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The impact of mechanical shear on membrane flux and energy demand

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A B S T R A C T

The use of forced mechanical shear for both disc membranes (rotating and vibrating disc filtration, RDF and VDF respectively) and hollow fibres (vibrating HF membranes, VHFM) is reviewed. These systems have been extensively studied and, in the case of the disc membranes, have reached commercialisation and proven effective in achieving transmembrane pressure (TMP) control for various challenging feed waters.

The effects of operating conditions, namely shear rate as enhanced by rotation and vibration speed and TMP, and feed water quality on the filtration flux and specific energy consumption are quantified as part of the review. A new relationship is revealed between the two empirical constants governing the classical relationship between membrane flux and shear rate, and a mathematical correlation proposed accordingly. A study of available information on energy reveals that operation at lower shear rates (i.e. rotation or vibration speeds) and more conservative fluxes leads to lower specific energy demands in kWh m^{-3} permeate, albeit with a larger required membrane area.

Contents

1. Introduction

All membrane processes where there is relative motion between the membrane and the fluid involve shear. In conventional crossflow membrane filtration shear is generated by pumping the liquid through a membrane channel. For a submerged membrane process, and specifically a membrane bioreactor (MBR), it is generated through the action of air bubbles scouring the membrane surface. An alternative to promoting the liquid motion, however, is to apply shear mechanically to move the membrane as opposed to the liquid.

The paper aims to identify possible relationships between flux and membrane motion which determine the nature of the impact of shear on both productivity (i.e. permeate flux) and specific energy demand (energy per unit volume of permeate). These aspects are considered for specifically for both rotating and vibrating membrane technologies of flat disc and hollow fibre membrane configuration.

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2. Rotating and vibrating disc filters (RDF and VDF)

2.1. Shear impacts on flux

The use of mechanically-imposed shear to enhance flux by reducing both concentration polarisation (CP) and/or the development of the filter cake is well established [1–3]. Dynamic or shear-enhanced filtration involves creating shear at the membrane by rotating (and thus rotating disc filtration or RDF) or vibrating (hence VDF) the membrane or some component near the membrane surface, with RDFs sometimes using overlapping multiple shaft discs (MSDs). The movement may be either axial or, more usually, torsionally around the axis for disc membranes, or horizontal (lateral) or vertical for rectangular membranes (Fig. 1). Using dynamic filtration has been shown by various investigators [4–11] to greatly suppress CP limitations, reducing the membrane area requirement [12]. The process appears especially effective for high-value, small-scale duties, including various dairy industry applications [6,13–25], the treatment of yeast dispersions and bovine albumin solutions [4,5,26], pulp and paper industry applications [7,27] and specialist beverage process separations, such as the treatment of chicory juice [28–30] or sugar beet juice [31,32]. It has also found use in landfill leachate treatment [33,34], arsenic removal from drinking water [11,35], treatment of brine and brackish water [36–38], removal of natural organic matter [10,39,40], livestock wastewater treatment [8,41,42], dishwasher detergent wastewater and surfactant solution treatment [43,44], separation of microalgae [45,46] and *Anammox* sludge consolidation [47].

Although most dynamic filtration investigations have shown filtration flux to increase with increasing surface shear, the precise relation evidently depends on feed type and concentration [4,5,48], pore size of the applied membrane [5,31,35,40] and system operating conditions [48,49]. However, the flux generally increases with vibration/rotation rate and amplitude, with rejection capability also affected in some instances [9,36,37,40].

The correlation of flux with shear takes the general form [3]:

$$J = k\gamma^n \tag{1}$$

where γ is the shear rate, in units of inverse time, and k and n are empirical constants. In this simple relationship the coefficient k can be viewed as the strength of the correlation and the exponent n the sensitivity, with respect to flux vs. shear.

A summary of available data for k and n values obtained for primarily vibrating and rotating ultra/microfiltration membrane systems (Table 1) indicates a number of interesting trends:

1. Exponent values relate primarily to feedwater characteristics. For example, reported values of n for skimmed milk, from data derived from four independent studies, lie between 0.48 and 0.60. The value appears independent of either the technology or the membrane characteristics (and specifically the material and pore size),
2. High exponent values are associated with high viscosity, which in turn relates to solid or solute concentration. Examples of such matrices include systems where the feed is being concentrated – sometimes referred to as “volume reduction” [49–51] – or innately high-solids systems such as fermentation broths [51] and soya milk [14,15].
3. There is also some dependence of n on applied pressure [44] across ranges of 0.5–10 bar for RDFs [4,48,49,52], 0.8–15 bar for VDFs [4,48,49,53], up to 3 bar for MSDs [44] and 0.005–0.008 bar for a vibrating hollow fibre membrane (VHFM) [54]. At lower pressures the initial flux has been reported to increase more rapidly with increasing shear than at higher pressures.
4. Exponent values tend to be higher for smaller pore sized (ultrafiltration, UF) membranes, as compared with coarser (microfiltration, MF) ones, under otherwise comparable conditions [5,55].
5. The coefficient value tends to increase with decreasing

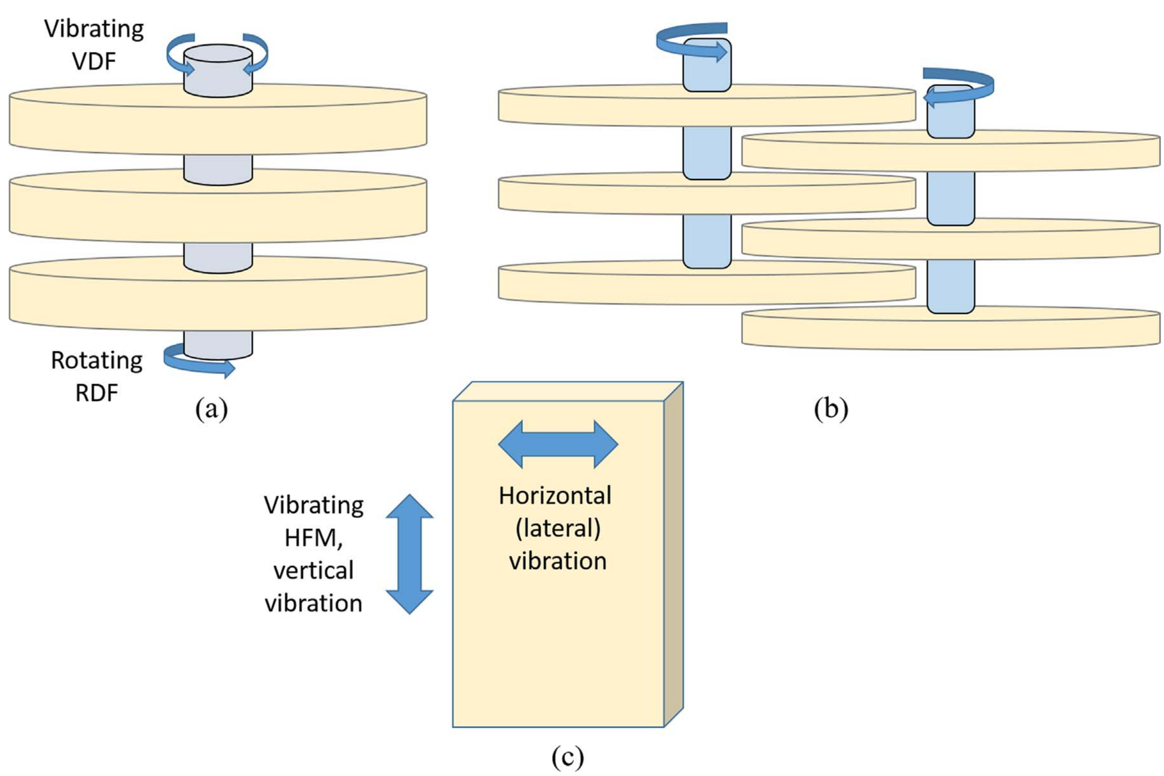

Fig. 1. Membrane technologies with modes of movement: (a) rotating and vibrating disc filters (RDF and VDF), indicating torsional motion; (b) multiple shaft disc (MSD), overlapping, (c) vibrating membrane (e.g. hollow fibre, VHFM).