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High concentration of skim milk proteins by ultrafiltration: Characterisation of a dynamic membrane system with a rotating membrane in comparison with a spiral wound membrane

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ABSTRACT

The purpose of this work was to characterise the ultrafiltration of skim milk with a dynamic system with a rotating membrane regarding flux in milk protein concentration. The flux of the dynamic system showed a maximum at medium rotational speeds, probably due to the permeate backpressure or a shift in the deposited particle size range to smaller particles above a critical rotational speed. The flux increased almost linearly up to a transmembrane pressure (TMP) of 100 kPa. At higher TMP, the curves levelled off, especially at higher protein concentrations. The dynamic system was less limited by the increasing retentate viscosity and reached significantly higher volume reduction ratios (VRR) as compared with a spiral wound module (SWM). SWM are suitable to achieve VRR <5–6 before a dynamic system, possibly in combination with tubular ceramic membranes, could be used to achieve higher VRR >8.

1. Introduction

Ultrafiltration (UF) is a commonly applied unit operation in the dairy industry. It is used, e.g., for the standardisation of the protein content of milk. For other applications, like cheese making or the manufacturing of milk protein concentrates (MPC) or isolates (MPI), the target is to achieve high volume reduction ratios (VRR; the ratio of the initial volume to the retentate volume at the end of the concentration). During MPC/MPI production, the dry matter of the liquid concentrates and isolates is often increased via evaporation prior to spray drying. Evaporation and spray drying are thermal processes and therefore, in comparison with the non-thermal membrane filtration step, quite energy consuming. By removing as much water as possible by membrane filtration, the energy consumption of the manufacturing process can be reduced. In addition, the diafiltration process during MPI production can be accelerated due to the low retentate volume.

In industry, spiral wound modules (SWM) are often employed for concentration processes because of their low investment and replacement costs. However, SWM are not capable of processing highly viscous fluids owing to the generation of high pressure drops within the module at high retentate viscosities (Akoum, Jaffrin, & Ding, 2005; Lipnizki, Casani, & Jonsson, 2005). As the enrichment of total milk protein is accompanied by a strong rise in viscosity (Aaltonen, 2012; Solanki & Rizvi, 2001) the employment of SWMs for this purpose is limited. An alternative to conventional systems is the application of dynamic filtration devices. Several authors have already shown for some biotechnological applications that dynamic devices perform better than conventional filtration units in terms of separation efficiency and permeate flux values.

Harscoat, Jaffrin, Bouzerar, and Courtois (1999) investigated the recovery of exopolysaccharides from a fermentation broth by a dynamic filtration system with a disk rotating above a fixed nylon membrane and compared it with a unit equipped with tubular ceramic membranes. The polymer transmission remained between 90 and 100% for the dynamic filtration device, whereas it dropped to 10% after a filtration time of 90 min for tubular ceramic membranes. In dynamic systems, shear rate and transmembrane pressure (TMP) are independent of each other. Thus, high shear rates can be generated at low TMP levels and fouling can be decreased. Consequently, a higher separation efficiency can be achieved (Jaffrin, Ding, Akoum, & Brou, 2004).

Lee, Burt, Russotti, and Buckland (1995) compared a rotating disk and a flat sheet membrane module for the harvesting of recombinant yeast cells. It was demonstrated that the pseudo-steady

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state flux after 2 h of filtration at a constant pressure drops below 25 L m^{-2} h^{-1} for the flat sheet membrane module. In contrast, the dynamic filtration system showed approximately a 4-times higher flux of 100 L m^{-2} h^{-1}. The high shear rates in dynamic systems effectively minimise concentration polarisation and deposit formation, leading to higher flux values. Another advantage is the possibility to operate such systems at low feed volume throughputs (Jaffrin, 2008). This reduces the energy demand, as lower pump capacities are sufficient. In addition, it enables the processing and production of highly viscous solutions that could not be pumped at higher throughputs. This leads to the assumption that dynamic systems may not only enhance flux and separation efficiency but also allow the achievement of higher VRR due to less limitation by the increasing viscosity of the retentate. Al-Akoum, Ding, and Jaffrin (2002) showed that by application of a vibratory shear-enhanced process (VSEP), higher VRR than in conventional systems can be achieved. They investigated the concentration of skim milk via UF-membranes (polyethersulfone, PES) and found a maximum VRR of 8.66 (calculated by extrapolation to zero flux), which was significantly higher than the VRR of 5.6 reported before for hollow fiber membranes (Al-Akoum et al., 2002; Bouzaza, Jaffrin, & Gupta, 1989).

The aim of the studies presented in this paper was to investigate whether the results obtained using a VSEP can be transferred to the concentration of total milk protein using a dynamic ultrafiltration device with a rotating membrane. The application of dynamic filtration units for dairy purposes has already been studied by several authors. However, most investigations have focused on vibrating membranes (Akoum et al., 2005; Al-Akoum et al., 2002; Frappart, Jaffrin, & Ding, 2008; Jaffrin et al., 2004) or rotating disk modules, where a disk rotates above a fixed membrane (Bhattacharjee, Ghosh, Datta, & Bhattacharjee, 2006; Ding, Akoum, Abraham, & Jaffrin, 2003; Ding, Al-Akoum, Abraham, & Jaffrin, 2002; Frappart, Akoum, Ding, & Jaffrin, 2006; Luo, Ding, Wan, & Jaffrin, 2012). Dynamic filtration systems, where the membrane itself rotates, have only been used in microfiltration applications (Espina, Jaffrin, & Ding, 2009; Espina, Jaffrin, Ding, & Cancino, 2010; Espina, Jaffrin, Frappart, & Ding, 2008; Espina, Jaffrin, Paullier, & Ding, 2010). Thus, the first goal of this paper was to characterise the ultrafiltration of skim milk with a rotating ceramic membrane by determining the impact of transmembrane pressure, rotational speed and protein concentration on the process. Furthermore, its performance in total milk protein concentration was examined. As dynamic filtration devices are still comparably quite expensive due to their complexity and limitations in membrane area (Jaffrin, 2008), the general idea was not to replace conventional systems, but to usefully supplement them. Therefore, in the second part of this paper, filtration with the rotating membrane module was compared with concentration using a SWM and a possible cascade connection of both was suggested.

2. Material and methods

2.1. Experimental set-up

2.1.1. Rotating membrane module

The module was equipped with a ceramic membrane with an outer diameter of 152 mm, an inner diameter of 25.5 mm and a thickness of 4.5 mm (membrane area = 0.036 m^2). The membrane was fixed on a rotating hollow shaft. The fixation on the hollow shaft reduces the active membrane area to 0.033 m^2. The shaft and membrane were enclosed in a thermostated housing. The test fluid was in a thermostated container and constantly stirred to ensure the homogeneity of the feed. The fluid was pumped into the filtration module via a gear pump (LAB 20T, Gather Industrie GmbH, Wülfrath, Germany). The feed inlet was located at the

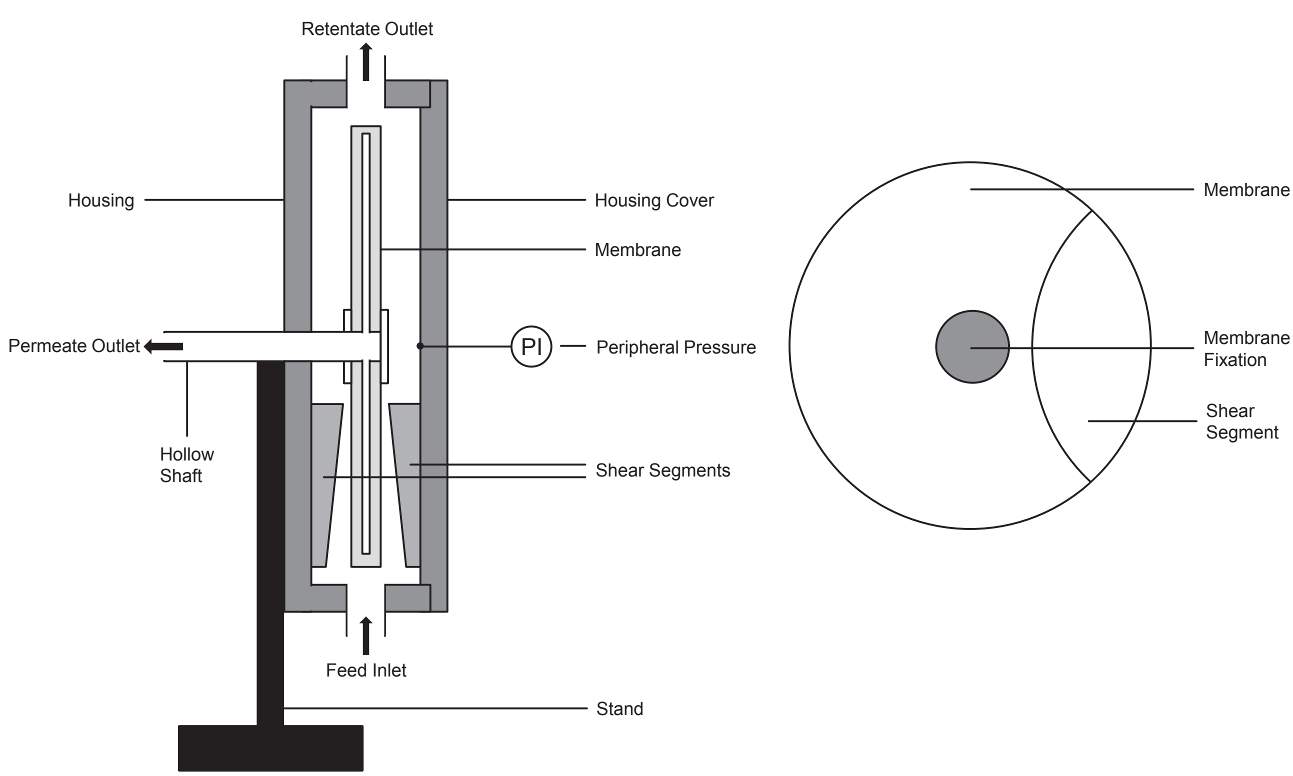

Fig. 1. Schematic of the rotating membrane module.