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Potabilization of low NOM reservoir water by ultrafiltration spiral wound membranes

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Abstract

Membrane technologies such as ultrafiltration offer an interesting alternative to integral treatment of surface water destined for human consumption. With this in mind, a pilot-scale ultrafiltration module was set up, equipped with spiral-wound polyethersulphone membranes (16.6 m^2) with an effective pore size of 0.05 μm. The system operated continuously with a stable production of 0.9 m^3/h (54 lmh) and a constant transmembrane pressure of −0.2 bar. The effluent obtained showed a total absence of faecal contamination indicators of both bacterial and viral origin, and also presented an excellent physico-chemical quality, independently of the quality of influent. Total aerobic bacteria counts revealed the problem of bacterial contamination in the membrane permeate zone, which could be controlled through daily chemical cleansing of the membrane. The chief problem presented by this type of system, applied as exclusive treatment, is low effectiveness in the retention of natural organic matter (NOM), in which respect the quality of the effluent was observed to depend on the quality of influent. This constitutes the principal limitation for applying the system to surface water due to the risk of disinfection by-products formation during the final post-chlorination. However, spiral wound ultrafiltration (SWUF) membranes could be used for low NOM reservoir water total treatment offering several advantages over conventional technologies.

Keywords: Ultrafiltration; Chlorine demand; Disinfection; Natural organic matter

1. Introduction

With the detection of certain compounds in potentially harmful concentrations, it has become evident that absence of faecal contamination indicators and high organoleptic quality are not a sufficient guarantee for water destined for human consumption. In the light of recent findings related to organic and inorganic contaminants, particularly those regarded as disinfection by-products, there is a need to improve the performance of potabilization systems in this respect.

At present, the most widespread disinfection method throughout the world is the use of chlorine and its derivatives, owing to its effectiveness and particularly to its low cost. However, evidence of the formation of chloroform as a by-product of chlorination in water destined for human consumption [1,2] has raised alarm with regard to the generation of chemical disinfection by-products, and a wide range of substances are now recognised to pose a serious threat to public health [3].

As a result of this problem, it is necessary to find ways of preventing the formation of disinfection by-products in the water without reducing effectiveness in the elimination of microorganisms. Various alternatives are currently being explored, with some researchers proposing the improvement of the quality of water with respect to the content of organic compound precursors [4], elimination of generated by-products [5], or the total or partial substitution of the practice of chlorination with alternative processes of a similar or different nature [6,7].

Membrane technologies, particularly ultrafiltration, represent an interesting alternative to the disinfection of water for human consumption [8]. These systems do not employ chemical oxidants, thereby reducing the generation of by-products. Instead they are based on a screening process which is highly effective at retaining both viruses and bacteria and avoids the

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problem of resistance, while improving the physico-chemical characteristics of the water [9].

Given that membrane technologies make it possible obtain a completely disinfected and clarified effluent, their application may lead to simplified potabilization facilities. However, since the treated water does not contain a residual concentration of disinfection, a final post-chlorination phase would need to be included in order to guarantee sanitary standards in the distribution network. Authors such as Galambos et al. [10] highlight the difficulty of retaining humic acids through membrane filtration, indicating that the disinfection process would also need to eliminate the possible precursors of chlorination by-product generation.

At the present time, low-pressure membrane technologies are used increasingly in the treatment of water for human consumption [8], applied in combination with other processes such as coagulation or ozonation [11,12]. The systems have also been applied at laboratory scale [6] and pilot-scale [13], with results indicating the possible application of ultrafiltration as an exclusive treatment for potabilization.

With these considerations in mind, it was decided to set up a pilot-scale ultrafiltration system working with surface water from a reservoir, in order to evaluate both the behaviour of the system and the final quality of the effluent obtained over 180 days' of continuous operation.

2. Materials and methods

2.1. Description of pilot-scale installation

The experimental pilot system (Fig. 1) was designed to produce a constant working flow of 0.9 m^3/h, by means of a pump of surface water (1 m^3/h, 30 m.c.a.) deriving from the reservoir of Canales (Granada, Spain). The plant comprised a ring-filter macrofiltration pretreatment phase (150 μm) and an ultrafiltration system using a SpiraSep module (TriSep Corporation).

The ultrafiltration module was equipped with spiral-bound polyethersulphone membranes (TriSep Corporation) with an effective pore size of 0.05 μm, installed in a 151-l capacity tank. The area of filtration was 16.6 m^2 (54 lmh), operating in a vacuum with a transmembrane pressure of −0.2 bar. Working conditions consisted of production periods of 60 min (0.9 m^3/h) with continuous aeration, followed by backwashing phases of 2 min (2 m^3/h) using filtered water. Chemical cleaning was carried out daily with chlorine (100 mg/l), and once a week using citric acid (pH 4.5).

2.2. Experimental methodology

The system operated continuously for a period of 180 days. Samples of both the influent and the effluent were taken on a daily basis. In all water samples, turbidity, total suspended solids, colour, permanganate oxidability and particles were analysed as physico-chemical parameters, while faecal coliforms, *E. coli*, enterococci, *Clostridium perfringens*, somatic coliphages and total aerobic bacteria were analysed as microbiological parameters.

For physico-chemical analysis, water samples were collected in thoroughly cleansed plastic bottles and analysed immediately. Analytic determination of turbidity was carried out using the quantitative diffuse radiation method described in Regulation UNE-EN ISO 7027: 2001. Suspended solids concentration was established by a filtration method using 0.45 μfilters, as reflected in *Standard Methods For the Examination of Water and Wastewater* [14]. For colour determination, the technique described in Regulation UNE-EN ISO 7887: 1995 was used, while determination of permanganate oxidability was based on the method described in Regulation UNE-EN ISO 846:1995.

Particle size distribution (PSD) of the permeate was conducted using a LiQuilaz-E20 particle counter (Particle Measuring Systems). The measuring principle is based on laser light extinction. A volume of 10 ml set at a fixed rate was analysed for each sample, which resulted in minimum counted particles of 100 ml^{-1} and maximum of 100,000 ml^{-1}. Particles were in a size range of 2 and 125 μm and the system was calibrated by inert latex particles of defined size.

For bacteriological and viral analyses, water samples were collected in sterile glass bottles (1 l) and analysed immediately after collection. The presence of faecal coliforms and *E. coli* was studied using the membrane filtration procedure (UNE-EN ISO 9308-1: 2001).

Enterococci were analysed using the method described in Regulation UNE-EN ISO 7899-2: 2001. Total aerobic bacteria count was carried out at 22 °C using the method described in Regulation UNE-EN ISO 6222: 1999. For determination of *C. perfringens*, samples were passed through membrane filtration (0.45 μm pores) and incubated anaerobically in PAB medium (Oxoid CM 587), supplemented with TSC (Oxoid SR0881E) and EYE (Oxoid SR047C) growing media, at 44 ± 1 °C for 24 h. After incubation, a count was made of colonies presenting the colour black. Somatic coliphages were examined using a modified form of the double agar layer method described by Adams [15], with *Escherichia coli* C (ATTC 13076) as host bacteria. Previous to analyses, 10 ml of sample was placed in a tube containing 2 ml of chloroform. The tube was shaken vigorously and then left to settle for 20 min. After heating at 45 °C, the chloroform was removed. This sample treatment removed all bacteria prior to coliphage determination.

Throughout the sampling period, chlorination curves were carried out for both the influent and the effluent, using aliquots of 1 l, and applying a quantity of NaClO (1 mg Cl) for the addition of chlorine to the water. After 30 min contact at slow agitation (30 rpm), free chlorine and total chorine were quantified by means of the volumetric evaluation method using *N*,*N*-diethyl-1, and 4-phenylenediamine, as described in Regulation UNE-EN ISO 7393-1.

All data obtained in this study were analysed using the statistical program STAGRAPHICS Plus 3.0 for Windows.

3. Results and discussion

One of the principal operational problems of membrane systems is fouling and clogging of the membranes. Although this may improve the capacity for retaining particles, it leads to a