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Biofilm evolution in the pretreatment line of a reverse osmosis system

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HIGHLIGHTS

- Bacteria in the pretreated seawater allow biofilm to develop on RO installation.
- Continuous chlorination is a better way to control biofilm on pretreatment line.
- Shock chlorination is ineffective in controlling the biofilm when combined with UF.

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ABSTRACT

The effectiveness of the chlorination of seawater for an open intake reverse osmosis (RO) installation, by continuous chlorination (CC) or shock chlorination (SC), associated with two different pretreatment processes has been analyzed. Ultrafiltration membrane pretreatment and physicochemical pretreatment were evaluated, associated with CC (1 mg Cl_2/L) or with SC dosed fortnightly to obtain 1 mg Cl_2/L at the end of the pretreatment line, by measuring the presence of total aerobic bacteria (TAB) in pretreated water and the development of biofilm on the walls of the different tanks of the pretreatment lines. Bacteriological seawater quality was similar for both pretreatment systems but CC enabled better control of TAB than SC, according to its concentration or the number of positive samples. Attached bacteria were observed on the surface of the tanks of both assayed pretreatment lines but biofilm was only observed in the influent tank. The bacteriological quality of the seawater affected the degree of biofilm development, resulting in poorer biofilm control when SC was applied, regardless of the pretreatment used. Our results show that although chlorination hinders the development of biofilms on the RO membranes, with SC there is a greater risk of bacteria adhering to the surfaces of RO installations.

1. Introduction

Desalination of seawater by reverse osmosis (RO) technology is an important option available to water-scarce coastal regions [1]. Its main advantages with respect to other desalination technologies are the simplicity of the process, normally composed of built-in modules, its long service life, the low maintenance costs of membranes, the fact that toxic chemicals are not produced during the process and the lower water production costs compared to other desalination processes [1,2].

RO has certain drawbacks such as high energy costs and membrane fouling [2,4], which have negative effects on the quality of the effluent and the total operational cost. Biofouling is a very complex problem that may cause irreversible fouling of the membranes [4,5]. Microorganisms may adhere to surfaces such as the membrane and excrete extracellular polymeric substances (EPS), in which they become embedded and form biofilms [4,6]. These biofilms have negative effects such as a significant decrease in permeate water flux, an increase in transmembrane pressure (TMP), membrane degradation and reduced efficiency in salt rejection [5].

All raw seawaters contain microorganisms, so biofilm often forms on the surfaces of the installation, including the pretreatment line [4]. Biofilm is difficult to remove because it protects bacteria against chemical agents and several stress conditions. The manufacturers of RO systems therefore recommend that biofilm development and growth be kept within an acceptable level, at which the negative effects of biofouling on RO membrane performance will be insignificant [7]. Biofouling can be prevented by conventional RO pretreatment of seawater using chlorine [1,7,8] by intermittent shock chlorination (SC) or by continuous chlorination (CC) [9,10]. CC has been the industrial standard for years [1,5]. Chlorine is added at the water intake and a residual free chlorine concentration of 0.5–1.0 mg Cl_2/L should be maintained throughout the whole pretreatment [7]. The disadvantage of this process is that chlorine is a strong oxidizer which can damage RO membranes irreversibly and dechlorination upstream is required [7,11]. To overcome this problem, periodical shock injection of chlorine with off-line RO stage is conducted [10] which results in reduced chemical and energy consumption [9].

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The physicochemical process (PC) and ultrafiltration membranes (UF) combined or not with chlorination are both technologies that produce better results in terms of RO feed water quality [2,8], although bacteria are usually present in the effluent from these technologies [8]. Many studies have concluded that chlorine disinfection of system feed waters does not necessarily ensure that membrane biofouling will not occur [4].

In view of this, the aim of this paper is to observe biofilm evolution in two RO pretreatment lines (UF and PC) by evaluating the effect of chlorination applied by continuous dosage or shock chlorination on the microbiological quality of pre-treated seawater and biofilm evolution on the walls of the tanks in pretreatment lines.

2. Materials and methods

2.1. Description of experimental installation

The experimental installation used for the study consisted of an influent tank of 1.5 m^3(HRT = 0.09 h) which was filled with raw seawater from the Mediterranean Sea (Melilla, Spain) by open intake from an underwater intake pipe located at a depth of 15 m. The influent tank guaranteed a homogeneous flow of seawater to two experimental full scale RO pretreatment lines (Fig. 1), which operated continuously in parallel. One of them was an UF treatment system, with a prior macro-filtration unit (90 μm mesh size), consisting of 24 aerated spiral wound membranes (ASWUF) of polysulphone (20 kDa of molecular weight cutoff and 389 m^2 of total filtration surface). The system worked under vacuum conditions (TMP between −0.1 and −0.27 bars) with production periods of 20 min (flux 21.8 L/m^2 h) with continuous membrane aeration, followed by backwashing phases of 0.5 min using ultrafiltered water (flux 31 L/m^2 h). This pretreatment line had an ultrafiltered seawater tank with a capacity of 10 m^3 (HRT = 1.25 h), which guaranteed sufficient seawater for backwashing and for feeding RO. Chemical cleaning was carried out every two days with chlorine (100 mg/L), and once a week using citric acid (pH = 4.5). The other line consisted of a PC treatment system with a capacity to treat 8 m^3/h by means of $FeCl_3$ coagulation (4 mg/L), hydraulic flocculation, lamellar sedimentation and dual media pressure filtration (anthracite and silica sand) with a 24 h production phase and 20 min of daily backwashing. This pretreatment line had a filtered seawater tank with capacity of up to 3 m^3 (HRT = 0.375 h), which guaranteed sufficient seawater for pressure filter backwashing and for feeding RO. For disinfection, the system was chlorinated with a dose of NaClO (150 g Cl_2/L) in the open intake prior to both pre-treatment lines. Residual active chlorine and seawater temperature were measured continuously at the end of the pretreatment line.

2.2. Experimental methodology

Chlorination was performed by continuous chlorination (CC) or shock chlorination (SC). For CC, chlorine was dosed continuously in raw seawater to both installations with the aim of obtaining 1 mg Cl_2/L throughout the whole of both pretreatments. In SC, chlorine was dosed every fifteen days and it was applied by dosing 2.5–5 mg/L of active chlorine in raw water for 2 h in order to obtain 1 mg Cl_2/L of residual free chlorine at the end of both pretreatments. The experimental installation began working with CC in January 2010 and remained until June 2011, after which it began working with SC. A thorough cleaning of the tanks was made after the change of the chlorination method.

Samples of raw seawater, filtered seawater and ultrafiltered seawater were collected daily in sterile plastic bottles (100 mL) for microbiological analyses. The microbiological quality of the water was evaluated by counting total aerobic bacteria (TAB) at 22 °C as described in Regulation UNE-EN ISO 6222:1999, using a TSA medium. Samples were considered positive if there was growth of bacteria.

The development of biofilm on the surface of different tanks was controlled by analyzing the presence of bacteria on the wall of the influent tank, the UF effluent tank and the filtration effluent tank (Fig. 1). Biofilm control was achieved by inserting a string with several PVC plates into each tank. A PVC plate was carried out monthly for each water tank and these were preserved with glutaraldehyde (3%) in phosphate-buffered saline solution (PBS) (130 mM NaCl and 10 mM Na_2HPO_4/NaH_2PO_4 pH 7) in order to be able to fix the possible biofilm on the PVC fragment. Samples were treated according to the methods described by de la Rúa et al. [6] and viewed by scanning electron microscopy (SEM) using a Zeiss DSM 950 SEM operating at 5–30 kV, equipped with an Energy Dispersive Spectrometer (EDS Link Analytical Pentafet Si (Li)). The observed areas of the micrographs were calculated, and single bacteria in each area were counted. The mean value was extrapolated to single bacteria units per m^2, these values were calculated by taking the average of 45 counts of SEM micrographs for each sample. After the period working with CC, the PVC plates were replaced.

2.3. Statistical analysis

Data obtained in this study were analyzed using the statistical program SPSS 20.0. Daily influent values were compared and correlated with both effluent values. The arithmetic mean ± standard error was

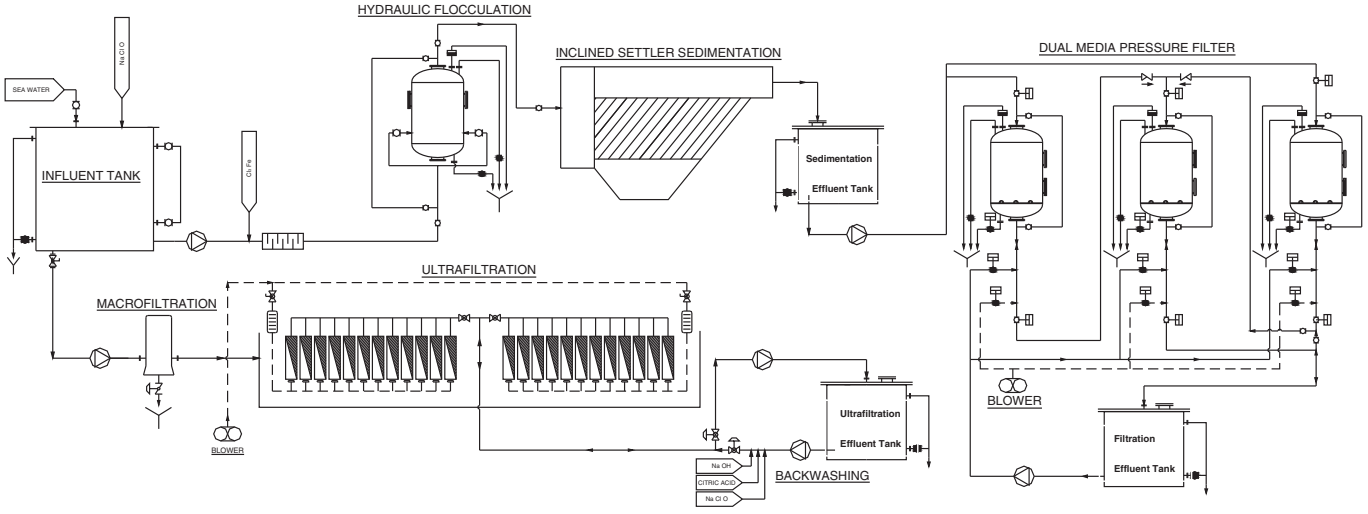

Fig. 1. Schematic diagram of experimental pilot plant.