Journal of Membrane Science 324 (2008) 7–25

Contents lists available at ScienceDirect

Journal of Membrane Science

journal homepage: www.elsevier.com/locate/memsci

Review

Dynamic shear-enhanced membrane filtration: A review of rotating disks, rotating membranes and vibrating systems

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ARTICLE INFO

Article history:
Received 27 March 2008
Received in revised form 19 June 2008
Accepted 22 June 2008
Available online 28 June 2008

Keywords:
Rotating and vibrating membranes
High shear rate filtration

ABSTRACT

This paper reviews various systems of dynamic filtration, also called shear-enhanced filtration, which consists in creating the membrane shear rate necessary to maintain the filtration by a rotating disk, or by rotating or vibrating the membranes. This mode of operation permits to reach very high shear rates, of the order of $(1–3) \times 10^5\ s^{-1}$ and to increase both permeate flux and membrane selectivity. Several types of industrial dynamic filtration systems are available, but their share of the market is still small. This paper reviews the operating principles and fluid dynamics basics of various types, cylindrical rotating membranes, disks or blades rotating near a fixed membrane, rotating flat circular membranes, multi-shaft systems with overlapping rotating ceramic membranes and vibrating systems with toroidal membrane oscillations around an axis, or vibrating hollow fibers cartridges. It also reviews their main applications published in the literature in microfiltration, ultrafiltration, nanofiltration and reverse osmosis with a comparison of permeate fluxes with cross-flow filtration data when available. A comparison of performances between the vibrating VSEP system and a rotating disk module in MF of yeast suspensions and in UF of skim milk is also presented. The discussion is focused on a comparison of merits of various designs in the light of fluid mechanics and energetic considerations.

Contents

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0376-7388/$ – see front matter
doi:10.1016/j.memsci.2008.06.050

1. Introduction

1.1. Definition of dynamic or shear-enhanced filtration

The use of high membrane shear rates has long been recognized as one of the most efficient factors for increasing permeate flux as it reduces both concentration polarization in ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO), and cake build-up in microfiltration (MF). In classical cross-flow filtration (CFF), high shear rates at the membrane surface are obtained by increasing the tangential fluid velocity along the membrane and reducing tube diameter or channel thickness, which generates large axial pressure gradients. This combination of large velocities and pressure gradients not only requires much energy to drive the pumps, but causes a decrease of transmembrane pressure (TMP) along the membrane leading to non-optimal membrane utilization.

Dynamic or shear-enhanced filtration consists in creating the shear rate at the membrane by a moving part such as a rotating membrane, or a disk rotating near a fixed circular membrane or by vibrating the membrane either longitudinally or torsionally around a perpendicular axis.

1.2. Advantages and drawbacks of dynamic filtration

This mode of filtration constitutes an alternative to cross-flow filtration, which not only increases substantially the permeate flux, but has a favourable effect on membrane selectivity. It also permits to decouple from membrane shear rate, the inlet flow rate into the module, which can be varied independently and does not need to be much larger than the filtration rate. Clarification of a suspension by MF requires a high microsolute transmission, and this transmission is increased in dynamic filtration, which reduces cake formation by combining a high shear rate with a low TMP. Conversely, in wastewater treatment by NF and RO, it is important to have the highest possible rejection. Since dynamic filtration reduces concentration polarization, the concentration of rejected solutes at the membrane is lowered, reducing the concentration gradient and diffusive solute transfer through the membrane and therefore increasing solutes rejection rate. At the same time, permeate fluxes keep increasing until high pressures, as the pressure limited regime is extended by the reduction of concentration polarization and very high fluxes can be obtained at high TMP.

The drawbacks are the complexity and limitations in membrane area for some systems, such as cylindrical rotating membranes or multi-compartment rotating disk systems, which raise the equipment cost. But, the recent availability of large diameter ceramic disk membranes permits the construction of immersed rotating membranes of 80 m^2 area or more, which are easier and less costly to build than multi-compartment systems.

2. Review of commercial dynamic filtration systems

2.1. Rotating cylindrical membranes

The first commercialized dynamic filtration systems were of Couette flow type with cylindrical membranes rotating inside a concentric cylindrical housing, such as the Biodruckfilter (Sulzer AG, Winterthur, Switzerland) and the Benchmark Rotary Biofiltration (Membrex, Garfield, NJ, USA) [1,2]. This concept takes advantage of Taylor vortices created at large Taylor numbers in the annular space between membranes and housing which increase the shear rate as compared to classical Couette flow. Another membrane can be mounted on the fixed housing, but the maximum membrane area of commercial systems seems to have been about 2 m^2. The most successful application of this concept was the Plasmacell filter (Hemascience, Santa Ana, CA, USA) introduced in 1985 for plasma collection from donors (Fig. 1) [3,4]. Since this device was

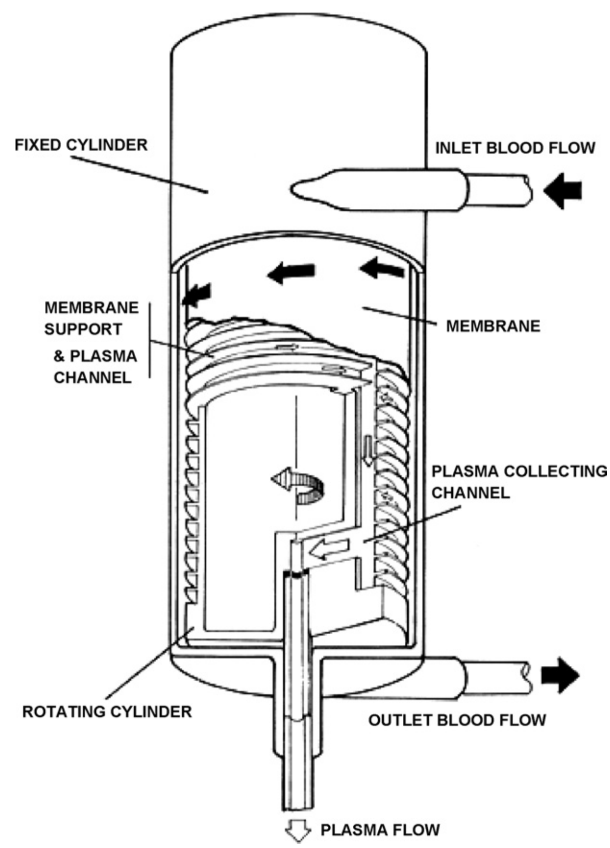

Fig. 1. Schematic of rotating cylindrical filter for plasma collection from donors.