J. Dairy Sci. 98:1–12
http://dx.doi.org/10.3168/jds.2014-8880

Factors that influence the membrane area of a multistage microfiltration process required to produce a micellar casein concentrate[1]

Emily E. Hurt and David M. Barbano[2]
Northeast Dairy Foods Research Center, Department of Food Science, Cornell University, Ithaca, NY 14853

ABSTRACT

The objective of the work reported in this paper was to develop a theoretical model to determine the effect of type of microfiltration (MF)-process feed, number of stages, and flux on the minimization of the MF membrane area required to produce a 95% serum protein–reduced micellar casein concentrate. The MF feed, number of stages, and flux were all factors that had an effect on the MF membrane area and should be taken into consideration when designing a MF system to produce a 95% serum protein–reduced micellar casein concentrate. Feeding the MF process with a diluted ultrafiltration retentate (DUR) diluted to the protein concentration of skim milk, as opposed to skim milk, reduced the required membrane area by 36% for a 5-stage process. When DUR was the MF feed, feed protein concentration, which depended on the number of MF stages, was optimized. The DUR protein concentration that minimized the required MF membrane area was 2.47, 3.85, 4.77, and 5.41% for a 2-, 3-, 4-, or 5-stage MF process, respectively. For a 5-stage process, increasing the protein concentration of the feed from 3.2 to 5.4% decreased the required MF membrane area by 10%. It was also found that as the number of stages increased from 2 to 5, the required MF membrane area decreased by 39%, when the MF feed was DUR at the optimal feed protein concentration. Finally, increasing the flux from 50 to 60 kg/m^2 per hour decreased the required MF membrane area by 17% when the MF feed was DUR at the optimal MF feed protein concentration. Overall, using DUR as a feed for MF could reduce the amount of MF membrane area required to make a 95% serum protein–reduced micellar casein concentrate.

Key words: microfiltration, membrane area, flux, micellar casein concentrate

INTRODUCTION

Microfiltration of Skim Milk

Microfiltration (**MF**) can be used to remove serum protein (**SP**) and lactose from the micellar CN in skim milk (**SM**). The micellar CN is retained by the MF membranes and concentrated in the retentate, whereas a major portion of SP, lactose, NPN, and serum-phase minerals pass through the membrane into the permeate. Both ceramic (Fauquant et al., 1988; Zulewska et al., 2009; Adams and Barbano, 2013) and polymeric MF membranes (Lawrence et al., 2008; Beckman et al., 2010) have been used to MF SM. The type of membrane has been found to have an effect on the SP removal efficiency. Zulewska et al. (2009) compared 2 types of ceramic MF membranes to a polymeric spiral-wound membrane. Zulewska et al. (2009) found that the ceramic membranes in a 1-stage system operating at a concentration factor (**CF**) of 3× removed 64 and 61% of the SP, which was close to the theoretical removal of 69% (Hurt and Barbano, 2010); the percentage of SP removed by the polymeric membranes was significantly less at 39%. Zulewska and Barbano (2014) reported that for a 3-stage MF process running at a CF of 3×, a total of 1,208 m^2 of a ceramic 0.1-μm graded permeability membranes would be required to remove 95% of the SP from 1 million kilograms of skim milk at flux of 92 kg/m^2 per hour, whereas 2,051 m^2 would be required for the same process using a uniform transmembrane pressure system at a flux of 54 kg/m^2 per hour.

The retentate from MF is a micellar CN concentrate (**MCC**) that could be used in multiple applications, including formulation of shelf-stable nutritional beverages. For nutritional-beverage applications involving high-heat treatment, the large reduction in the heat-labile components in MCC (SP and lactose) may be critical. The sensory properties of fresh liquid MCC retentates could be superior to other dried CN ingredients (i.e., rennet CN, sodium and calcium caseinates). The composition of MCC with respect to SP and lactose concentration as well as protein concentration will depend on the MF process and membrane equipment. The permeate from MF will consist mainly of SP and

---

Received September 20, 2014.
Accepted December 9, 2014.

[1] Use of names and names of ingredients and identification of specific models of equipment is for scientific clarity and does not constitute any endorsement of a product by the authors, Cornell University, or the Northeast Dairy Foods Research Center.

[2] Corresponding author: dmb37@cornell.edu

Table 1. Micellar casein concentrate (MCC) target composition (% by weight) and percent reduction of lactose and serum protein compared with skim milk

Item	Protein	Serum protein	Lactose
Concentration in MCC (% by weight)	9.00	0.098	0.20
Percent reduction (compared with skim milk)	—	95	98.8

lactose. Further processing of the MF permeate by UF to concentrate the SP would produce SP concentrates. These SP concentrates could be used in applications similar to whey protein concentrates and in new applications in protein fortification where their clarity relative to whey protein concentrates (Luck et al., 2013) would be an advantage.

MF Process Design

In designing a multistage MF process to produce an MCC, the number of stages, retentate protein concentration, and the flux at which the system will operate at all have to be specified. These parameters could have an effect on the overall MF membrane area required and the cost of the system. A processor considering installing an MF system to produce MCC may already be using UF to produce milk protein concentrates (**MPC**). In this case, it will be possible to feed the MF-process-with-UF SM (MPC) as opposed to SM. Because the UF process will remove lactose, an MCC produced from UF SM would be expected to have a lower concentration of lactose compared with an MCC produced with SM using the same MF process.

For a MF process designed to produce an MCC, a main objective would be to produce an MCC meeting customer specifications while minimizing the cost of the system, including the cost of required diafiltration water. In the current work MF membrane area was used as a proxy for system cost, and the amount of MF permeate produced (and diafiltration water) was also calculated. To determine the relationship between the process design parameters and required MF membrane area, a theoretical MF model was developed where the effect of MF-process feed, number of stages, and flux on MF membrane area could be determined. The objective of the work reported in this paper was to develop a theoretical model to determine the effect of type of MF-process feed, number of stages, and flux on the minimization of the MF membrane area required to produce a 95% SP-reduced MCC.

MATERIALS AND METHODS

MCC Composition

The goal of the theoretical MF process was to produce an MCC with a reduced concentration of SP and lactose. The MF process would also reduce the concentration of other serum-phase components of SM such as NPN and ash in the MCC, but the concentration of these components in the final MCC was not specified. The target MCC composition is shown in Table 1. The target MCC protein concentration was 9% with at least 95% of the SP and 98.8% of the lactose removed. The target MCC composition was somewhat arbitrary, but input from retorted milk-based-beverage processors indicated that it was desirable to remove a large amount of the heat-labile SP, as well as to have a high final protein concentration. Additionally, a very low level of lactose in the MCC was desired so that the beverages produced using this protein ingredient could be labeled lactose free.

Model Development

A theoretical model was developed using Excel 2007 (Microsoft, Redmond, WA) to determine the composition and mass of the retentate and permeate produced from each stage of a MF process that could consist of 2 to 5 stages. The retentate from the final stage was the MCC. The model was based on previous work by Hurt and Barbano (2010). It was assumed that each MF stage was a continuous feed-and-bleed system (with the composition of the material in the recirculation loop equal to the composition of the retentate removed from that stage) with water dilution between stages. The composition used for the SM feeding the first MF stage is shown in Table 2. A mass of 150,000 kg of SM was used in the model as the initial MF feed.

The CF and diafiltration factor (**DF**) determined the mass and composition of the retentates and permeates produced as shown in Figure 1. The CF was the mass of MF feed for a stage divided by the mass of retentate produced in that stage. The DF determined how much water was added to the retentate from the previous stage to arrive at the feed for the current stage. The DF was the mass of MF feed from the current stage divided by the mass of retentate from the previous stage.

Model Assumptions

As in the research by Hurt and Barbano (2010), it was assumed that two-thirds of the ash in the SM was associated with the CN micelles and could not