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Factors influencing the ultrasound-enhanced cleaning process of an ultrafiltration ceramic cembrane fouled by reactive dye particles

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Introduction

Membrane processes such as Ultrafiltration (UF), Nanofiltration (NF) and Reverse Osmosis (RO) are widely employed in the treatment of textile wastewater because of the versatility of this technology [1]. Unfortunately, one of the critical issues in the development of membrane processes is the decline in system performance due to membrane fouling, which limits the economic efficiency of the process. Membrane fouling is generally characterized as a reduction of permeate flux through the membrane as a consequence of several mechanisms [2]. This phenomenon imposes the need for the frequent cleaning of the membrane. Therefore, an improvement of the cleaning procedure may have significant influence on the overall process efficiency. The use of chemical agents like acid, alkali, surfactants, enzymes or hypochlorite is a common membrane cleaning procedure. However, these methods may be unsafe and expensive. In addition to chemical treatments, there are several other methods to reduce membrane fouling based on physical operations: hydrodynamic forward or reverse flushing, permeate back pressure, ultrasonication, cleaning under magnetic or electrical fields, among others [3]. Of particular interest to the present work is the use of ultrasound in order to reduce membrane fouling and to improve the membrane cleaning efficiency. Ultrasound (US) is a sound wave traveling through a medium at a frequency above 18 kHz. When ultrasound is irradiated through a liquid medium, an alternating rarefaction and compression of the medium occurs. During the rarefaction stage, the formation and growth of micro bubbles may take place. The compression cycle makes bubbles collapse, releasing sufficient energy to overcome the interaction between the foulant and membrane and to remove the foulant from the surface of the membrane [4].

US-enhanced cleaning of membranes is influenced by several factors such as frequency, power intensity, cross-flow velocity, temperature, pressure etc. The study of the influence of these factors is an important part of the pilot-scale studies, with the aim of improving the cleaning efficiency. In order to determine the optimal cleaning conditions, methods such as Response Surface Methodology (RSM) are available. RSM is a set of mathematical and statistical tools used for modelling and analysing complex processes where a variable response is affected by several factors which can interact among them. In RSM all factors are varied simultaneously and therefore all the conjugated effects are taken into account. The response model can be used for the optimization of the process [5].

Methods

The aim of the present study is to investigate factors affecting ultrasonic cleaning of a particle-fouled UF ceramic membrane. The membrane was fouled by filtering a solution of Reactive Black 5 (RB5), an azo reactive dye widely used in textile industry. Subsequently it was subjected to ultrasound in a cleaning-in-place system under flow conditions at different

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transmembrane pressures (TMP), cross-flow velocities (CFV) and US power. A Box-Behnken design of response surface methodology was used to analyse the efficiency of the cleaning process. The linear and quadratic effects of the factors studied and the interactions on the response were obtained using analyses of variance (ANOVA).

An INSIDE CéRAM® (Tami Industries) multichannel tubular ceramic membrane was used. It had an active layer made of ZrO_2-TiO_2, a molecular weight cut-off of 150 kDa and an effective area of 132 cm^2. Experiments consisted of the following stages: deionized water flux measurement, fouling with RB5 solution, rinsing, US cleaning with deionized water and deionized water flux measurement. The membrane was immersed in an US bath (Elmasonic P-70H) and the ultrasonic experiments were performed by switching between 37 and 80 kHz US frequencies every 20 seconds. Three factors affecting the US cleaning process were considered: TMP, CFV and US power. According to the Box-Behnken design, three levels of each factor were studied, and the selected ranges of the variables were 0.5-2.5 bar, 1-3 m/s and 40-100% of the total US power respectively. A total of 15 runs were performed, including three replications of the central point. The cleaning efficiency of each treatment was determined and the acquired data were statistically analysed.

Results and Discussion

The cleaning efficiencies obtained ranged between 18.4% and 32.74%, depending on the operating conditions during the cleaning process. Figure 1 shows the Pareto chart resulting from the statistical analysis of the cleaning efficiency. In this case, only CFV and TMP have influence on cleaning efficiency, apart from the squared effect of TMP.

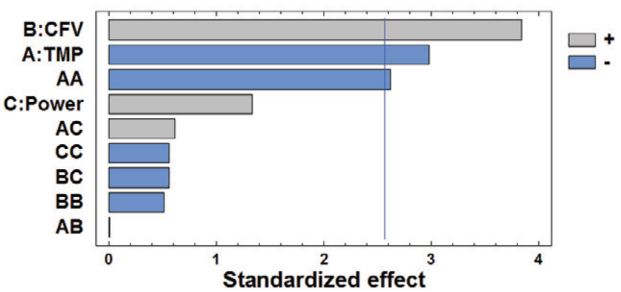

Figure 1. Statistical analysis of cleaning efficiency (Statgraphics Centurion XVI®).

The positive influence of CFV on the cleaning process could be explained because a greater turbulence is created at higher CFV. Therefore, dye particles could be easily removed from the surface and the pores of the membrane. On the other hand, an increase of TMP might cause that the particles removed during the cleaning stage and present in the bulk tend to approximate to the membrane again. This would explain the negative effect of TMP on the cleaning efficiency. The relatively low values of cleaning efficiency obtained might be due to the kind of fouling affecting the membrane. A combination of US with a chemical agent could be an interesting way to improve the efficiency of the cleaning process.

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