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Combining air sparging and the use of a static mixer in cross-flow ultrafiltration of oil/water emulsion

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Abstract

The simultaneous use of a static mixer and air sparging technique has been investigated during cross-flow ultrafiltration of oil/water emulsion. It is found that the use of a static mixer leads to a considerable increase in the permeate flux. However, the presence of a static mixer reduced hold-up in the feed channel leading to a high pressure drop along the length of the membrane and therefore the increase in energy consumption. Combining air sparging and the use of a static mixer demonstrated that a high permeate flux can be obtained at a relatively low energy consumption. The results suggest that the simultaneous use of these techniques could be interesting in membrane processes which already use gas injection, such as aerobic membrane bioreactors.

Keywords: Cross-flow ultrafiltration; Oil/water emulsion; Static mixer; Air sparging

1. Introduction

Ultrafiltration represents a highly attractive and promising technique for treating oily wastewaters, especially stable oil/water emulsions which require more sophisticated treatment to meet more and more rigorous wastewater effluent standards. The use of an ultrafiltration membrane to separate stable oil/water emulsion has been reported in many studies [1–7]. High water quality and low energy costs provide to ultrafiltration a decisive

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advantage over conventional treatment of stable oil/water emulsions. However, this process has several limitations, foremost among them the low permeate fluxes due to fouling. Oil/water emulsions induce three kinds of fouling mechanisms: oil drop deposit, concentration polarisation and adsorption of dissolved organic compounds [8].

The reduction of concentration polarisation and membrane fouling has been the focus of many studies. Several methods have been developed in various applications of ultrafiltration: the use of higher cross-flow velocities, pulsed flow [9], production of centrifugal instabilities such as Dean vortices [10], use of corrugated and/or modified membranes [11], operation under uniform transmembrane pressure [12], use of static turbulence promoters such as static mixers [13], screw-treaded inserts [14] or helical baffles [15] and more recently proposed high-shear rotary ultrafiltration [16] and the use of vibrating membranes (VSEP system) [17]. Some of these methods have been investigated for improving the flux in ultrafiltration of oil/water emulsions. Viadero, Jr. et al. [16] have shown that high-shear rotary ultrafiltration allows concentration of oil beyond the typical operating limitations of conventional ultrafiltration modules. Faibish and Cohen [18] have reported the increase by over 20% in oil rejection for a commercial cutting oil emulsion with polymer-modified zirconia-based ultrafiltration membrane compared to the native membrane. Krstiæ et al. [19] have shown that the use of the Kenics static mixer as a turbulence promoter during crossflow ultrafiltration of a stable oil/water emulsion can provide flux values up to 5 times higher compared to the fluxes obtained during operation without using the static mixer. However, the increase in pressure drop across the membrane module due to presence of the static mixer, and therefore the increase in energy costs, represents the main limitation of the systems with a turbulence promoter placed in a tubular membrane.

Among the various ways to reduce fouling in ultrafiltration, another interesting process is gas sparging. Gas bubbles are introduced directly into the feed leading to the creation of a gas/liquid two-phase flow. Gas sparging, and particularly air sparging, has been shown to be efficient in disruption of the concentration polarisation layer, and compared with conventional cross-flow operation, considerable permeate flux increases have been reported with hollow fibres [20,21] and tubular membranes [22,23]. Cui and Wright [22,23] have obtained flux increases of between 60 and 320% when ultrafiltering dextran, dryed dextran and BSA solutions. They have shown that the orientation of the membrane (horizontal or vertical) and the kind of flow (upwards or downwards) affect the effectiveness of gas sparging technique. However, few studies have investigated the effect of gas injection on ultrafiltration of oil/water emulsion. Um et al. [24] have shown that nitrogen injection causes positive effect on promoting turbulence leading to flux enhancement, but it also had a negative effect of decreasing the effective membrane area due to partial occupation of membrane pores by bubbles. The efficiency of gas sparging was found to be dependent on bubble fractions in the mixture: at sufficient bubble fraction the higher flux was observed, but at lower bubble fractions the flux decreased compared to the one without gas sparging.

Gas sparging technique and a gas/liquid two-phase flow has proved to be an attractive method to enhance ultrafiltration. The technique is simple and effective involving a high wall shear stress at a relatively low pressure drop across a membrane module. Even though gas sparging does seem to be effective as, for example, using the static turbulence promoters, a gas sparged ultrafiltration is an interesting system from an energetic point of view. Possible limitation of gas sparged ultrafiltration is the problem of gas distribution and its handling in the membrane system. In order to reduce membrane fouling and improve gas distribution into the membrane module, Derradji et al. [25] have suggested a new configuration with injecting air in such a way to obtain a gas/liquid