SM 204

DESALINATION

Desalination 000 (2005) 1–11

www.elsevier.com/locate/desal

Development of the most adequate pre-treatment for high capacity seawater desalination plants with open intake

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Received 17 March 2005; accepted 12 April 2005

Abstract

Pre-treatment systems in reverse osmosis seawater desalination plants can be relatively simple or complex depending upon the direct function of the physical, chemical and microbiological quality of the water which is fed through the reverse osmosis membranes which separate the salts and the other disperse matter (colloids and micro-organisms) which are present in the processed water which, according to type and quantity, will produce a progressive or accelerated process of fouling of the same. Thus, the less quality of water to be desalinated, the greater or more intensive will be the pre-treatment system. The process water which is the result of systems of open intake is less recommendable since the characteristics are lower in quality, above all, the micro-biological parameters (the worst). All of this has a basic repercussion by increasing the cost per unit of the cubic metre of water produced and supplied to the end consumer or by reducing the profits for the companies exploiting the seawater desalination plant.

As a result, it is enormously important to carry out a study designed at ensuring the optimisation of the pre-treatment system for seawater desalination plants with open intake in order to optimise the quality of the water fed through the reverse osmosis membranes to guarantee the highest performance and to minimise the number of shutdowns for chemical cleansing which produce losses in turnover together with other operational costs which reduce the life cycle of the membranes significantly, resulting in the need for these to be replaced prematurely. This article attempts to show how important the adequate system for optimisation of the pre-treatment system of seawater desalination plants of open intake is. These desalination plants are not necessarily either highly complicated or sophisticated in their use of diverse chemical products but merely require a new system of pre-treatment which is more simplified and coherent in order to ensure that the membranes function highly satisfactorily [1–4]

1 *Keywords*:

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1. Introduction

As it is well known in this field, the operation of seawater desalination plants by reverse osmosis, which are of a high capacity of production, and capture their process waters through an open intake system, generally has to process a bad quality water mainly as for their high biological pollution that can also have high turbidity values; this is the reason why they normally have very
2 complicated pre-treatment systems [5–9] conceived and operated according the following criteria:

- Dosage of a series of chemical products, and nearly always in excess, such as:
- Sodium hypochlorite-NaClO (or other similar oxidant biocide: Cl_2, $KMnO_4$, O_3, etc.), in order to control the membranes dirtying processes by bio-fouling [10–15]
- Acid ($H_2\ SO_4$), in order to increase the power of the biocide action of NaClO, to regulate the process water pH, as well as to help the action of the scale inhibitors (Sodium Hexametafosfate) that is often dosed in order to control the membranes dirtying processes that are commonly known as scaling.
- Coagulant (Cl_3Fe, $Fe_2(SO_4)_3$, etc.), as well as some type of polielectrolite, in order to control the dirtying process of the reverse osmosis, commonly known as fouling.
- Sodium Metabisulfite-$NaHSO_3$ (reducing agent), in order to neutralize completely the residual active chlorine (Dechlorine), when the modules of the structure have polyamide reverse osmosis membranes installed.
- And some other chemical products, in particular cases (algaecides, fungicides, etc.)
- Several types of filters to carry out different filtration levels, such as:
- Open filters (gravity), or closed filters (pressure) that can be: Bilayer (gravel and sand, gravel and glauconite); Multilayer (gravel, sand and anthracite); with a level of filtration ranging from 10 to 20 micra (μm)
- Filter cartridges (alone or with 'pre-layer') installed in closed vessels, generally operate at 5 pressure atmospheres (filtration level from 1 to 10 μ)

Previous articles [1–4] have touched upon the problem of accelerated fouling, both as the result of colloidal particles (fouling), precipitation of inorganic salts (scaling) and as the result of the accumulation of live and dead biological matter (bio-fouling) of the reverse osmosis membranes (made with polyamides, in spirals) which affect high production open intake seawater desalination plants chronically.

This postdoctorate research was carried out in the desalination plant of Anfi Tauro which belongs to the desalination plants forming 'AQUALYNG S. L.', in the period between May and November 2002. This desalination plant works with open intake treating open sea surface seawater. The series of preliminary research work previously cited [1–4] allowed us to establish a working profile where precisely this variant with respect to traditional desalination plants should make it attractive for high capacity plants. The criteria to be considered are the following:

- Control of scaling, via sole doping of H_2SO_4, to regulate the pH of the seawater to appropriate values for this to feed the membrane modules plyamide spirals.
- Control of Biofouling (in polyamide membranes), via experimental tests based on the hypothesis which consists basically in refraining from treatment with sodium hypochloride (or any other biocide) of the seawater in the pre-treatment phase, accompanied by optimisation of the process of coagulation-flocculation (for a more efficent mix of the colloidal particles

which produce the fouling, and of micro-organisms which promote biofouling), and optimisation of performance of the plant filter units.

- The hypothesis additional to these two previous actions proposed a series of washing and disinfection procedures which tended mainly towards elimination of the accumulation of live and/or dead micro-organisms in the interstices of the filtering media (sand, fibres and filtering material from the cartridge filters and the diotomea of the pre-layer filters).

The original hypothesis works on the basis that these three actions when adequately planned will allow for optimum functioning of the reverse osmosis membranes during the process of desalination of seawater caught in open intake (which is the most appropriate way of guaranteeing sufficient quantity of untreated water to feed large capacity desalination plants). This basically means that the membranes require chemical washes only once or at the most twice per year, according to the membrane manufacturers' recommendations which will allow for the useful life of the same to be extended by over 50% with all of the repercussions that this represents.

2. Operating conditions

The open intake sea water desalination plant at Anfi Tauro can handle 1000 m^3/day of desalinated drinking water. The desalination plant is in the municipality of Mogan in the South of the island of Gran Canaria. The flow diagram of the same is shown in Fig. 1 and is made up of the following sections:

- A system for catchment of rough seawater which consists in a sinkable pump producing 115 m^3/h some 200 m from the coastline on a platform 12 m below the sea surface.
- Two sand filters, each of which is 6 m long, 4 m wide and 2 m deep. These filters receive the water driven by the catchment pumps and operate strictly thanks to the force of gravity, discharging the water

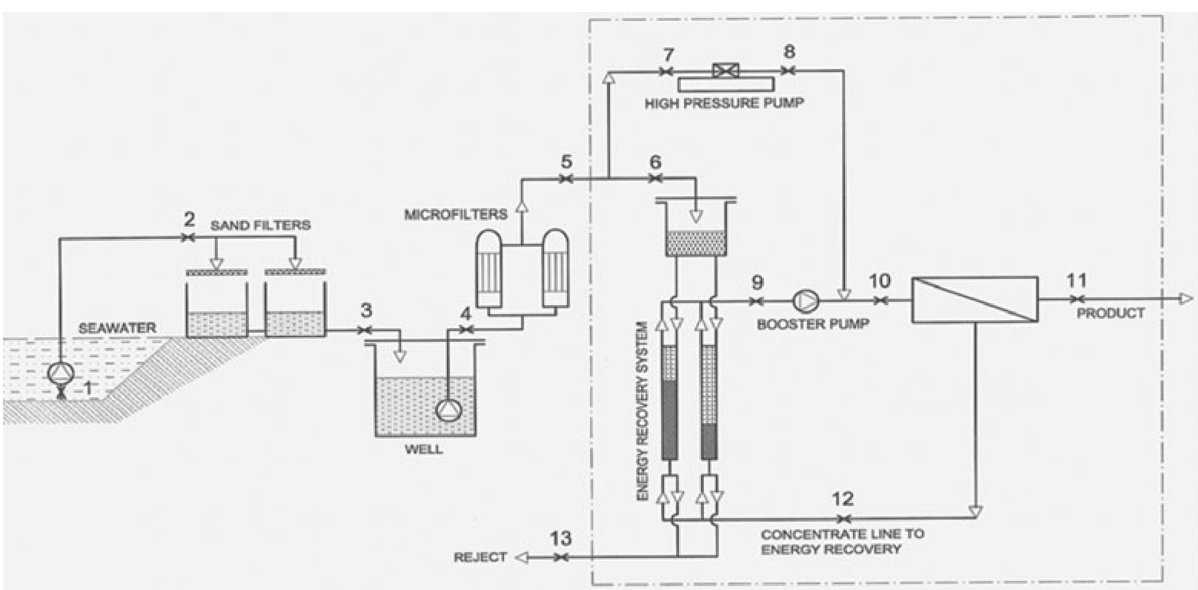

Fig. 1. Flow diagram for the seawater desalination plant at Anfi Tauro.

filtered into a tank below the lower level of the sand filters.

- Two regulatory tanks, each of which has 50 m^3 capacity and which are below the seabed level. These tanks have two pumps which are used to pump the filtered water through to the next section of pretreatment.
- Two bag filters (bag micro-filters) which basically allow for filtering of afino (1 μ nominal) filtered water which drives the two pumps in the regulatory tanks pumping it through the filters at 5 bar.
- Two high pressure pumps which operate in parallel and suck up a part (approximately 37%) of the total effluent from the bag filters (Which is equivalent to the flow of permeate produced by the rack, some 43 m^3/h) thus elevating the water pressure to the membrane feed pressure (between 56 and 60 bar).
- One unit for energy recovery (by pressure exchange) made up of cylindrical recipients which operate alternately during the process of pressure exchange which occurs inside, between the effluent brine of the reverse osmosis membranes and the effluent from the bag filters, whose pressure rises during the process from 5 to 58 bar.
- A booster pump which receives filtered water the energy of which has been raised by the system of energy recovery to 58 bar (approximately 2 bars less than the operating pressure within the rack which is the water pressure produced by the high pressure pump). This pump which is between the energy recovery system and the membrane rack is there to increase the water pressure from the pressure exchange to the operating pressure of the membrane rack which is approximately 60 bar.
- A membrane rack made up of 15 pressure tubes with each pressure tube housing 6 membrane elements shaped in spirals and made of polyamide.
- A desalinated water tank made of steel and holding 20 m^3 of water which constantly pumps desalinated water through two centrifugal pumps to the points of consumption (artificial lakes, irrigation for parks and gardens, irrigation for golf courses amongst other uses: But which is not used for human consumption).

2.1. Characteristics of the crude seawater

The crude seawater, captured via a surface catchment system and driven to the desalination plant of Anfi Tauro has the following average physical, chemical and microbiological characteristics which are typical of the waters of the Atlantic Ocean around the Canary Islands and are summarized in Table 1.

2.2. Operating conditions as defined for the research work.

The operating conditions defined for the research work at the seawater open intake desalination plant of Anfi Tauro were the following:

- Without dosage of Sodium Hypochloride or any other biocida with similar characteristics

Table 1

Cations	Concentration (ppm)	Anions	Concentration (ppm)
Na^{+}	11,810.00	Cl^{-}	21,317.20
Mg^{++}	1438.70	SO_{4^-}	2900.00
Ca^{++}	448.90	HCO_{3^-}	171.90
K^{+}	392.60	F^{-}	0.50

in the pre-treatment section of the Anfi Tauro desalination plant.

- Dosage of sulphuric acid (H_2SO_4) to regulate the pH of the pre-treated water (which feeds the reverse osmosis membranes) to a value of approximately 6.5.
- Optimised efficiency of filters thanks to setting of filters at maximum rates at each level of filtering:

Maximum rate of filtering at the sand gravity filters: 8 m^3/m^2 h

Maximum rate of filtering at the bag filters (bag filter): 10 m^3/m^2 h

3. Experimental results

In this section, we review the experimental results and data collected in relation to the evolution of the variables in the quality of the seawater (physical, chemical and microbiological as defined analytically) throughout the whole process of treatment from the moment the seawater is fed into the Anfi Tauro plant through to its ejection as brine together with the most significant operation parameters of the membrane modules which form part of the open intake surface seawater catchment desalination plant at Anfi Tauro.

3.1. Variation over time of the parameters of quality of the crude seawater

In Figs. 2–4, we show the data collected with respect to the evolution over the time of research of the most significant quality variables of the crude seawater (physical and chemical as analytically determined) before its being fed into the seawater desalination plant at Anfi Tauro and then as fed through to the reverse osmosis membranes.

3.2. Variation over time of operating parameters of the rack

In this section, in Figs. 4–6 and the following, we show the data collected in relation to the evolution, during the period of research, of the most significant parameters for operation of the membrane supply rack in the Anfi Tauro seawater desalination plant after being fed effluent seawater from the pre-treatment section.

3.3 Variation over time of the quality of the product water or permeate and the microbiological quality of the seawater processed in the desalination plant.

In this section, we present the data collected with respect to the evolution, over the

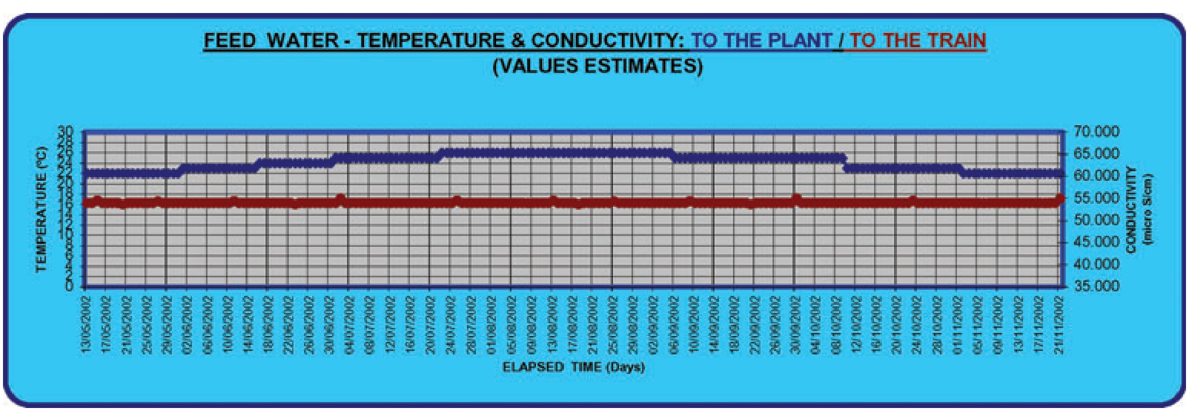

Fig. 2. Temperature and electrical conductivity of the feed water to the plant/to the rack.

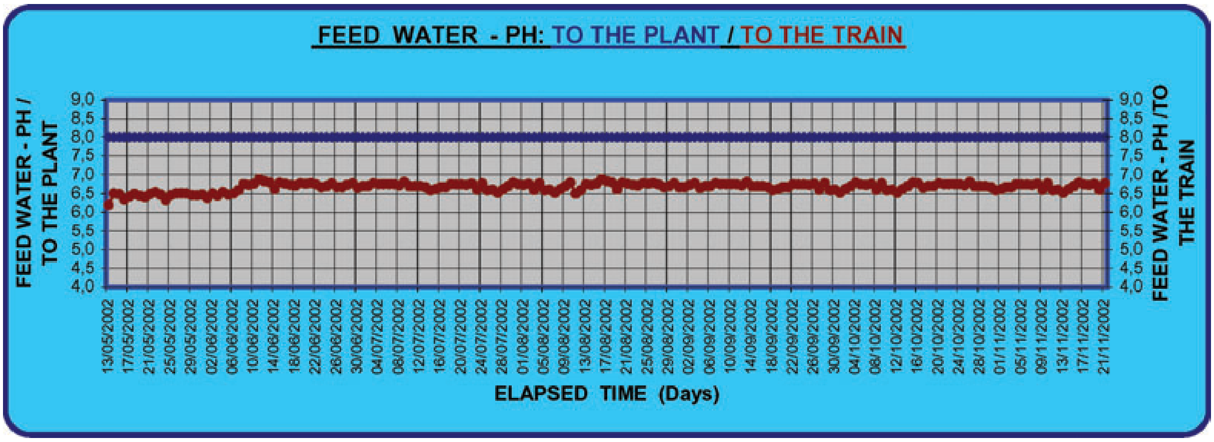

Fig. 3. pH of the feed water to the plant/to the rack.

time of research, of the quality of the product water or permeate produced by the seawater desalination plant at Anfi Tauro as reflected in Fig. 7 mainly through the significant change in the Electric Conductivity. Likewise, the data with respect to the variation in the microbiological profile of the crude seawater before being fed into the seawater desalination plant are given for the same period together with the feed to the reverse osmosis membranes and finally the details of the efflu-
3 ent brine (Figs. 8 and 9)

4. Analysis of the experimental results

In this section, we shall basically analyse the experimental data shown in the previous sections which we obtained during the period of research carried out at Anfi Tauro, the open intake seawater desalination plant.

The analysis or evaluation of our experimental results will be carried out in terms of the main aim which we tacitly posed when we defined the operating conditions of our reverse osmosis membrane rack where the final process of separation of the SALT

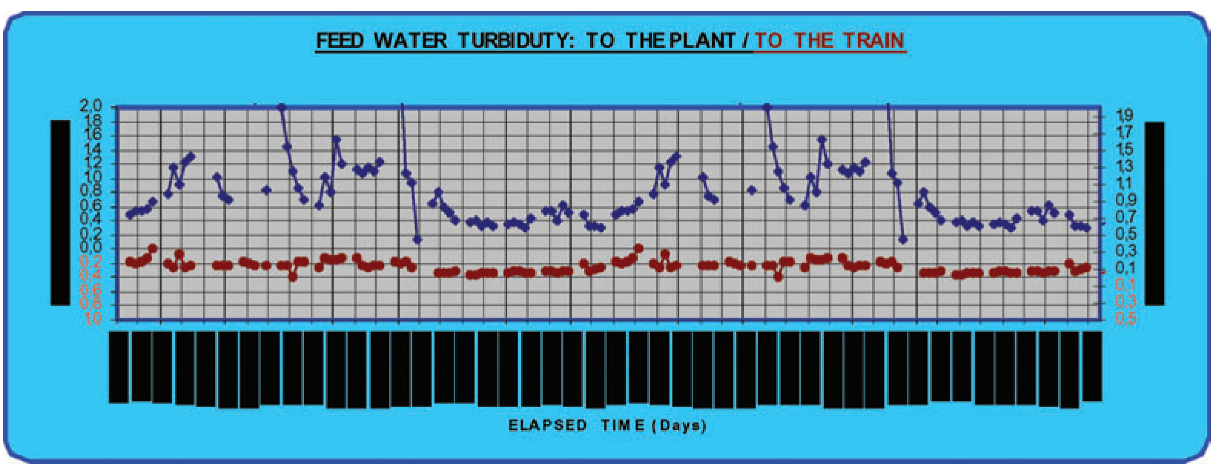

Fig. 4. Clouding of feed water to the plant/to the rack.

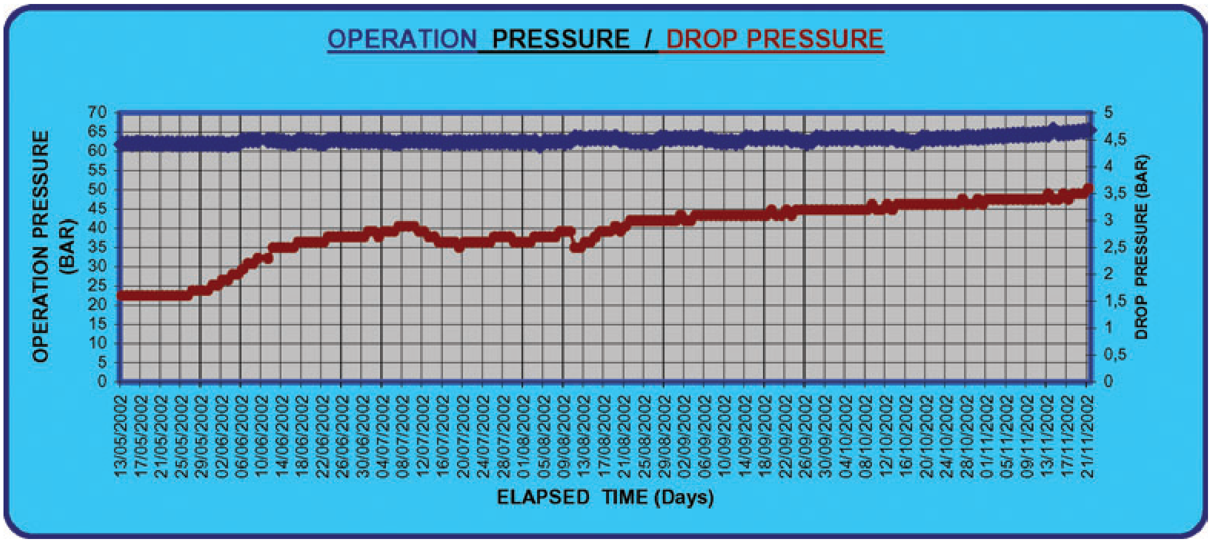

Fig. 5. Operating pressure/loss of pressure (on the membrane rack).

(brine) and the water (permeate) will be produced in the system known as water treatment or desalination. The main aim which was defined, as we say, tacitly when the operating conditions were considered was to guarantee the optimum functioning of the reverse osmosis membranes, that is by reducing fouling to a minimum and thereby maintaining the quality and quantity of the product water constant over time. This aim was fully and amply satisfied as the results obtained reveal:

- By maintaining the parameters of the quality of the crude seawater from an open intake system, we observed that the quality of the

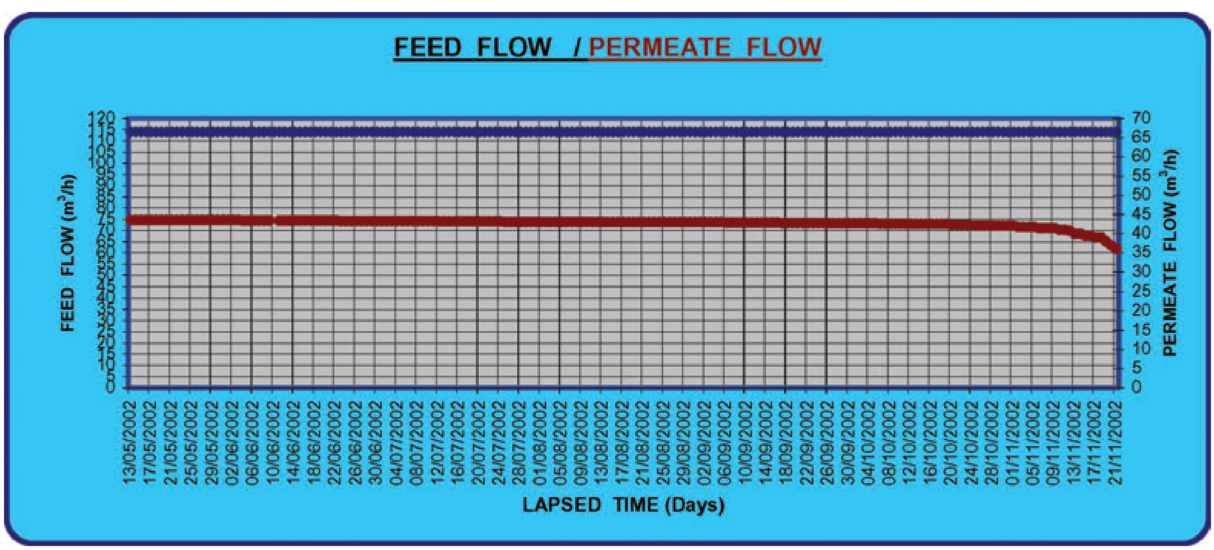

Fig. 6. Feed flow/permeate (at membrane of rack).

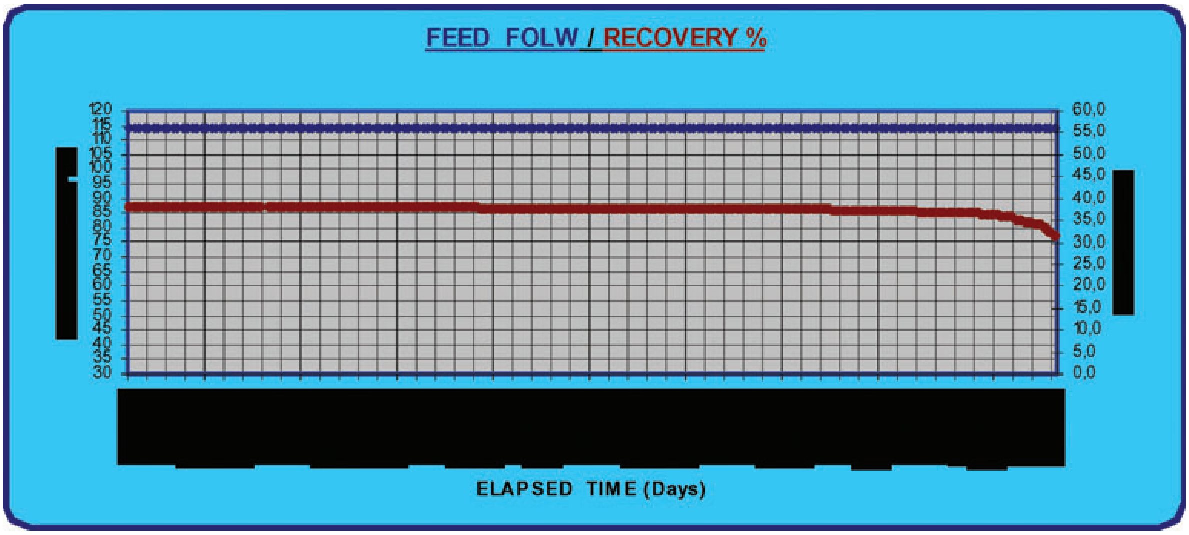

Fig. 7. Feed flow/percentage of conversion (at membrane of rack).

product water (in basic terms such as total solids dissolved (TSD) quantified via the corresponding electric conductivity) was also kept within the accepted levels of quantity (between 700 and 900 μS/cm) over a period of almost 7 months.

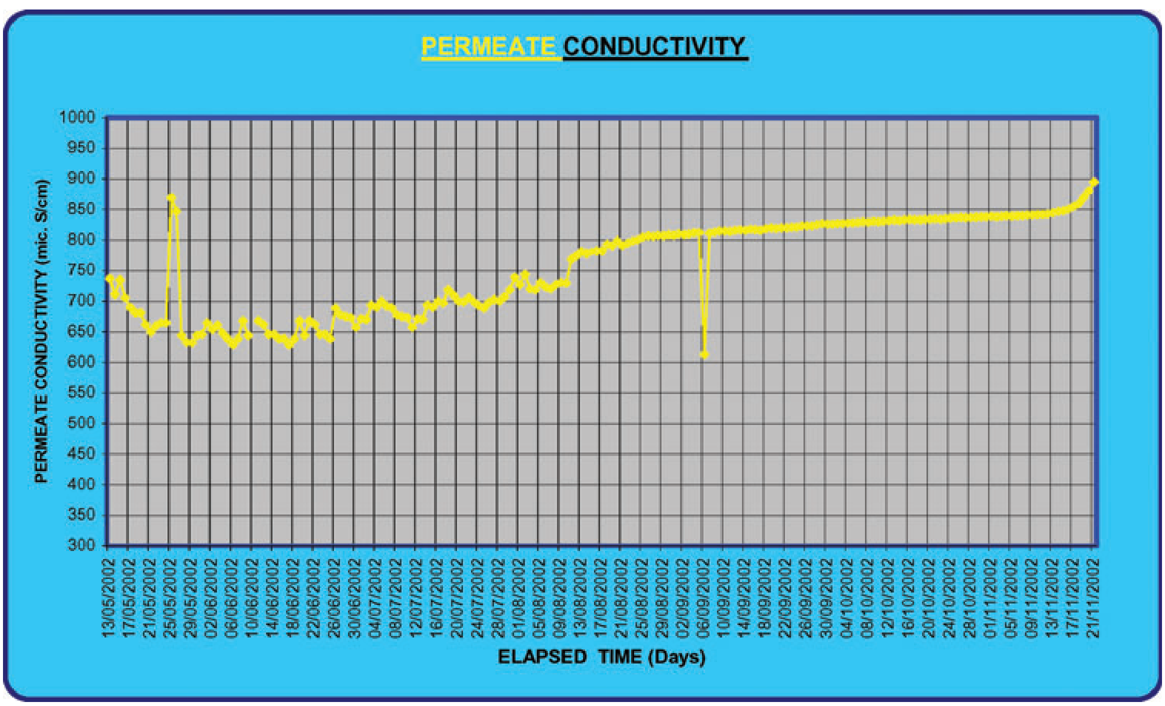

Fig. 8. Electric conductivity of permeate.

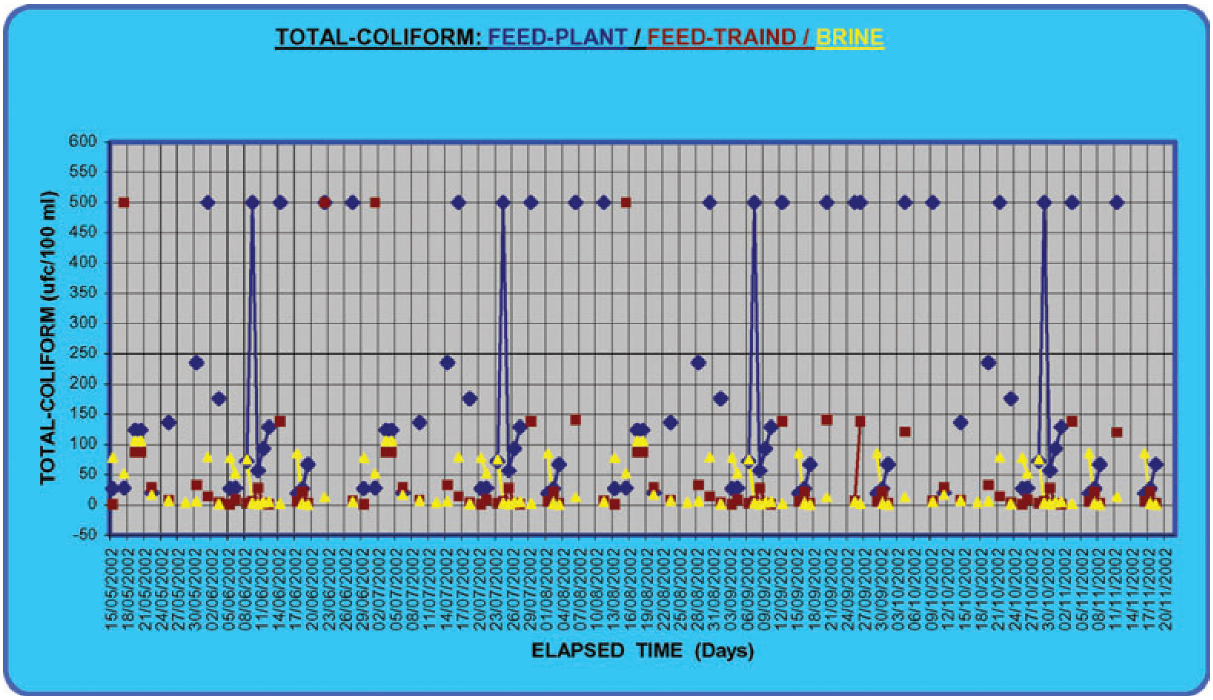

Fig. 9 Total colliforms of plant feed/of rack feed/of eject from rack.

- By maintaining the flow of crude seawater approximately constant in time, we observed that the effluent flow from the plant (around 42 m^3/h) was also kept more or less constant over a period of almost 7 months after which it decreased with over 15% loss of flow which indicates (according to the recommendation of the manufacturer of the membranes) that the time has come to chemically wash the reverse osmosis membranes. We should recall that the manufacturers of the membranes recommend that chemical washes should be carried out on average once or twice per year in order to guarantee the useful life of the same.
- Another important aspect that we should underline is how it is possible to control satisfactorily the problem caused by the reverse osmosis membranes without the need for dosing with sodium Hypochloride or any other similar biocide thereby preventing the natural microbiological contamination present in all seawater absorbed in open intake systems as has been confirmed by the results shown in Fig. 8. This result is basic since it shows us that clotting of membranes due to biofouling has been reduced to a minimum which has allowed for the adequate functioning of the reverse osmosis membranes as underlined in points 1 and 2 previously.
- Likewise, the fact that the membrane rack feed water pH has been regulated (around 6.5) without the need for any anti-incrustant or other equivalent chemical product has allowed us to adequately control the problem of fouling of the reverse osmosis membranes due to scaling.

5. Conclusions

Both processes of bio-fouling and scaling have totally adverse effects upon the operating parameters of the reverse osmosis membrane rack. In the presence of accelerated increases of either, there is also a rapid fall-off in pressure ((ΔP) at the rack which obliges us to increase the rack operating pressure rapidly (P_{op}) if we want the production of desalinated water to be maintained at the design flow rates or, otherwise, the flows of permeate (Q_P) will diminish rapidly which will leave no other option but to proceed to chemical cleansing of the reverse osmosis membranes.

In conclusion, with the application of the pre-treatment designed to make the quality and the characteristics of the seawater adequate (in the open sea intake system) for its being fed through to the reverse osmosis membranes for the corresponding desalination, we have achieved optimum performance of our seawater desalination system as shown by:

The operating parameters of the membrane rack ((ΔP, P_{op} and Q_P) remain approximately constant over almost seven months after which they begin to fluctuate unfavourably. This means that the pre-treatment used for the seawater from open intake has allowed us to adequately control processes such as bio-fouling and scaling thus making chemical wash of the reverse osmosis membranes necessary on maximum twice a year as is recommended by the membrane manufacturers.

The quality of the product water is closely linked to the achievements mentioned in the earlier paragraph as evaluated through the electric conductivity of the permeate (as related to the concentration of STDs). These also have been stabilised in the permitted range over almost seven months after which they shoot up.

The results obtained with the application of the pre-treatment designed specifically to condition seawater from an open intake system substantially reduce the operating costs of the desalination plants which treat this kind of water. The total benefits will increase in direct proportion to the amount of capacity installed in the desalination plants.

6. Future projection of the results obtained

The results obtained in this piece of research are in line with former research [1] thus leading us to consider that it is a significant contribution towards resolving one of the major problems in larger capacity installations. We consider, therefore, that this is doubtless a highly significant way of solving one of the present problems faced by larger desalination plants which may be implemented in the construction phase or in the design of the same when there is a need to define the way in which crude water supply is to be processed, such as will guarantee a permanent supply in open intake systems.

Acknowledgements

Our thanks to the company, AQUALYNG S. L., and, in particular, to Mr. Lyng himself and the chief engineer, Leigh Drablos, for allowing us access to the seawater plant and, thus, to corroborate our research.

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