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Enhancement of membrane permeability by gas-sparging in submerged hollow fibre ultrafiltration of macromolecular solutions: Role of module design

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Abstract

Permeability in membrane filtration processes suffers from two major limiting factors: concentration polarization and membrane fouling. Gas-sparging, which involves bubbling of a gas in close proximity of a membrane, is known to minimise both of these. Gas-sparged membrane filtration is carried out either by pressurising a gas-sparged feed side or by using suction to draw the permeate through a membrane from the un-pressurised, gas-sparged feed side. The first approach is mainly used in ultrafiltration processes. The second approach which is easier to implement and is widely used in microfiltration processes. This paper discusses the enhancement of permeability by gas-sparging in suction-driven, submerged hollow fibre ultrafiltration using two different membrane module types. These modules were prepared using hollow fibre membranes having nominal MWCO of 150 kDa and were used to ultrafilter polysaccharide solutions. Depending on the operating conditions and on the module design, gas-sparging enhanced effective hydraulic permeability by as much as 115%. The extent of membrane fouling was also significantly lower in the gas-sparged mode. The effectiveness of gas-sparging was found to be greater with one membrane module type, clearly highlighting the effect of module design on process efficiency.

Keywords: Ultrafiltration; Gas-sparging; Hollow fibre; Submerged membrane; Flux enhancement; Fouling; Membrane module

1. Introduction

Ultrafiltration (UF) is widely used for processing natural polymers such as proteins, polysaccharides and nucleic acids. UF is mainly used for the concentration (i.e. removal of solvent) and desalting (i.e. removal of low molecular weight contaminants) of polymer solutions. In recent years, UF is also being tried out as a method for polymer fractionation. Membrane-based separation processes generally suffer from two major limiting factors: concentration polarization and fouling. Concentration polarization which is basically the build-up of the retained species near the membrane surface can limit the permeate flux, i.e. transport of liquid through the membrane and thus render a separation process unviable or uncompetitive. Several concentration polarization controlling or minimizing strategies have been proposed. Gas-sparging, which involves bubbling of a gas, typically air, in close proximity of the membrane is one of the more recent approaches towards minimising concentration polarization [1–23]. Fouling which refers to the adsorption and deposition of material on the membrane, particularly in and around the pores is widely regarded as the Achilles' heel of membrane filtration. This problem is linked to concentration polarization: generally, the greater the concentration polarization, the greater is the fouling. Gas-sparging has therefore been found to be useful in reducing membrane fouling. The application of gas-sparging in membrane filtration has been reviewed in a recent paper by Cui et al. [23].

The use of gas-sparging for improving membrane process efficiency has been reported for both ultrafiltration and microfiltration. In each case, several mechanisms are

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simultaneously responsible for the beneficial actions of gas-sparging and their relative contributions are system specific, i.e. depend on type of membrane filtration, type of membrane module, type of solute/particle and so on. Identifying which ones of these predominate in a particular system will help in rationalizing the use of gas, thus increasing the competitiveness of gas-sparged ultrafiltration. Gas-sparging is mainly used for high-bulk, low-value product processing where gas-sparging cost could be a significant factor. Some of the more recent reports have attempted to analyse the mechanisms responsible for the beneficial effects of gas-sparging and quantify them [6–10].

Gas-sparged membrane filtration processes can broadly be classified into two categories, one in which the feed is on the pressurised side (i.e. where permeate is driven by positive transmembrane pressure), and the other in which the permeate is driven by suction (as with submerged hollow fibre membranes). The earlier developments in the area of gas-sparged membrane filtration took place in the former category [1–5]. The main advantage of using positive pressure to drive filtration is that higher transmembrane pressures can be used. The disadvantages include the necessity to use a pressurized system and the requirement for compressed gas of appropriate pressure. Pressurization of the feed side using a valve on the retentate line, which is common in both microfiltration and ultrafiltration, does not work very well in gas-sparged processes. This is due to the fact that the retentate stream is a two-phase system and it is difficult to control the transmembrane pressure. One way to overcome this problem is to use a pressurized feed tank [11,12].

One of the earlier reports on the use of a gas-sparged membrane system operated in the suction mode was by Shimizu et al. [13]. They discussed cross-flow microfiltration using a submerged hollow fibre membrane. Gas-sparging was shown to facilitate continuous solid–liquid separation using a system based on simple equipment, such as a low-rate suction pump, an air blower and an open feed vessel. There have since been several reports on the use of gas-sparged submerged hollow fibre systems, some in the context of aerated membrane bioreactors [13–22]. Most of these have dealt with gas-sparged microfiltration processes. Gas-sparged ultrafiltration of dextran and indeed other macromolecules has been discussed in several papers [1–5,24,25]. However, all of these are based on sparging on the pressurised feed fide of the membrane. To the best of the author's knowledge there are no reports on suction-driven, gas-sparged submerged hollow fibre ultrafiltration of macromolecules. The fact that the transmembrane pressure is limited in suction-based processes could be one of the factors responsible for this since ultrafiltration processes are typically carried out at higher transmembrane pressures than microfiltration. However, with the increasing trend of

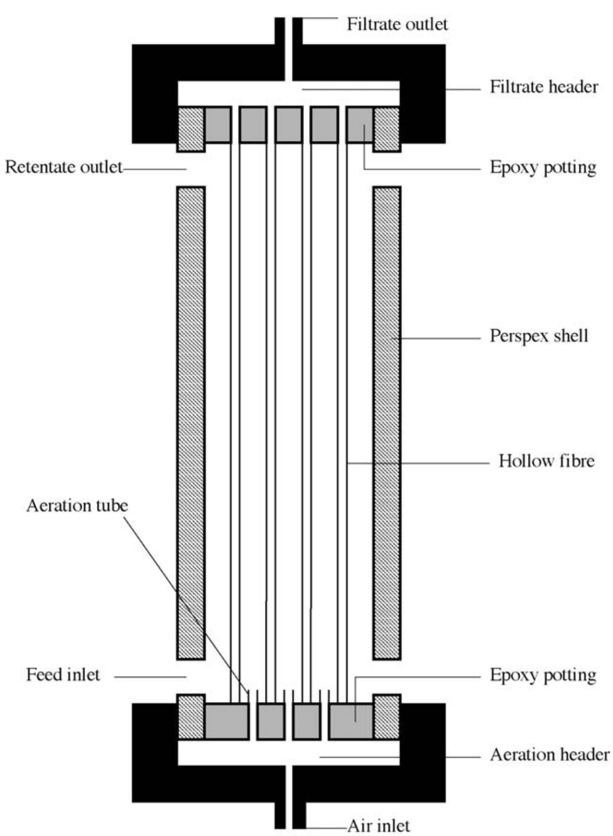

Fig. 1. Type 1 submerged hollow fibre membrane module.

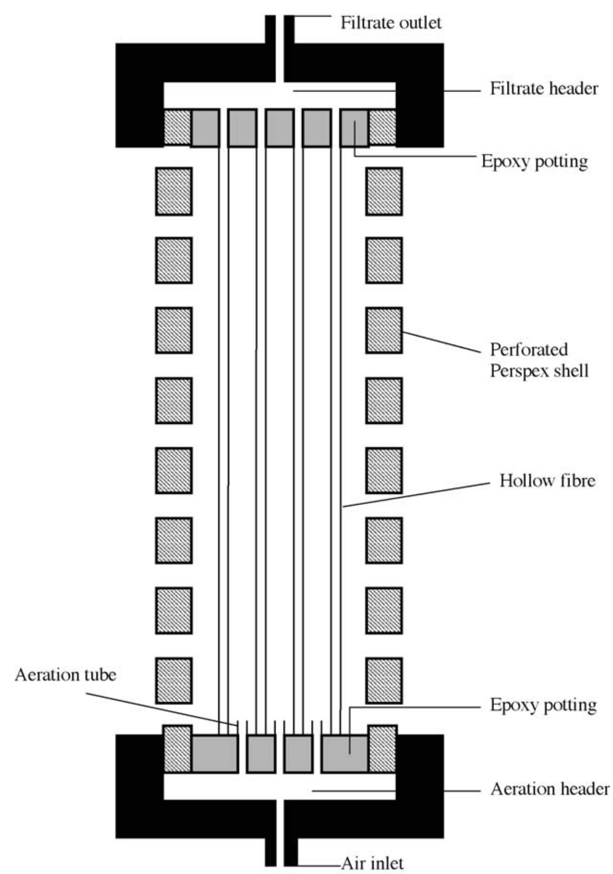

Fig. 2. Type 2 submerged hollow fibre membrane module.