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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