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Production of drinking water using a multi-barrier approach integrating nanofiltration: A pilot scale study

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ABSTRACT

A multi-barrier system was studied for the production of drinking water with high chemical and microbiological quality. The integration of nanofiltration (NF) and ultraviolet (UV) photolysis was tested at pilot scale in a surface water treatment plant.

The NF membranes tested, Desal DK and NF270, allow for the production of permeates with high quality standards, although the membrane with higher molecular weight cut-off (NF270) revealed to be the best option for surface water treatment due to its higher permeability. The NF270 membrane was also efficient to deliver high quality water, even under high pollutant concentrations, making possible to operate with water recovery rates as high as 98%.

Extensive studies were performed in the water treatment plant where the proposed system was tested at three locations of the drinking water production line. Seeking to achieve the best compromise between high recovery rate, high retention of chemicals and microorganisms as well as preventing operational problems (flux decline and fouling), it was found that the integrated system should be placed after the conventional sand filtration, operating at a 91% recovery rate. Under the selected conditions – TMP of 8 bar and recovery rate of 91% – it is possible to operate at constant permeability without flux decline for a period of 15 days, after which a gentle CIP procedure is recommended.

Membrane fouling was also investigated and the major foulant classes identified were proteins, polysaccharides and humic acids. A cleaning protocol was also tested and the impact of each cleaning step on the recovery of permeability evaluated.

1. Introduction

Drinking water legislation requires a tight control of the water quality for human consumption in order to assure adequate public health conditions [1]. Quality parameters include microbiological parameters, chemical parameters, and other indicator parameters (e.g. total organic carbon, turbidity, and colour). There is a growing interest of water providers and researchers to find solutions to increase the chemical and microbiological quality of the drinking water produced, anticipating future regulations that will include new micro pollutants (e.g. pesticides), which are currently being studied for their potential adverse health effects, even when present in the aquatic environment at extremely low concentrations. Pesticides are intentionally used to control pests. However, their toxic action is not specific to the target organisms and they are toxic to many non-target species, including humans [2].

Conventional surface water treatment often includes screening, coagulation/flocculation, sedimentation, sand filtration, and final disinfection which is often achieved by chlorination. However, such treating systems may not be sufficient to retain the new micro pollutants of concern. Additionally, the use of high quantities of chlorine may induce the formation of disinfection by-products, which are harmful to human health. In this work a multibarrier treatment system is proposed by introducing a combined process with nanofiltration and low pressure UV radiation in a conventional surface water treatment plant. Both treatment processes have shown promising results at independent laboratory scale studies [3–6].

One of the first nanofiltration plants for treating surface water was constructed in Méry-sur-Oise, France, with a capacity of 140,000 m^3/d [7]. This plant shows high efficiency for the removal

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of organic matter still present at the end of conventional treatments. The removal of such organic material is important to prevent the growth of bacteria in the water distribution system and, therefore, decreases the necessity of adding chlorine during water distribution.

Nanofiltration systems are also able to reduce the level of micro pollutant contamination of the drinking water supplies due to retention based on size exclusion (down to ≈200 Da molecular weight) and interactions with the membrane surface. Additionally, nanofiltration is able to eliminate water colour and turbidity, increasing the performance of the UV radiation treatments. The introduction UV photolysis after nanofiltration introduces an additional protective barrier that allows the inactivation of microorganisms [8], as well as photo-degradation of resilient contaminants such as pesticides [9].

The removal of pesticides from surface waters to levels below $\mu g\,L^{-1}$ has been also a subject of interest in the last years. Several works report the removal of such compounds using membrane technology [5,9–13], UV photolysis and advanced oxidation systems [14–21]. However, literature reports the use of such technologies separately and, as demonstrated by previous results, under controlled laboratory conditions, the combination of both nanofiltration and advanced oxidation systems is necessary to achieve an efficient removal of the most resilient micropollutants [3].

Numerous researchers focused their studies on membrane fouling, which remains the main obstacle to an efficient membrane performance [22–25]. Membrane filtration leads to accumulation of material at the membrane surface and intraporous structure, which increases resistance of the membrane to permeation. As a consequence, chemical cleaning has to be applied frequently (which may deteriorate membrane performance and reduce membrane lifetime [26]), leading to higher operational costs. Fouling has been investigated [27–31] using various types of techniques and different characteristics of feed water, membrane material and operating conditions (e.g. pre-treatments, back flushing, flushing forward, and gas bubbling) [32–35].

The present research work is focused on the validation of a multi-barrier system incorporating both nanofiltration and UV photolysis at pilot scale, in a fully operational surface water treatment plant, in order to guarantee the production of a high quality drinking water in terms of chemical composition and microbial inactivation.

The pilot system (combination of nanofiltration and UV photolysis) was assembled and tested in a surface water treatment plant of the major Portuguese water provider EPAL, which provides water to around 3 million people in 35 districts corresponding to a total area supplied of 7090 Km^2. The water treatment plant is allocated in Vale da Pedra and treats surface water abstracted from the Tagus River in Valada Tejo.

The validation of the multibarrier system was performed by testing the performance of the nanofiltration operation at three different points of the surface drinking water production line. Even though placement of the multibarrier system was expected to be optimal after conventional sand filtration, different locations were tested in order to better evaluate the impact of the new treatment system when retrofitting a water production plant. The UV photolysis was also evaluated on site to determine the benefit of its use and the impact in terms of water quality, with the objective of producing a high quality drinking water.

A complete and careful analysis of the NF membrane fouling agents was performed in this study after continuous operation at the drinking water treatment plant. Different membrane cleaning agents were also tested to determine their efficiency for removal of the detected fouling components.

2. Materials and methods

2.1. NF system operation and membrane selection

The nanofiltration system represented in Fig. 1-A was used for membrane selection. This system is composed by a spiral wound NF270-2540 membrane module, a valve at the end of the module for pressure control and a diaphragm pump (Hydra-cell G-3, Wanner Engineering, USA), which is able to deliver a constant flow for pressures up to 60 bar. The feed flow rate used in the experiments was 420 l/h. The feed water used in these tests was surface water collected from the Tagus River where EPAL abstracts water. Before being fed to the nanofiltration system, water was firstly filtered through a 0.75 mm filter followed by a 5 μm filter. This system was tested using two spiral-wound membranes – NF270 (Dow Filmtec) and Desal-DK (GE Osmonics) – with different molecular weight cut-off (MWCO), as described in Table 1.

This system was used under two different operation procedures: concentration and single pass mode. The membrane module used has the same configuration of the membrane module used in full scale systems and the two different Both operation procedures allowed to simulate the conditions of a full scale nanofiltration operation.

In the single pass operation, the retentate and permeate were collected continuously in different tanks (TMP = 10 bar). This operation mode can be used to simulate the performance of the first membrane module in a membrane system composed of several membrane modules placed in series.

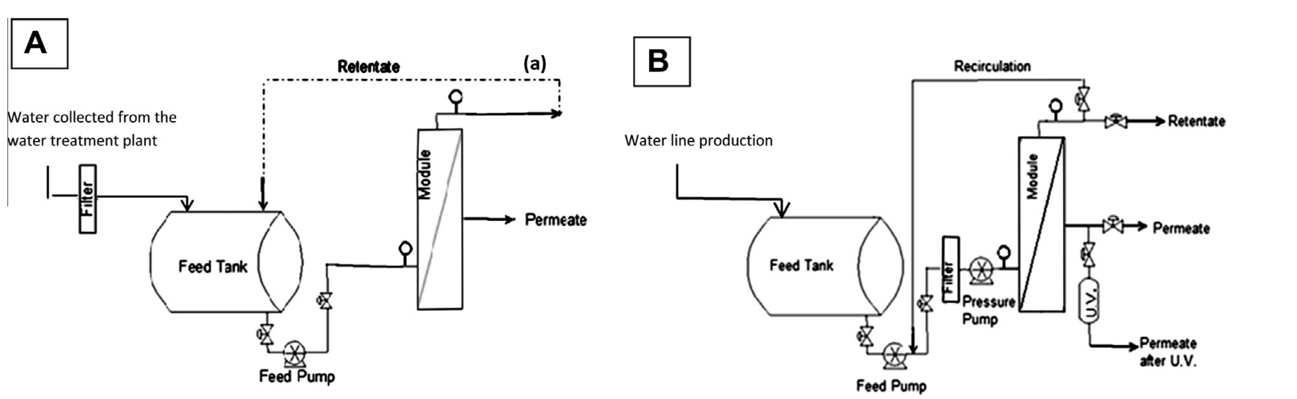

Fig. 1. Schematic diagram of the pilot systems used: (A) for membrane selection operating in two different modes: single pass and concentration mode (in the later case, the retentate is fully recycled; see line a), and (B) in the pilot tests at the water treatment plant.