DESALINATION

Desalination 191 (2006) 365–370

www.elsevier.com/locate/desal

Effect of fiber lumen radius on the permeate flux of hollow fiber membrane modules

Martin Mondor[a]*, Christine Moresoli[b]**

[a]*Département de Génie Chimique, Université de Sherbrooke, Sherbrooke, Quebec, Canada, J1K 2R1*
[b]*Department of Chemical Engineering, University of Waterloo, Waterloo, Ontario, Canada, N2L 3G1*
Tel. +1 (519) 888-4567-5254; Fax +1 (519) 746-4979; email: cmoresol@cape.uwaterloo.ca

Received 15 March 2005; accepted 8 July 2005

Abstract

Microfiltration of rigid spherical particle suspension in a hollow fiber module operating with inside–out flow, at a constant module inlet flow rate, was simulated using the shear-induced hydrodynamic diffusion model of Mondor and Moresoli, with consideration of the axial variation of the pressure drop through the cake layer and the membrane. The influence of the particle size and of the lumen radius, on the length-averaged permeate flux, was investigated for two typical membrane resistances. The results show that different patterns can be observed: A situation where there is negligible or no cake layer formation, a situation where the cake layer resistance is the main resistance to the permeate flux and finally a situation where both cake layer and membrane resistances are similar in magnitude. For the first situation, the length-averaged permeate flux increases with an increasing lumen radius, for the second situation the length-averaged permeate flux decreases with an increasing lumen radius and for the third situation, there exists an optimal lumen radius corresponding to a maximum length-averaged permeate flux. Finally, the current approach was compared with a similar analysis that has been performed for crossflow microfiltration by Arora and Davis.

Keywords: Hollow fiber; Lumen radius; Microfiltration; Pressure drop; Shear-induced diffusion

* Current address: Food Research and Development Centre, St-Hyacinthe, Quebec, Canada, J2S 8E3

**Corresponding author.

Presented at the International Congress on Membranes and Membrane Processes (ICOM), Seoul, Korea, 21–26 August 2005.

doi:10.1016/j.desal.2005.07.029

1. Introduction

Microfiltration applications in biotechnology, food, water and wastewater treatment and mineral processing have grown significantly in the recent years. Crossflow microfiltration is primarily a size-exclusion pressure-driven membrane process used for the separation of particles ranging in size from 0.1 to 30 μm. Low operating pressures and high permeate fluxes are characteristic of microfiltration. In many situations, the retained components are significantly larger than the membrane pores, such that the accumulated components at the membrane will lead to the formation of a cake at some position along the filter.

Hollow fiber module configuration is most often used if high shear rates are desired. Typical hollow fiber modules consist of a bundle of hundreds of porous fibers arranged in parallel and glued at the end. A high membrane filtration surface area per unit module volume (packing density), is obtained with small aspect ratio (diameter to length), but is characterized by significant internal axial and radial pressure drops. Variation of the radial pressure gradient along the length of the fiber will lead to axially-dependent fluxes through the membrane which will affect particle deposition and ultimately cake formation.

Particle transport during microfiltration and its influence on the permeate flux have been the object of intense research. At steady state, the convection of particles toward the membrane is balanced by the back-transport of particles away from the membrane and their convection along the membrane surface caused by the retentate tangential flow [1]. The motion of the feed particles away from the membrane surface is represented by various back-transport mechanisms: Brownian diffusion, shear-induced diffusion, inertial lift and particle surface transport [1]. For typical crossflow microfiltration applications, particles with diameters between 0.5–30 μm and high shear rates, shear induced diffusion appear to be the predominant back-transport mechanism [1,2]. In the concept of shear-induced diffusion, particles interact with neighboring particles due to velocity differences, resulting in random displacements from the streamlines as they interact with and tumble over other particles. The models based on shear-induced diffusion for crossflow microfiltration have generally assumed constant transmembrane pressure (radial pressure gradient) situations with model predictions for monodisperse feed within 30% of the measured permeate fluxes, for a flat membrane microfilter [3–5]. Only a few predictive models have investigated the axial variation of the pressure profile and the hydrodynamics of the flow through permeable fibers but no account of the feed components or of the particle back-transport mechanism is considered [6–9]. The particle behavior was first analyzed by Arora and Davis [10]. They report on the effect of the axial variation of radial pressure profile using Darcy's Law, together with considerations of the particle behavior using the shear induced diffusion and the excess particle flux concept. The axial pressure profile within a fiber is described by Poiseuille's law where a constant pressure is assumed on the permeate side, an approach that simplifies the estimation of the radial pressure drop once the lumen pressure profile is known. Their analysis for monodisperse rigid spherical feed suspensions, predicts a significant radial pressure drop along the fiber length for thick cake layer since the cake layer obstructs a significant portion of the fiber cross-section area for longer tubular membrane.

Recently, we have developed a model that has considered the transmembrane profile along the membrane length and the flow within the fiber, the membrane and the extracapillary space together with the shear induced diffusion back-transport of particles for microfiltration of monodisperse rigid spherical feed suspensions [11]. Experimental validation of this model has shown that the flux predictions are significantly improved suggesting that both back-transport mechanisms and hydrodynamic considerations play a major role in microfiltration operations [12,13]. In the