NaHSO_3$).

Using two metering pumps, a 20% (by weight) sodium metabisulphite solution is dosed in at the filter outlet proportionally to the concentration of residual chlorine present in the water, approximately 15 l/h (some 15 ppm in the process water). This chemical reagent is dosed into avoid the precipitation of dissolved salts that might be present in the water that enters into contact with the membranes, when they exceed their saturation concentrations. These include, principally, carbonates, sulphates and/or fluorides of the alkaline earth metals (Ca, Mg, Ba, Mn, etc.), iron, silica, etc. [5,9,11].

The HMF is dosed in at 25% solution proportionally to the raw water flow which feeds the plant via pumps which inject it into the pre-treated water pressure line, just before the safety filters, at approximately 30 l/h (some 6 ppm in the process water).

3. Aims of the research project

In light of the above, it was determined that the main aims of the research project would be:

(1) To undertake a detailed study of the drastic and accelerated fouling process of the reverse osmosis

membranes installed in the module frames of the commercial seawater desalination plant LP3, with open intake surface catchment [1–4,6].

(2) To formulate the most appropriate procedure to minimize the accelerated fouling process to levels recommended by the membrane manufacturers (one or, at most, two membrane washes per year), thereby resolving the various technical problems [2–4,6].

In order to achieve the aforementioned aims, the following partial objectives were also defined for progressive implementation:

(1) To undertake a more detailed theoretical study of so-called membrane technology and reverse osmosis desalination techniques for the removal of salts from seawater, in order to obtain a full and complete knowledge and understanding of their theoretical fundamentals and the mechanisms which govern their operation. This study would then be used as the basis for the formulation and execution of the research project [7–10,15,17,24].
(2) To identify, prioritise and study the technical problems and main reasons for the problems affecting the operation of the LP3 plant.
(3) To formulate and test at pilot plant level technological procedures that would enable appropriate control of the main reasons for the technical problems in question [2,3,6].
(4) To extrapolate the most appropriate test results obtained from the pilot plant to the actual commercial plant.

4. Test procedure

A description is provided in this section of the test procedure, comprising three stages, that was followed to reduce the fouling problems of the polyamide spiral-wound membranes of the LP3 desalination plant.

The specific preliminary research work in the process sections comprised, firstly, consideration of the shock dosage of sodium hypochlorite in the catchment area. The final conclusion was to definitively suspend this dosage of 50 ppm of NaClO in the seawater catchment area, but to maintain the same dosage in the feed line to the plant. A detailed description of the test procedure can be consulted in reference [3]. Secondly, consideration was given to optimization of the dosages of ferric chloride (Cl_3Fe) in the plant's pre-treatment line [1,2]. Jar tests were performed to determine the optimum dosage. Various seawater samples which were taken from the catchment area over a two-month period were used for the jar tests with different dosages of Cl_3Fe. It was determined that the optimum dosage required for the seawater was 12.5 ppm. Thirdly, the dosages of sodium hypochlorite and sodium metabisulphite in the plant's pre-treatment line and refinement treatment were optimized [6]. The final concentrations were set at 0.5 ppm of residual sodium hypochlorite at the outlets of the candle filters and 1 ppm of sodium metabisulphite dosed in for the complete neutralization of any residual chlorine. Finally, the matter that was deposited on the active layer of the membranes was identified after a membrane autopsy performed by the chemical company Houseman (Manchester, England) employing physical, chemical and microbiological techniques. The results, amongst others, revealed that 47% of the matter was organic (namely the amount of the sample which is lost or burnt when subjected to heating of up to 550°C) and 50% inorganic, comprised mainly of 30% silica [4]. A microbiological analysis was also conducted of matter deposited on the membrane surface, the feed channel spacer and the internal spacer which takes the permeated water. Identification was made of staphylococcus, arthrobacter and sulphate-reducing bacteria, and fungi in the form of genus aspergillus.

4.1. Hypothesis for investigation in the pilot plants

The bases of the research work to be tested at two pilot plants, Toyobo and EM, were defined as:

(1) Control of scaling via dosages of H_2SO_4, to regulate to an appropriate pH value the seawater which feeds the membrane modules, instead of the use of scale inhibitors like hexametaphosphate as used in the commercial plant.
(2) Control of fouling through optimization of the coagulation–flocculation process and optimization of the plant's filtration units.
(3) Control of biofouling through the experimental testing of two hypotheses resulting from the preliminary work that was undertaken [2,3,6]. These hypotheses were:
   (A) Continuous dosing of sodium hypochlorite (0.5 ppm) in the seawater without its neutralization with sodium metabisulphite, thereby allowing uninterrupted contact between the biocide and membrane which would necessarily require a high degree of tolerance towards this biocide

(tests were conducted on the Toyobo experimental plant, equipped with hollow fibre cellulose triacetate membranes [2,3].

(B) No dosing of sodium hypochlorite (or any other biocide) in the seawater in the pre-treatment stage. This was specifically tested at the EM pilot plant which was manufactured in exactly the same way as the commercial plant and equipped with polyamide spiral-wound membranes which are extremely sensitive to oxidizing biocides (NaClO, $Ca(ClO)_2$, O_3, H_2O_2, etc.).

4.2. Protocol for the experimental tests conducted at pilot plant level

A brief description is provided in this section of the aims, duration and sequence for each of the experimental tests that were conducted at each of the two pilot plants.

The first test plant, TOYOBO, was equipped with hollow fibre, cellulose triacetate membranes (Hollosep HM10255FI). This plant was provided for the research study as a result of a technical cooperation agreement prepared by the Public Works Studies and Experimentation Centre (Spanish initials: CEDEX) between EMALSA and the Japanese company TOYOBO, manufacturer of Hollosep HM10255FI membranes, who financed the aforementioned test plant [2,5].

The second test plant, EM, commissioned by EMALSA at a cost of €180,000, was designed as a smaller scale replica of the commercial desalination plant, with its own fully autonomous automatic control system. This plant was built for the specific purpose of undertaking the research work described in this paper. It was equipped with spiral-wound polyamide membranes.

4.3. Protocol for the TOYOBO test plant

The experimental tests which were conducted at this plant are described in reference [2], with the establishment of the following objectives: firstly, to examine the feasibility and improved performance of hollow fibre cellulose triacetate Hollosep HM10255FI modules against hollow fibre polyamide membranes, and secondly to confirm or otherwise two hypotheses formulated on the basis of the preliminary research work. These hypotheses were as follows:

- That any intermittent biocide dosage (of NaClO, Ca $(ClO)_2$, O_3, H_2O_4, etc.) in water to be desalinated using a reverse osmosis system is always less favourable than continuous dosage of the biocide. Therefore, the process water should contain the dosage of biocide from the moment it is fed to the plant until it exits the cellulose triacetate membrane modules as reject. If the membranes are polyamide based, then no dosage of any biocide should be applied.
- It is possible to adequately control the scaling process only through H_2SO_4 dosing of the process water in order to regulate at 6.5 the pH of the water which feeds the membrane modules. This type of fouling principally affects the quality of the permeate (total dissolved solids, TDS and/or electrical conductivity).

The experimental tests were therefore conducted in this test plant in two stages:

Stage 1, between June and September 1998. Testing was conducted of the desalination process using Hollosep HM10255FI membranes with seawater at a pH of 7.1 and intermittent NaClO dosing (30 contact minutes of biocide and membrane each 24 h).

Stage 2, between October 1998 and April 1999. The specific process was tested using Hollosep HM10255FI membranes with seawater at a pH of 6.5 and continuous NaClO dosing of 0.5 ppm.

4.4. Protocol for the EM test plant

Using as a reference the preliminary work described above and conducted on the TOYOBO test plant and the commercial plant, for determination of the seawater pH to feed the membrane modules and of the optimum dosage of Cl_3Fe, and above all in pursuance of the primary objective, namely the identification of a new technological procedure that would enable minimization of the accelerated fouling of spiral-wound polyamide membranes used in the commercial plant, an experimental procedure was designed for the EM test plant which comprised the following three stages:

Stage 1, between April 13 and June 15, 1999. Tests were conducted for specific adjustment of the chemical dosages previously determined, and the effect that such adjustments had on the quality of the pre-treatment and refinement treatment effluent water:

- Sulphuric acid dosing (H_2SO_4) to regulate to pH 6.5 the pre-treated seawater that would feed the reverse osmosis membranes
- Dosing of the coagulant ferric chloride (Cl_3Fe), with 12.5 ppm being the optimum dosage for the raw water which must then undergo highly efficient flocculation and filtration
- Optimization in terms of efficiency and maintenance time of each filtration unit (sand, precoat and safety), and evaluation of their respective operation

- Determination of the sampling points over the pre-treatment process, and physical, chemical and microbiological analyses to enable evaluation in quantitative terms of the operation and efficiency levels of the pre-treatment process as a whole
- Definition of the operating parameters in order to quantitatively evaluate the efficiency of each unit and/or unitary process of the pre-treatment process in the pilot plant
- Preparation of the formats for data collection (parameters, analyses, etc.) which needed to be put together for evaluation of the results of the experimental tests

Stage 2, between June 16 and October 1999. The pre-treatment operating conditions which were optimized in the first stage were maintained during this second period. Suitably pre-treated seawater was fed to the membrane modules of the pilot plant which was put into operation on the first day of this second stage. It was observed that the operating parameters of the pilot plant frame, such as first-stage pressure drop ($\Delta P1 = 4$ bar), second-stage pressure drop ($\Delta P2 = 6$ bar), permeate flow ($Qp = 24$ m^3/day) and permeate quality (1,700 μS/cm), were very different to the operating parameters of the commercial plant ($\Delta P1 = \Delta P2 = 1.5$ bar, PQ = 800 μS/cm, with a design permeate flow for the pilot plant of around 31 m^3/day). It was therefore decided to increase the diameter of the high pressure line pipes (from 0.5 to 1 inch) and the internal diameter of the coupling hoses (from 10 to 20 mm) between the pressure tubes and between these and the high pressure line pipes (316-L steel).

Stage 3, between 3 November 1999, and April 2000. The pre-treatment operating conditions which were optimized in the first stage were maintained during this third period. Suitably pre-treated seawater was fed to the membrane modules of the pilot plant which was put into operation for the second time. It was observed in this third stage that there was a considerable change in the operating parameters of the frame of the pilot plant: first-stage pressure drop ($\Delta P1 = 1.7$ bar), second-stage pressure drop ($\Delta P2 = 3$ bar), permeate flow ($Qp = 34$ m^3/day) and permeate quality (1,150 μS/cm) were considerably closer to the corresponding parameters of the commercial plant.

5. Analysis of the test results

This section presents a discussion of the results of the tests conducted at each of the pilot plants. The collected data are presented in graphical form, with detailed observation over time of the following:

- Analytically determined seawater quality parameters (physical, chemical and microbiological) throughout the desalination process, from the moment the water is fed to the pilot plant to when it is rejected as brine.
- The operating parameters of each section, particularly the membrane modules installed in the TOYOBO test plant (HM10255FI: CTA—hollow fibre configuration) and the EM test plant (polyamide—spiral wound configuration).

5.1. Characteristics of the seawater fed to the pilot plants

The raw seawater, obtained through an open intake surface catchment system, and which was fed to the LP commercial plant as well as the TOYOBO and EM test plants, had the following characteristics:

Physical quality parameters

$T_{min} = 15$°C	$T_{max} = 25$°C	$T_{average} = 20$°C
$Turb_{min} = 0.42$ UNT	$Turb_{max} = 1.62$ UNT	$Turb_{average} = 1.0$ UNT
$SDI_{min} = 4.6$	$SDI_{max} = 8.5$	$SDI_{average} = 5.5$

Chemical quality parameters

$pH_{min} = 7.9$	$pH_{max} = 8.2$	$pH_{average} = 8.1$
$TOC_{min} = 1.14$	$TOC_{max} = 3.69$	$TOC_{average} = 1.8$
$CE_{min} = 53{,}300$ μS/cm	$CE_{max} = 55{,}800$ μS/cm	$CE_{average} = 55{,}000$ μS/cm

Microbiological quality parameters

$CT_{min} = 50$ cfu/100 ml	$CF_{max} = 500$ cfu/100 ml
$CF_{min} = 12$ cfu/100 ml	$CF_{max} = 200$ cfu/100 ml
Bacillus $SPp = 60$ cfu/100 ml	Bacillus $SPp = 600$ cfu/100 ml

6. Conclusions of the research work

As a result of a totally objective analysis of all the data analytically obtained in the laboratory, as well as of the operating parameters of the two pilot plants used for this research study, it was possible to realize the objectives that were initially established. The conclusions corresponding to each of the principal stages of the study are set out below. The results were used as part of the doctoral thesis of one of the authors of this paper and have made a scientific/technological contribution to reverse osmosis technology.

6.1. Conclusions of the tests conducted at the TOYOBO test plant

The results for the Hollosep HM10255FI membranes represent an interesting alternative to polyamide spiral-wound membranes, based on the following aspects:

(1) It can be observed from an analysis of the test results in the first stage, when seawater with a pH of 7.1 was fed to the pilot plant, that in just 4 months, even though some operating parameters varied only very slightly, the electrical conductivity of the permeate rose from 300 to 850 µS/cm (Figs. 1–4). Meanwhile, in the second stage when seawater with a pH of around 6.5 was fed to the pilot plant for the 7 months of the test period, the flow and quality (electrical conductivity) of the permeate was approximately constant at around 250 µS/cm (Figs. 5–8).

(2) In terms of NaClO dosing and taking into account the results of a series of preliminary research studies conducted in the catchment area and other pre-treatment sections of the LP3 commercial plant, as well as the results at the TOYOBO test plant, it was shown that in order to maintain the microbiological quality of the seawater continuous dosing of an oxidizing biocide (0.5 ppm de NaClO) (Figs. 6–8) is more suitable than intermittent dosing as the latter encourages a slow biofouling process. Continuous NaClO dosing clearly helps to maintain stable operation of the membranes, which in turn results in constant flow and quality of the permeate (Stage 2).

(3) The performance of the Hollosep HM10255FI cellulose triacetate membranes in the second stage

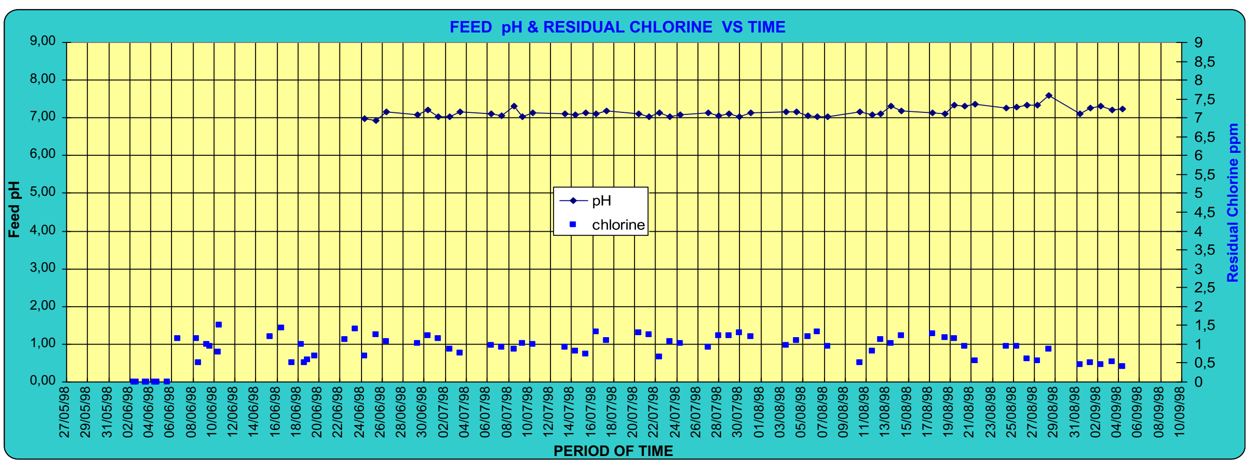

Fig. 1. Analysis of test data: Toyobo pilot plant (Stage 1).

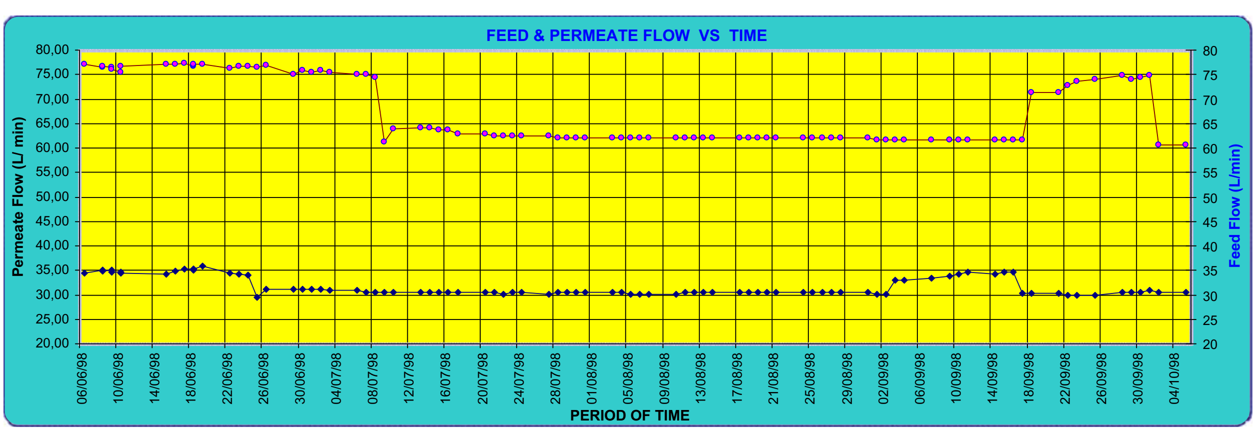

Fig. 2. Analysis of test data: Toyobo pilot plant (Stage 1).

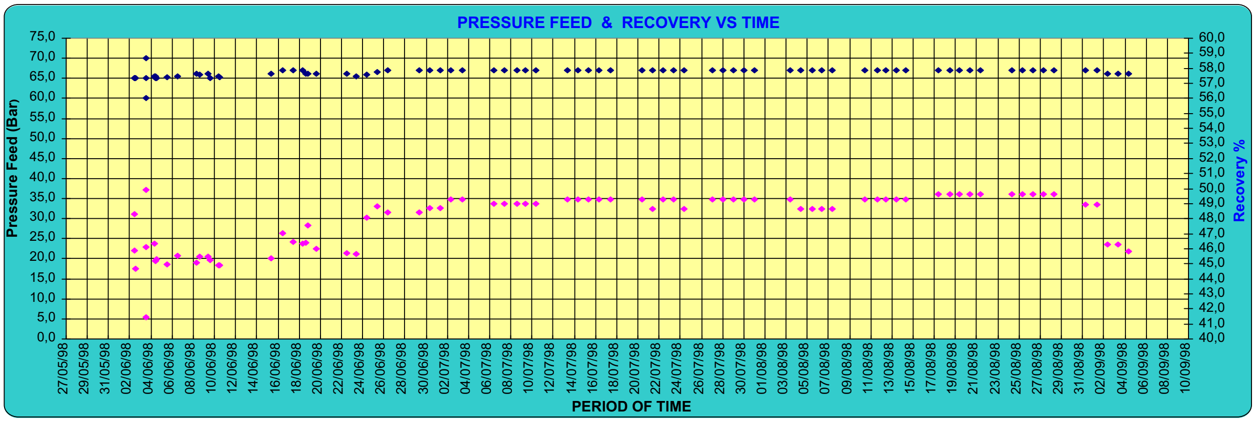

Fig. 3. Analysis of test data: Toyobo pilot plant (Stage 1).

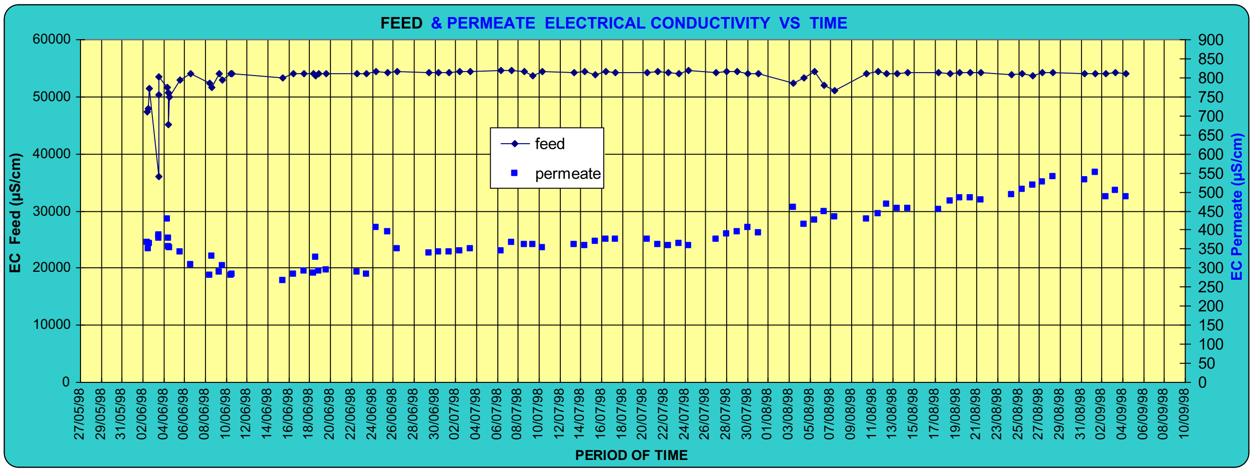

Fig. 4. Analysis of test data: Toyobo pilot plant (Stage 1).

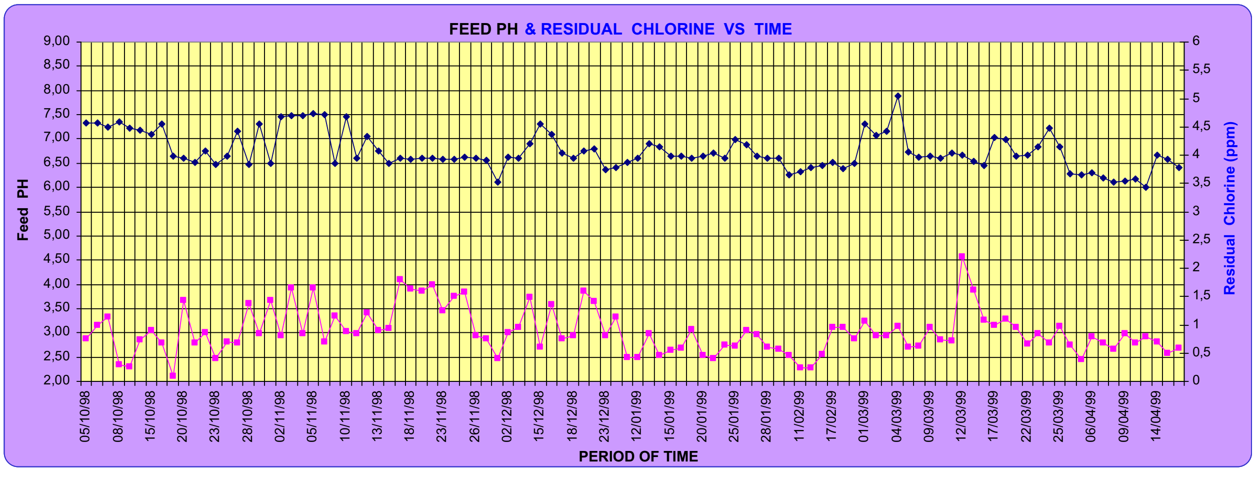

Fig. 5. Analysis of test data: Toyobo pilot plant (Stage 2).

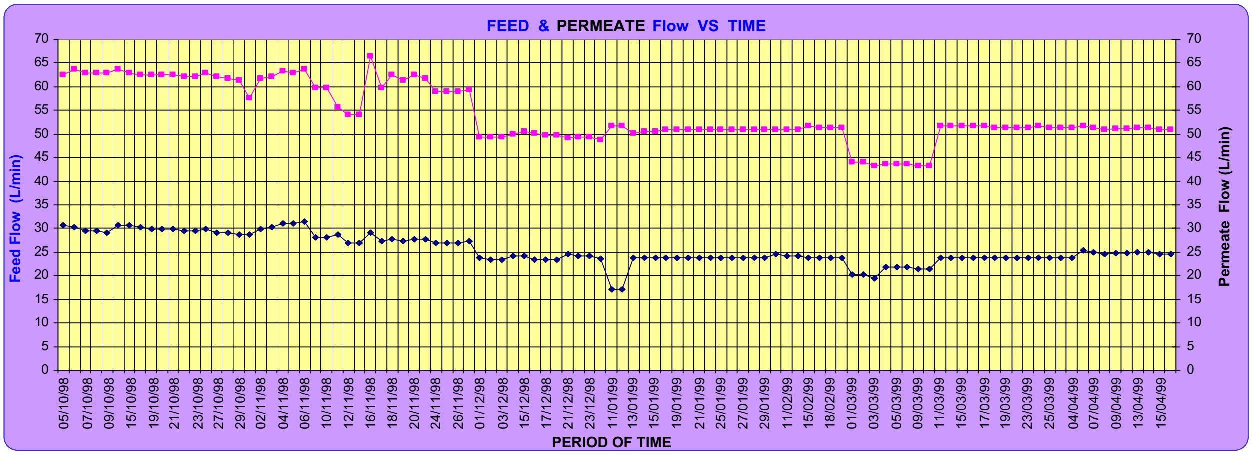

Fig. 6. Analysis of test data: Toyobo pilot plant (Stage 2).

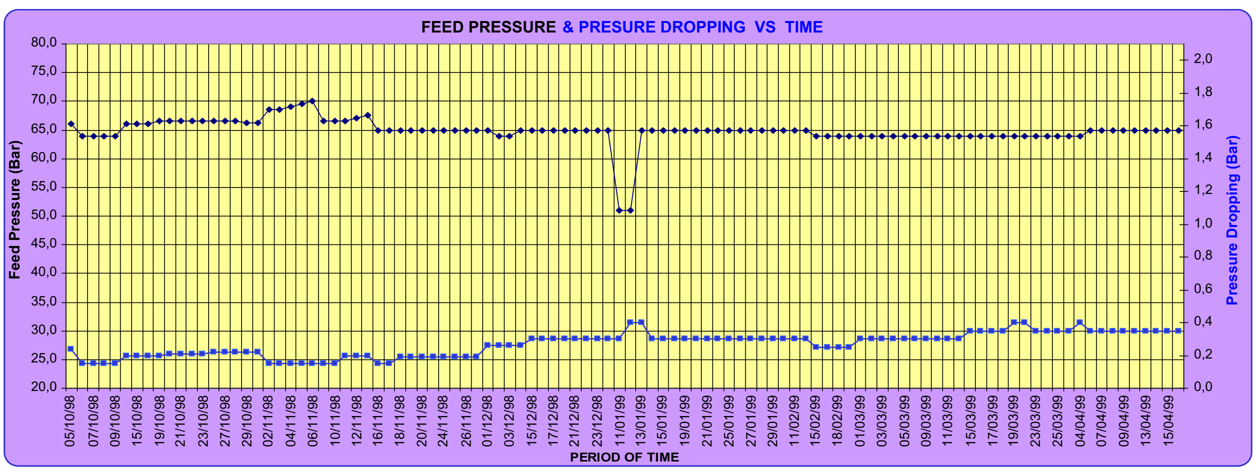

Fig. 7. Analysis of test data: Toyobo pilot plant (Stage 2).

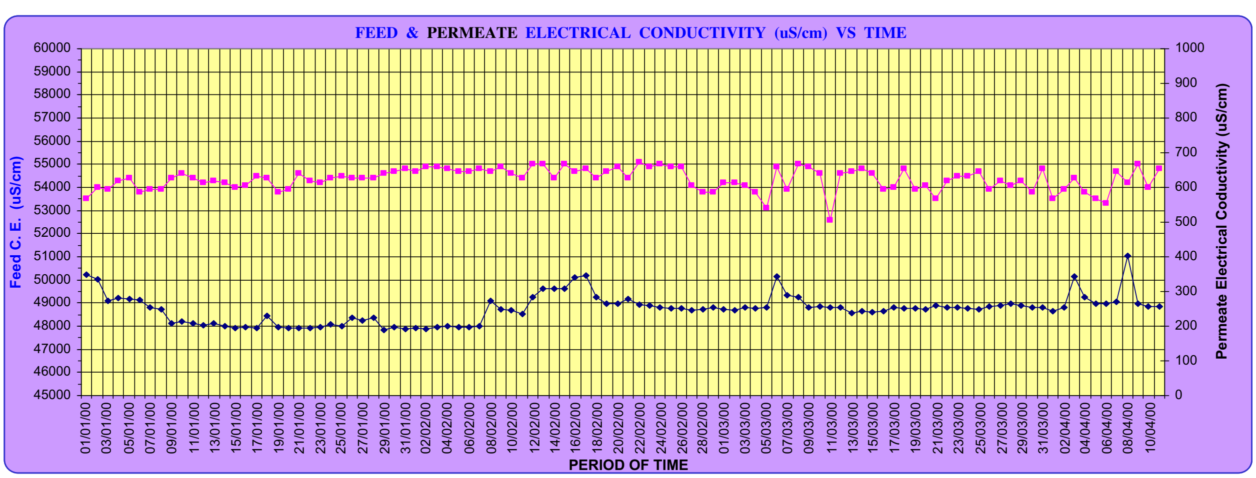

Fig. 8. Analysis of test data: Toyobo pilot plant (Stage 2).

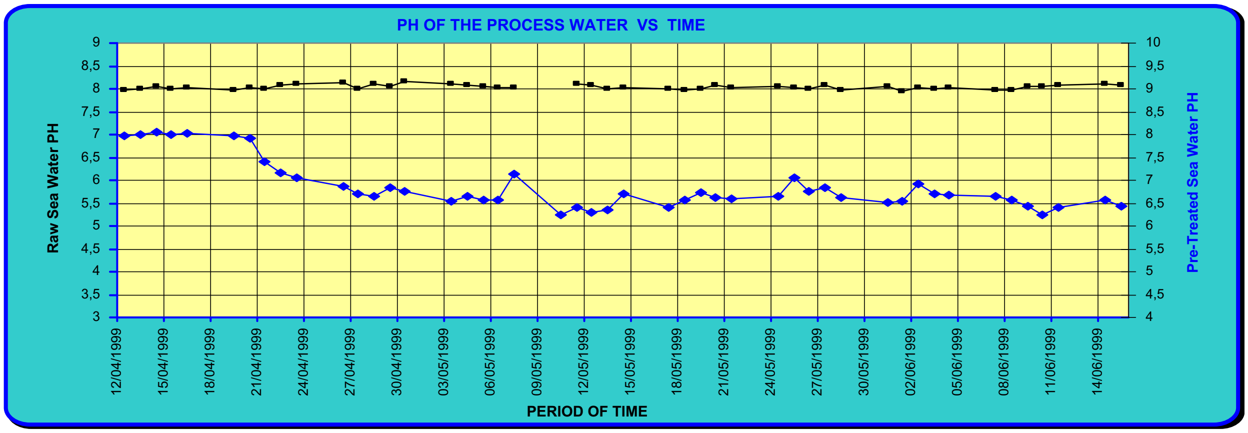

Fig. 9. Analysis of test data: EM pilot plant (Stage 1 and 2).

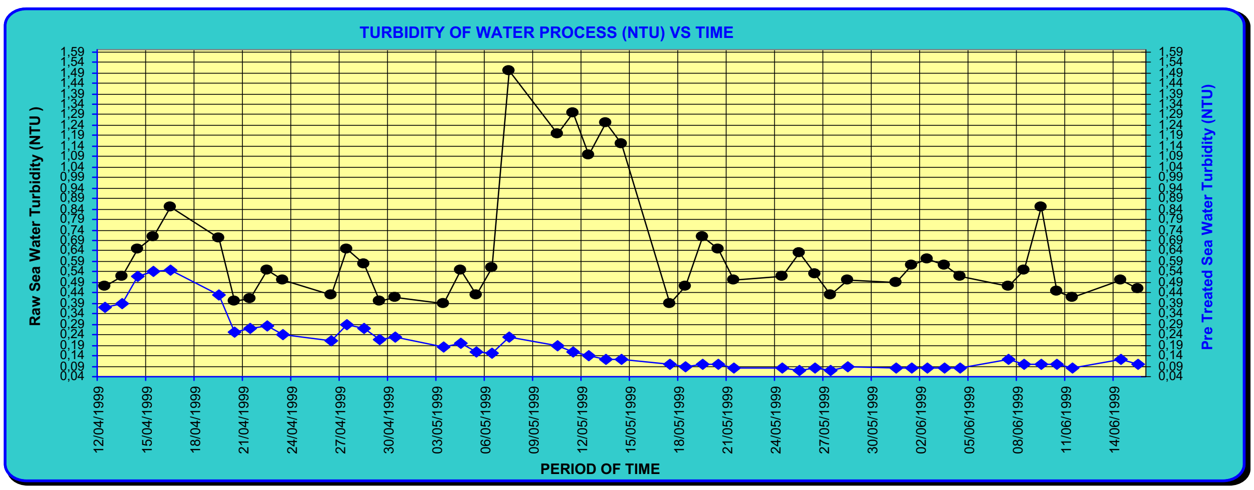

Fig. 10. Analysis of test data: EM pilot plant (Stage 1 and 2).

(pH = 6.5, and 0.5 ppm continuous NaClO dosing) showed under test evaluation conditions the high tolerance to fouling, biofouling and scaling of these membranes. They are capable of stable operation for long periods of time, maintaining practically constant permeate water flow and quality, with an even higher quality (250 to 300 µS/cm) and low pressure drop (0.3–0.4 bar) (Figs. 6–8). This contrasts with the spiral-wound polyamide membranes (700–900 µS/cm and greater pressure drop of 2–4 bar).

6.2. Conclusions of the experimental tests conducted at the EM pilot plant

The main aim of the research work conducted at the EM pilot plant was to determine an alternative technology that would enable control of the accelerated fouling process that was having a critical effect on the polyamide spiral-wound membranes installed in the module frames of the LP3 seawater desalination plant.

(1) The definitive suspension of sodium hypochlorite (NaClO) dosing, and the non-use of any other biocide for the seawater that was fed to the membrane modules of the pilot plant, enabled appropriate control of microbiological growths in the process water. This in turn allowed minimization to a large extent of the biofouling process of the reverse osmosis membranes (Figs. 13 and 14). This result, in addition to the implementation of the so-called operating requirements (acid wash of the sand of the filters, disinfection with $KMnO_4$ of the sand and filter cartridges of the precoat

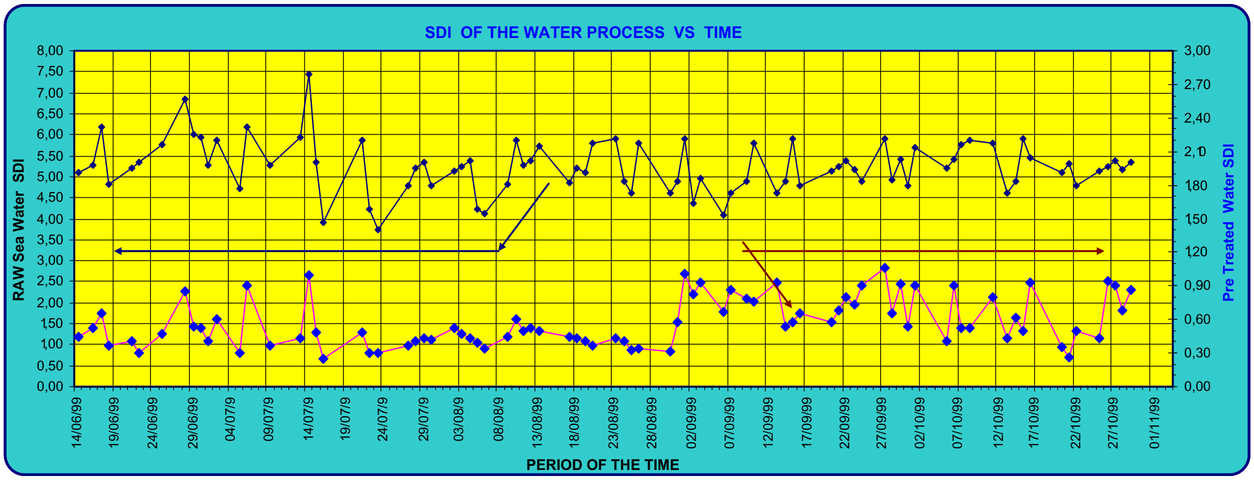

Fig. 11. Analysis of test data: EM pilot plant (Stage 1 and 2).

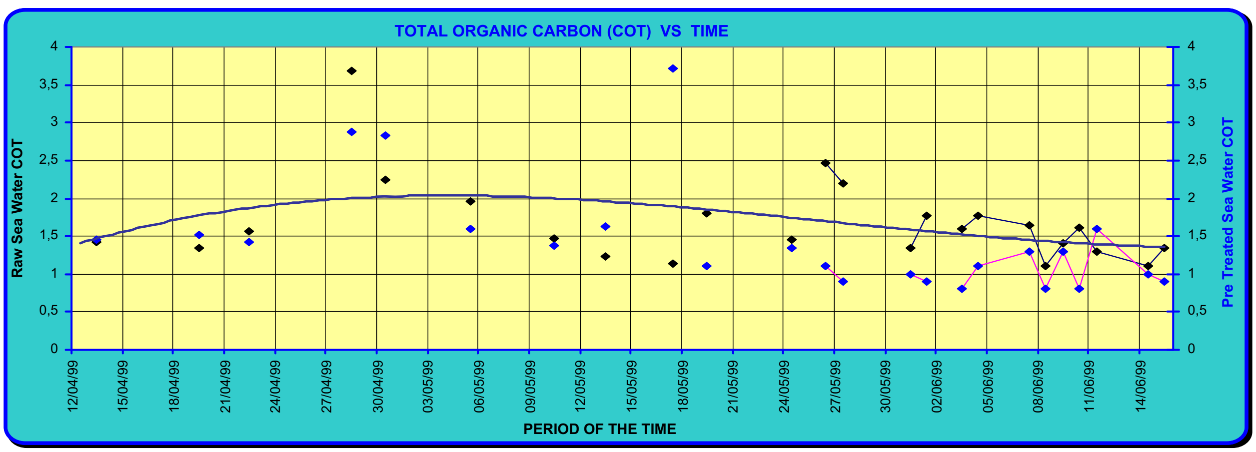

Fig. 12. Analysis of test data: EM pilot plant (Stage 1 and 2).

and safety filters) is the most relevant in terms of scientific contribution of the research work undertaken as part of a doctoral thesis as it constitutes an alternative technological procedure to the traditional procedure of operating seawater desalination plants using reverse osmosis membranes with an active polyamide layer.

(2) It was possible to adequately control scaling of the reverse osmosis membranes by regulating at around 6.5 the pH of the feed water to the pilot plant's membrane modules with sulphuric acid (H_2SO_4) dosing. This was a consequence of the results obtained in the Toyobo pilot plant and the analysis of the test results from the EM pilot plant (Figs. 14–17).

(3) It was possible to maximize the removal of colloidal particles and also of the microorganisms present in the process water, notably improving the quality of the water fed to the membranes (Figs. 9–13), by implementing optimum ferric chloride (Cl_3Fe) coagulant dosing at around 1.5 ppm, even though this was not complemented with appropriate siting of the dosing point, determination of optimum agitation or optimum pH, which normally allow maximization of the coagulation processes. By comparing the process water parameters for physical quality, turbidity and SDI before and after the filtration units in the EM pilot plant, it can be seen that the implementation of the aforementioned coagulant dosage clearly resulted in the improved performance of the complementary processes of coagulation and flocculation with respect to the initial operating conditions of the plant.

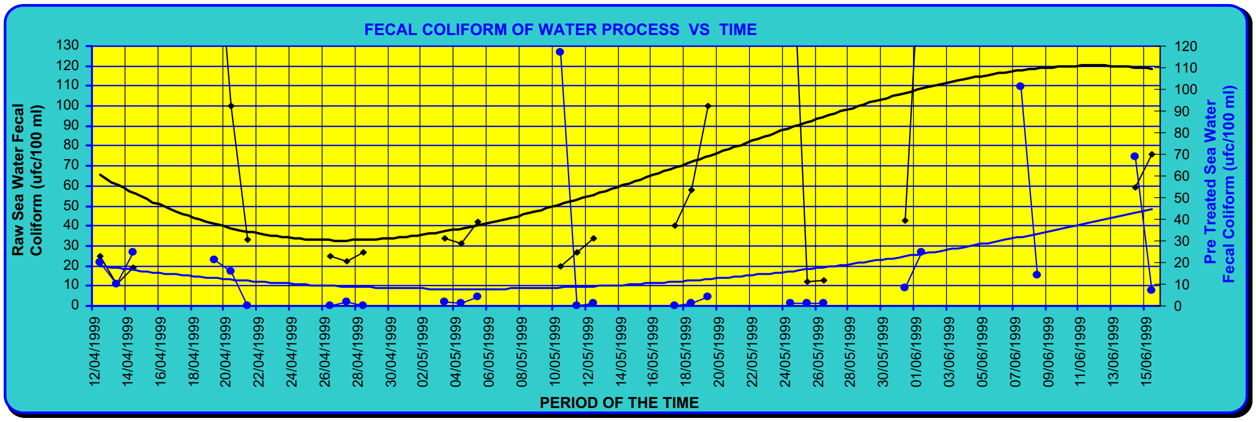

Fig. 13. Analysis of test data: EM pilot plant (Stage 1 and 2).

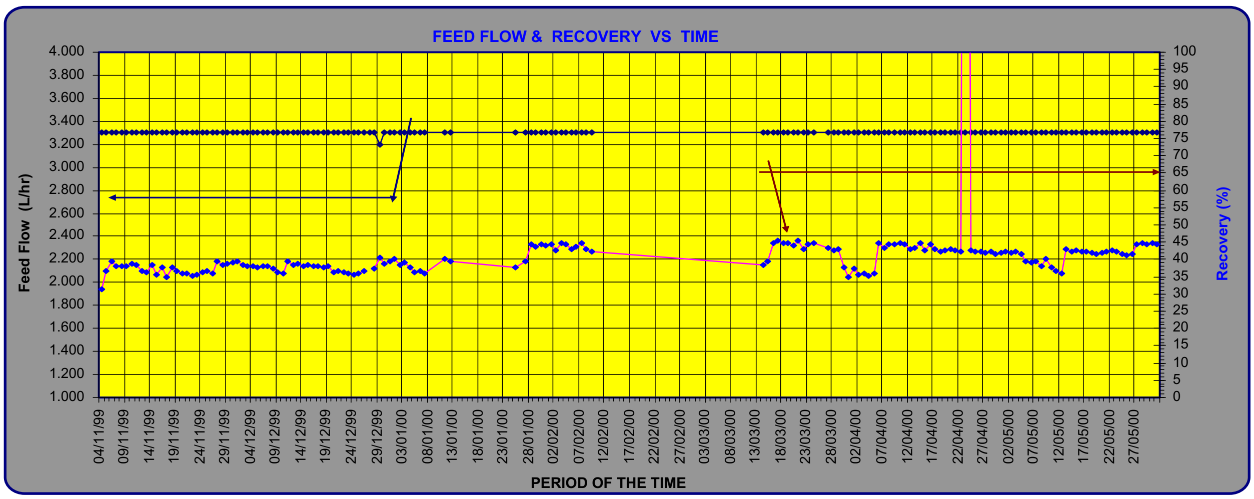

Fig. 14. Membrane performance: stage 3.

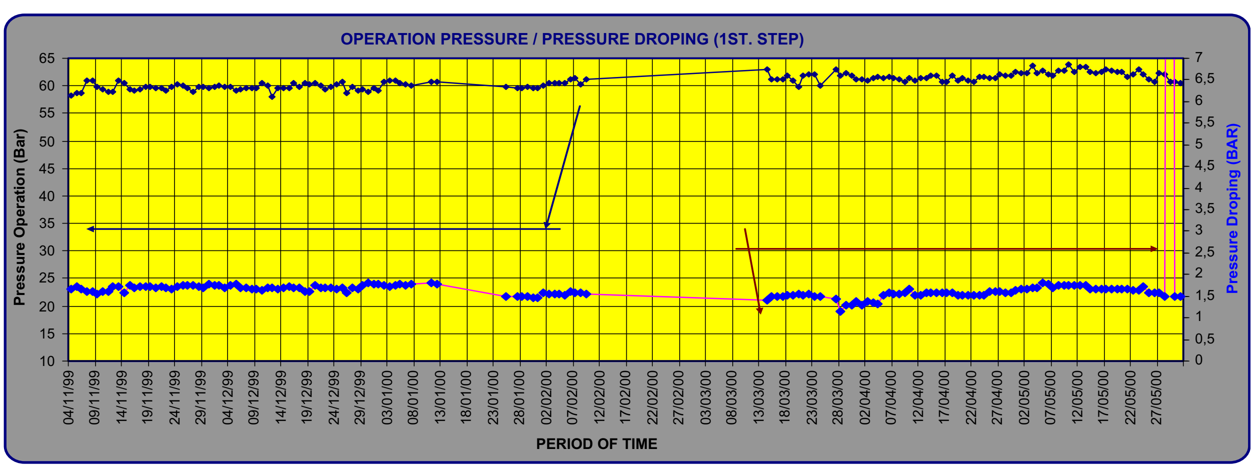

Fig. 15. Membrane performance: stage 3.

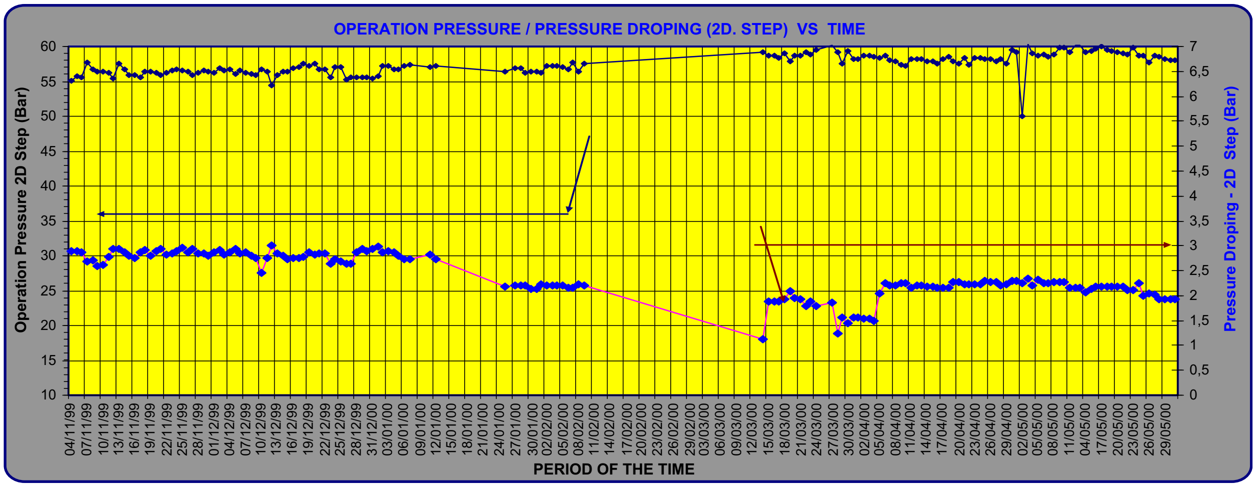

Fig. 16. Membrane performance: stage 3.

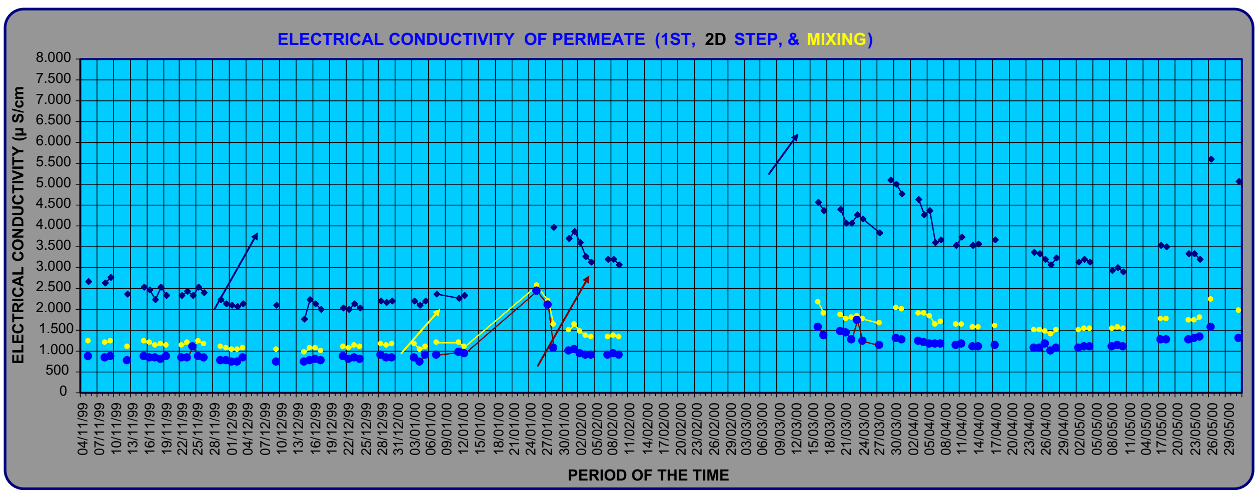

Fig. 17. Membrane performance: stage 3.

6.3. General conclusions of the research work

On the basis of the results obtained from the research studies conducted at the two pilot plants, the following general conclusions are made:

(1) It was possible to satisfactorily minimize fouling, biofouling and scaling of the EM pilot plant membranes by suspending NaClO dosing, regulating operating pH to 6.5, applying an optimized coagulant dosage, optimization of the filtration units and implementation of their operational requirements.

(2) No chemical wash of the reverse osmosis membranes was required and their operating parameters (operating pressure, pressure drop, permeate flow and quality) remained stable over the 5 months of the first stage and the seven months of the second and third stages at the EM pilot plant. If these data are extrapolated to the LP3 commercial plant then, in combination with implementation of the so-called operational requirements, chemical washes will most likely only be required once or, at most, twice a year as recommended by the manufacturers when the reverse osmosis membranes are carrying out their work satisfactorily.

6.4. Contributions made by the research work

The most relevant contributions obtained with the research work described in this paper are in two fundamental areas of importance for which the worldwide community seeks feasible solutions. They are as follows:

(1) Solution to the problem of the scarcity of water of a suitable quality to cover human needs. In this sense, the contributions obtained facilitate the development of so-called membrane technology in general and reverse osmosis technology in particular so that they can be economically feasible technologies in the search for solutions to water scarcity in areas of the world especially affected by this problem.
Since the number of chemical substances for dosing purposes is limited to just H_2SO_4 and Cl_3Fe, less equipment will be required (storage tanks, transfer pumps, dosing systems, measuring and control instruments, etc.) and, since the need to perform chemical washes of the membranes is limited to just one or two occasions a year, much simpler reverse osmosis desalination systems will be available with simpler and more economic operation (lower investment and operating costs).
Savings in terms of chemical products, energy, permeated water, filter cartridges and extra payments in man hours for chemical washes to extend the working life of the membranes and minimize the need for their replacement all contribute to reducing investment and operating costs. There is also, of course, the important added bonus of increased net monthly and annual production. The benefits of more economic, profitable and competitive reverse osmosis systems are evident.
By making reverse osmosis desalination systems more profitable and less expensive in terms of investment and operating costs, they will be much more competitive in the face of other desalination techniques (evaporation, electrodialysis, ion exchange, etc.). Indeed, they should also be more competitive in the face of conventional potable water systems (for river water, lake water, etc.).
(2) The protection and preservation of the environment. In this sense, the results obtained in this research work make the following contributions:A significant reduction is achieved in the use of chemical products which are commonly used in the operation of potable water plants (biocides, scaling inhibitors, detergents, foam inhibitors, several acids, diverse alkaline products, etc.), and which are directly and constantly emitted in the form of reject or concentrated brine. Such a reduction is clearly desirable in terms of reduced environmental pollution.
Specifically, through the elimination of sodium hypochlorite dosing, or the dosing of any other similar biocide, in the raw seawater which has to be processed in the reverse osmosis membrane modules, the possibility of the formation of so-called trihalomethanes is completely eliminated. These substances are considered hazardous and carcinogenic and it is known that they are formed through the chemical reaction between chlorine and a series of organic compounds (principally humic and tannin acids and others which constitute the 'organic colour' of water) which are generally present in surface water bodies (sea, ocean, river, lake water, etc.).

Acknowledgements

The authors would like to thank EMALSA company, and in particular, the general manager Mr Vicente Camacho and the production manager Mr Javier Alday Anzola, for their faith in Aldo Muñóz and for their kind assistance in ensuring provision of the necessary means and equipment for the realization of this work, which was a major contribution to his doctoral thesis as well to the improved performance of the desalination plant.

References

[1] Manual de Operaciones de la Planta Potabilizadora de Agua de Mar, Las Palmas III (in Spanish), Pridesa (1989).
[2] A. Muñoz Elguera, et al., Experimental test of TOYOBO membranes for seawater desalination at Las Palmas, Spain, Desalination 125 (1999) 55–64.
[3] Aldo Muñoz Elguera, J. Alday, A. Gómez Gotor, S.O. Pérez Báez, Inconvenientes de Realizar Dosificación Intermitente de Hipoclorito de Sodio, en línea de Pretratamiento de una Planta Desaladora por Ósmosis Inversa (in Spanish) Tecnología del Agua, Elsevier Información Profesional, S. A., Madrid - España, April 2001.
[4] M.V. Barry, J. Baker, Membrane Autopsy Report, prepared for Las Palmas III (EMALSA); Permacare-Houseman Limited, 19 November, 1997.
[5] Specification of Toyobo RO Module Test Facility in Las Palmas Plant; Toyobo Co. Ltd., April, 1998.
[6] A. Muñoz Elguera, J. Alday, A. Gómez Gotor, S.O. Pérez Báez, Optimización de la Dosificación de Hipoclorito de Sodio y MBS, en línea de Pretratamiento de la Planta Desaladora LP3 (in Spanish), Tecnología del Agua, Elsevier Información Profesional, S. A., Madrid - España, April-2001.
[7] Dow Europe Separation Systems: Filmtec Membranes, Technical Manual, 1993.
[8] G.G. Piqué, Randy Truby; Manual Práctico de Ósmosis Inversa; UOP Fluid Systems.
[9] Tratamiento del agua por procesos de membranas: Principios, procesos y aplicaciones (in Spanish), AWWA (Research Foundation), Lyonnaise des Eaux, WRCSA, McGraw-Hill, Madrid - España, 1998.

[10] M. Fariñas Iglesias, J.M. Crovetto de la Torre, Desalación de agua por Ósmosis Inversa: los principios de la O. I., Degremont, Ingeniería Química, June, July, August and September, 1983.
[11] Manual Técnico del Agua; 4th ed. (in Spanish), Degremont, Editorial GRAFO S. A., Bilbao - España, 1979.
[12] D.J. Shaw, Introduction to Colloid and Surface Chemistry, 2nd ed., Butterworth, London, 1970.
[13] W.F. Langelier, The Analytical Control of Anti-Corrosion, Water Treatment, J.A.W.W.A./28, 1936.
[14] Manual del Agua: Su Naturaleza, Tratamiento y Aplicaciones (in Spanish); Nalco Chemical Company, McGraw-Hill, 1993.
[15] M. Mulder, Basic Principles of Membrane Technology, Kluwer Academic, Amsterdam, 1991.
[16] HOLLOSEP: Much Experience for Desalination, RO Section, AC Operations Department, Toyobo Co. Ltd., Technical Bulletin, 1997.
[17] T.K. Osta, L.M. Bakheet, Pretreatment system in reverse osmosis plants, Desalination 63 (1987) 71–80.
[18] Manual de Potabilización de Aguas, (Manual I: Teoría y Evaluación; Vol II: Diseño de plantas), (in Spanish); Regional Programme HPE/OPS/CEPIS for Water Quality Improvement for Human Consumption, Lima, Peru, 1992.
[19] David H. Paul, Understanding desalination technology: Water microbiology, Desalination & Water Reuse, Vol. 3/1.
[20] H.F. Ridgway, M.G. Rigby, D.G. Argo, Bacterial adhesion and fouling of reverse osmosis membranes, Research and Technology, Journal AWWA, July, 1985.
[21] H.F. Ridgway, D.M. Rodger, D.G. Argo (Orange County Researchers, California, USA); Biofilm on reverse osmosis membranes, Water &Waste Treatment, March, 1986.
[22] J.W. Costerton, H.M. Lappin-Smith, Behaviour of bacteria in biofilms, American Society of Microbiology News, 55(12), 1989.
[23] J.L. Siler, Remediating Biofouling of Reverse Osmosis Membranes, United States Department of Energy, Washington, DC,. Report No. WSRC-RP-1059, 1991.
[24] E. Soriano Acosta, J. L. Zaragoza Carbonell, Membranas Sintéticas en sistemas de Ósmosis Inversa, (in Spanish), Chemical Technology Dept., Valencia Polytechnic University, Chemical Engineering, October, 1984.
[25] Manuel Fariñas, Osmosis Inversa, Fundamentos, Tecnología y Aplicaciones, (in Spanish), 1999.
[26] J. A. Medina San Juan, Desalación de aguas salobres y de mar, Osmosis Inversa, (in Spanish); Ediciones Mundi Prensa, Madrid - España, 2000.