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Selection of the most suitable ultrafiltration membrane for water disinfection in developing countries

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Abstract

One of the most critical problems in developing countries is the lack of drinking water. People in these regions are supplied with surface water, which contains a significant amount of microorganisms that can cause several diseases. In fact, one of the main causes of infantile mortality is the high incidence of diarrhoeic diseases and other illnesses related to impure drinking water. Ultrafiltration (UF) is a pressure-driven membrane process that separates on the basis of size and can remove bacteria and viruses from water. Therefore, UF can be applied for disinfecting water, avoiding some illnesses or epidemics where people consume ultrafiltrated water. The Chemical and Nuclear Engineering Department of the Polytechnic University of Valencia in Spain is working in cooperation with a non-governmental organisation to develop a system to make water drinkable in a region of Ecuador. The system consists of an UF plant with one spiral-wound module, equipped with a pressure pump driven by a petrol engine. Before the application of the process, the UF plant has to be completely tested and fine-tuned in order to assure that it will successfully perform once in Ecuador. One of the stages of these preliminary tests was the selection of the most suitable UF membrane from the point of view of kind of material and cut-off, bearing in mind the following points: quality of ultrafiltrated water, performance conditions, membrane fouling and cleaning and maintenance conditions. This paper describes the preliminary tests carried out with different UF membranes to select the most suitable one for disinfecting surface water.

Keywords: Ultrafiltration; Disinfection; Potabilisation; Developing countries

1. Introduction

One of the most critical problems in developing countries is the lack of drinking water. As a consequence, people in these regions are usually supplied with water from rivers, lakes, etc., which contain a significant amount of microorganisms that can cause several diseases. In fact, one of the main causes of infantile mortality in these regions

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is the high incidence of diarrhoeic diseases and other illnesses related to impure water consumption. This situation exists for the population of Pucará in the province of Azuay (Ecuador) where the non-governmental organisation, Association for the Cooperation with Ecuador (ACOEC) and the humanitarian organisation, Fundación SER, are carrying out a project to improve infantile health. The Chemical and Nuclear Engineering Department of the Polytechnic University of Valencia in Spain is cooperating with these two organisations for the purpose of designing and constructing an ultrafiltration (UF) plant that will be installed in the Pucará community to make potable water (AQUAPOT project) [1].

UF is a well-known membrane technology based on particle size that can retain macromolecules or high-molecular-weight compounds, as well as colloidal and suspended matter. UF also excludes bacteria and viruses, which allows its application for water disinfection [2], producing drinkable water as the permeate of the process. UF has many advantages in comparison with conventional disinfecting processes [3–5]: production of water of invariable quality; smaller quantity of added chemical reagents (coagulants, flocculants, etc.); absence of bacterial regrowth and residual toxicity; compact installation and plant; easy automation. Thanks to these advantages, among others, UF is being used more and more often for treating various water sources, with 50% of the UF plants being used with surface waters [6].

In order to assure the success of the AQUAPOT project, the UF plant has to be completely tested before going to Ecuador and starting to produce drinkable water. Once designed, the UF plant, equipped with a polysulfone spiral-wound membrane with a cut-off of 100 kDa, was tested with surface water with a higher microbiological content than the water to be treated in Ecuador. These experiments showed excellent results from the point of view of microorganism rejection, with values near 100% [7]. Now that UF viability for disinfecting water has been proved, the next stage of the project consisted of testing membranes of different characteristics to optimise the process. The following points had to be assessed: quality of ultrafiltrated water, performance conditions, membrane fouling, and cleaning and maintenance conditions. This paper describes the experiments carried out to select the most suitable UF membrane from the point of view of microorganism removal.

2. Experimental

2.1. Materials

Four IRIS organic UF membranes from Orelis (Rhodia) of different cut-offs were tested in the experiments. Table 1 shows the characteristics of these membranes.

2.2. Feed characteristics

Experiments were performed in the laboratories of the Chemical and Nuclear Engineering Department with three different surface waters taken from different places, with low (water 1), medium (water 2) and high (water 3) microbiological activity. Table 2 shows the main characteristics of the three waters used in the experiments.

2.3. Pilot plant description

Fig. 1 shows the flow diagram of the pilot plant used in the experiments. Before entering the membrane module (9), feed water goes through a 50 micron filter (4) to remove suspended solids. After this, feed is driven by a piston pump with variable speeds (5). The membrane module comprises four flat membranes, each with an effective area of 30 cm^2. In each experiment the permeate was collected in a different container, while the retentate was returned to the feed tank, thus increasing feed water concentration.

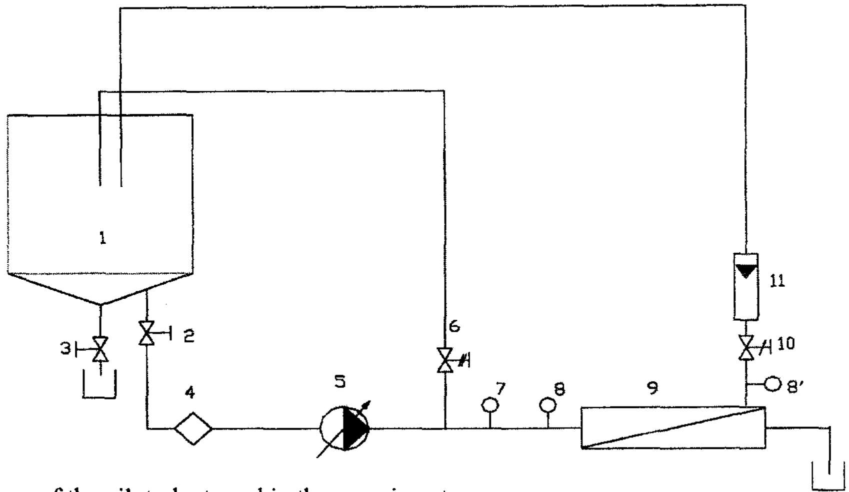

Fig. 1. Flow diagram of the pilot plant used in the experiments.

Table 1
Characteristics of the ultrafiltration membranes tested

Membrane	Model	Cut-off (kDalton)	Material
M1	IRIS 3028	10	PES[a]
M2	IRIS 3028	30	PES
M3	IRIS 3050	50	A[b]
M4	IRIS 3028	100	PES

[a]Polyethersulfone
[b]Acrylonitrile copolymers.

Table 2
Characteristics of the raw water sources

	Water 1	Water 2	Water 3
Total coliform/ 100 mL (cfu)	Countless (>300)	Countless (>300)	Countless (>300)
Faecal coliform/ 100 mL (cfu)	6	80	Countless (>300)
Faecal enterococus/100 mL (cfu)	4	14	Countless (>300)

2.4. Experimental procedure

Several experiments were carried out with the four UF membranes working simultaneously. Three experiments were carried out at a pressure of 0.2, 0.4 and 0.6 MPa with each of the three surface waters. Feed water temperature was kept constant by means of a heat exchanger in the feed tank.

During the experiments, permeate flow of each membrane was periodically measured. The permeate flux (J_P) of each membrane was calculated by the following expression:

$$J_P = \frac{Q_P}{A_{\text{memb}}}$$

where Q_P represents the permeate flow (L/h) and A_{memb} the membrane effective area (m^2).

In order to determine membrane selectivity to microorganisms, samples of each permeate were taken in each experiment for measuring their microbiological content.

3. Results and discussion

3.1. Membrane permeability

As has been described above, membrane permeability was determined by calculating the permeate flux. Figs. 2–4 show the results of membrane permeability of the four UF membranes with each feed water.

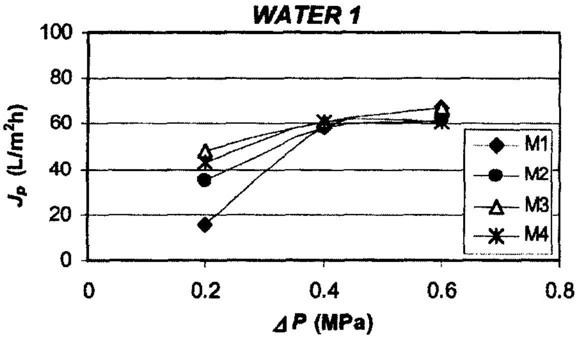

Fig. 2. Membrane permeability with WATER 1.

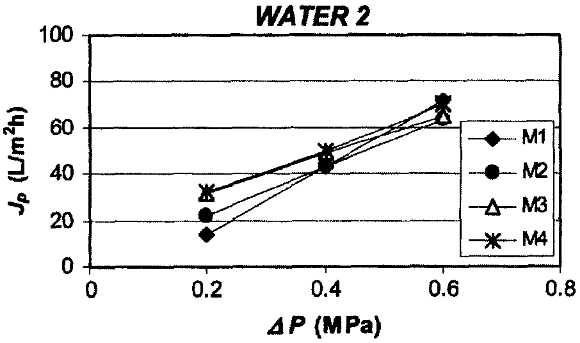

Fig. 3. Membrane permeability with WATER 2.

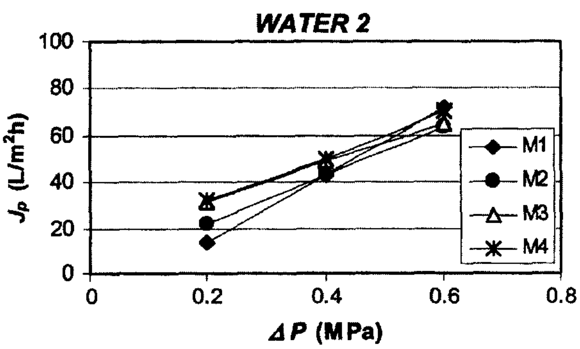

Fig. 4. Membrane permeability with WATER 3.

As can be seen in the figures, permeate flux results were very similar for M2, M3 and M4, despite having very different cut-offs (30, 50 and 100 kDalton, respectively). This similarity is more significant in the case of M3 and M4. According to the cut-off of these two membranes, it was expected that M4 (100 kDalton) permeability was much higher than M3 (50 kDalton). However, M3 performance with regard to permeability was very close to M4, and even higher under some conditions. This can be due to the different material of the membranes, since M3 is made of acrylonitrile and M4 is made of polysulfone. Thus, it seems that acrylonitrile membranes perform better than polysulfone ones.

Another advantage of acrylonitrile membranes is that they are more resistant to free chlorine (50 ppm in continuous) than polysulfone membranes (25 ppm in continuous). This is very important from the point of view of membrane cleaning when they suffer biofouling, which can happen when treating surface water.

In relation to working pressure, it was found that the increase of permeate flux when pressure changes from 0.2 to 0.4 MPa is significantly higher than the increase when pressure changes from 0.4 to 0.6 MPa. In the first case, that increase was between 70 and 100%, whereas in the latter it was between 5 and 50%. Therefore, bearing in mind the energy consumption associated to working pressure, it would be more suitable to work at a pressure of 0.4 MPa.

3.2. Membrane selectivity

The results of membrane selectivity have been very successful with all the tested membranes. In all cases, the removal of the bacteria showed in Table 2 was complete (100% of rejection), having obtained permeates with no bacteria content. Fig. 5 shows the samples of a faecal enterococus assay of feed and permeate of one of the experiments. The results were very similar in all the experiments with all the bacteria analysed.

No difference was found with regard to membrane cut-off, working pressure or feed characteristics. Therefore, it can be stated that all the tested membranes are suitable for treating surface water, even water with microbiological conditions much more critical than the water to be treated in Ecuador.

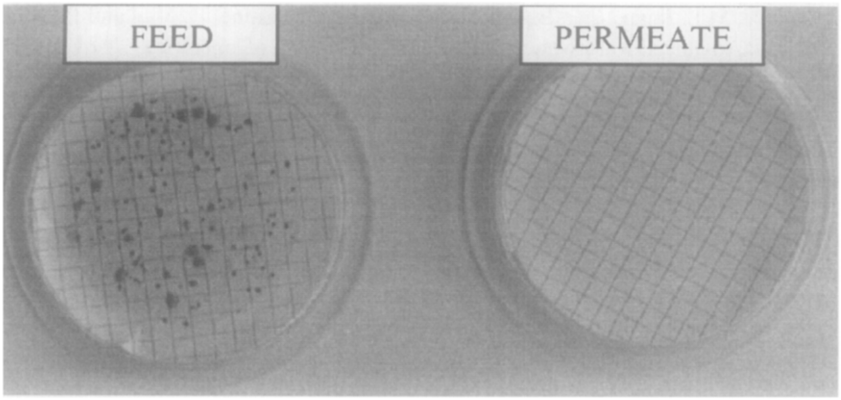

Fig. 5. Microbiological assay of feed and permeate samples.

According to the experiments performed, it has to be emphasised that, in the case of treating surface water, it is essential to displace feed water from the membrane module and the rest of the plant when a lengthy pause is expected in order to avoid membrane biofouling. In the experiments presented herein, membranes were cleaned between one feed water and another by means of a sodium bisulphite solution of 4% volume concentration during approximately 2 h.

4. Conclusions

UF membranes made of different materials and with a cut-off within a range of 10 and 100 kDalton were found to be very successful from the point of view of bacteria removal from surface water with different microbiological contents. All the tested membranes showed bacteria rejection values of 100%, with no difference with regard to membrane material, membrane cut-off, working pressure or feed water characteristics. Thus, all the tested membranes can be successfully applied to water disinfection.

In relation to permeability, tested UF membranes with a cut-off equal to or higher than 30 kDalton produced very similar permeate fluxes, but the permeability of the acrylonitrile membrane was even higher than the permeability of polysulfone membranes in some experiments. Thus, it can be said that acrylonitrile membranes are more suitable for treating surface water because of higher permeability performance and higher resistance to free chlorine.

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