As. J. Food Ag-Ind. **2010**, 3(02), 236-243

OPEN ACCESS

Asian Journal of Food and Agro-Industry
ISSN 1906-3040
Available online at www.ajofai.info

Research Article

Separation of lactose from milk by ultrafiltration

Pongsathon Limsawat and Suwattana Pruksasri*

Department of Biotechnology, Faculty of Engineering and Industrial Technology, Silpakorn University, Nakhon Pathom 73000 Thailand.

*Author to whom correspondence should be addressed, email: pruksasri@gmail.com

This paper was originally presented at Food Innovation Asia, Bangkok, August 2009.
Recieved 21 June 2009, Revised 26 October 2009, Accepted 29 October 2009.

Abstract

Milk and milk products have been considered to be an important nutritional food because they are good sources of protein and calcium. However, most people have suffered from gastrointestinal problems such as bloating, nausea, gas and diarrhea after drinking milk and milk products as called lactose intolerance. This is due to the inability to digest the lactose which is a major sugar found in milk. It is thus desirable to remove lactose from milk to accommodate people suffered from lactose intolerance and to improve its storage stability and functionality. Ultrafiltration (UF) is an attractive process for reducing lactose from dairy products because it has MWCO in the range of 1,000-500,000 Dalton. Therefore, lactose can easily pass through the membrane while retain all the protein in the retentate. Even though other minerals such as calcium can also pass through the membrane, they can be recovered by heating and adjusting the pH of the permeate. The separated lactose in the permeate can be used for functional foods production such as galacto-oligosaccharides which can be supplemented into the low lactose products or other dairy products. The goal of this project is to evaluate the feasibility of removing lactose from milk by UF and to determine effects of transmembrane pressure and feed flowrate on permeate flux and rejections of protein and lactose. A Quixstand Benchtop cross flow hollow-fiber system is used in this project. UF membrane with MWCO of 5,000 Dalton is selected for lactose separation. The effects of transmembrane pressure and feed flow rate on lactose and protein rejection, lactose recovery yield and permeate flux were evaluated. Our results showed that the lactose and protein rejection value were approximately 13% and 100% respectively. A high degree of removal of lactose from milk could be achieved. Therefore, the low lactose milk and milk products can be obtained by this technique.

Keywords: dairy, ultrafiltration membrane, low lactose milk, hollow fibre, galacto-oligosaccharides, Thailand

Introduction

Milk and milk products have been considered to be an important nutritional food because they are good sources of protein, vitamins and calcium. However, many people suffer from lactose intolerance making them unable to consume milk and dairy-based products. This is due to the inability to digest the lactose which is a major sugar found in milk. The maldigestion of lactose can cause the gastrointestinal problems such as bloating, nausea, gas and diarrhea. Therefore, it is desirable to remove lactose from milk to minimize lactose maldigestion. In general, there are several technologies for removing lactose from milk. Lactose can be hydrolyzed into glucose and galactose. This method, however, has some disadvantages in terms of sweetness. It has been reported that the sweetness increases up to 70% related to sucrose [1]. This can be advantage or disadvantage depending on the purpose of the products. The removal of lactose can also improve its solubility, storage stability, and functionality [1, 2]. Another approach to separate lactose is crystallization. This method, however, is limited to by products from whey or whey permeate [2]. Recently, membrane technology has gained more interest because of its energy saving process. Ultrafiltration membranes (UF) have molecular weight cut-off in the range of 1,000-500,000 Daltons [3]. Therefore, lactose can easily pass through the membrane while retain all fat and milk proteins in the retentate. Even though other nutritional minerals such as calcium can also pass through the membrane, they can be recovered by heating and adjusting the pH of the permeate [2]. The separated lactose in the permeate can be used for functional foods production such as galacto-oligosaccharides which can be supplemented back into the low lactose products or other dairy products [4, 5, 6]. The milk retentate from ultrafiltration is considered to be concentrated milk which is suitable for cheese and yoghurt production [5, 7]. The objective of this work was to determine effects of process parameters (transmembrane pressure and feed flow rate) on permeate flux and rejections of protein and lactose.

Materials and Methods

Commercial low-fat UHT milk under the brand name of “Foremost” was used as raw material in all experiments. The following parameters were measured: protein (Bradford Biorad Assay kit), lactose (HPLC) and permeate flux.

Filtration system

A cross-flow hollow fibre unit (Quixstand- Benchtop system, GE Healthcare Bioscience, USA) was used for the laboratory scale ultrafiltration experiments. Figure 1 shows the schematic diagram of this cross-flow separation unit. A commercial hollow-fibre cartridge membrane from Amersham (GE Healthcare Bio-science, USA) with a molecular weight cut-off 5,000 Dalton was used in this study. The membrane effective surface area is 650 cm^2. Pure water flux (PWF) was measured before each run in order to test whether the membrane was damaged. The acceptable fluctuation range for an undamaged membrane is within ±20%. Permeate and retentate solutions were collected to measure lactose concentrations by HPLC. After each run, the membrane was rinsed and cleaned in situ with distilled water followed by 0.1 N NaOH for 30 mins, thoroughly drained the system and rinsed the cartridge with distilled water until the pH is neutral. PWF after cleaning was also measured to determine whether the membrane was clogged or fouled.

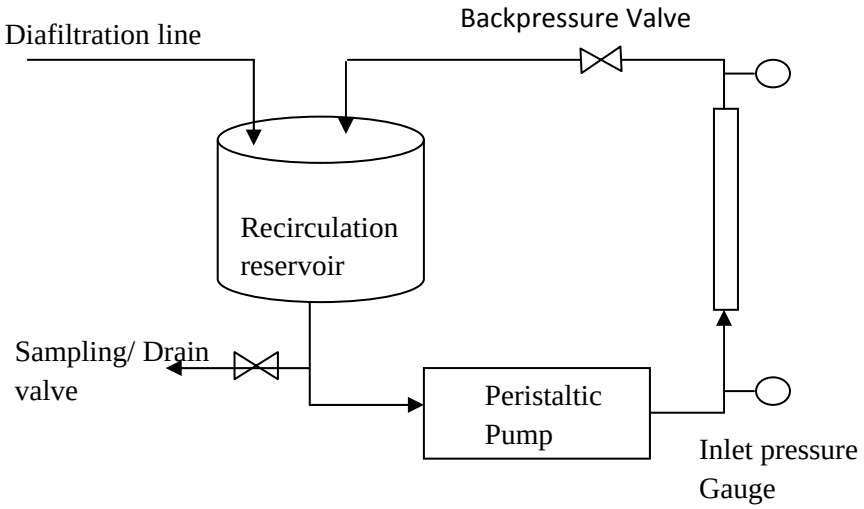

Figure 1. Schematic diagram of cross-flow hollow fibre separation unit.

Effects of transmembrane pressure

The effects of transmembrane pressure on permeate flux, lactose and protein rejection were evaluated to determine appropriate pressure range for effective separation of lactose from milk. The feed flow rate was kept constant at 0.64 L/min. Commercial low fat milk was tested at 2.5 psig, 3.5 psig, 4 psig, 4.5 psig and 5.5 psig.

Effects of flow rate

The effects of feed flow rate on ultrafiltration performance were studied by varying the feed flow rate at 0.94 L/min, 1.24 L/min, 1.45 L/min and 1.72 L/min.

Determination of lactose concentrations by HPLC

The concentrations of lactose in sample solutions were determined by HPLC. A carbohydrate analysis column (Phenomenex, Rezek RNM Carbohydrate column, 7.8 x 300 mm) was used in the HPLC system (Waters, USA), which consisted of a refractive index detector (Waters model 410), a pump (M510), a column oven and a system for data analysis (Chromatopac CR-5A). The eluent used was pre-degassed distilled water at 80°C and fed at a flow rate of 0.4 ml/min.

Lactose and proteins concentrations in both permeate and retentate were measured in order to analyze the data in terms of permeate flux (J), rejection (R_i) and % recovery (R) using the following equation [3]:

$$J = \frac{V_p}{A \cdot t} \quad (1)$$

where V_p is the permeate volume, A is the membrane effective area and t is time.

The rejection of lactose and protein is calculated from the following equation [3].

$$R_i = \frac{\ln(C_r/C_f)}{\ln(VCF)} \quad (2)$$

where C_r and C_f are retentate and feed concentration, respectively. The equation for volume concentration factor (VCF) is given by

$$VCF = \frac{V_f}{V_r} \quad (3)$$

where V_f and V_r are the feed and retentate volume, respectively.

The % recovery of lactose in permeate is calculated from the fraction of lactose in the permeate recovered from the original feed.

$$\%R = \frac{C_p V_p}{C_f V_f} \quad (4)$$

where C_p and V_p are permeate concentration and permeate volume, respectively.

Results and Discussion

Effects of transmembrane pressure

Pressure is the main driving force in the membrane separation process. The effects of the transmembrane pressure on permeate flux and rejections of lactose and protein were thus studied. Figure 2 presents the permeate flux at different transmembrane pressure while the feed flow rate was maintained constant at 0.64 L/min. In general, there was a linear correlation between the transmembrane pressure difference and the permeate flux up to 4.5 psig. Beyond 4.5 psig, there was no significant increase in the permeate flux, indicating that it reached the limiting flux, J_∞ as the resistance in the membrane boundary layer also increased with increasing the pressure [3,8]. The effect of transmembrane pressure on %lactose recovery is shown in Figure 3. As can be seen, % lactose recovery had the same correlation with the permeate flux. At pressure beyond 4.5 psig, % lactose recovery decreased indicating the concentration polarization problem occurred on the membrane surface. Table 1 shows the effects of transmembrane pressure on lactose and protein rejections. There was no protein lost in the permeate. Therefore, the transmembrane pressure of 4.5 psig was selected to be the operating pressures for this application because it gave a high permeate flux without reaching the limiting flux region. Also, the amount of lactose recovered in the permeate was significantly high at this transmembrane pressure.

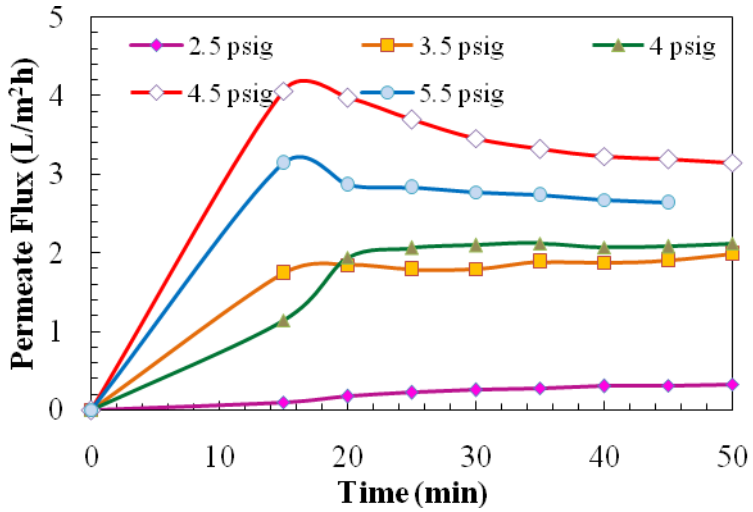

Figure 2. Effect of transmembrane pressure on permeate flux with a constant feed flow rate at 0.64 L/min.

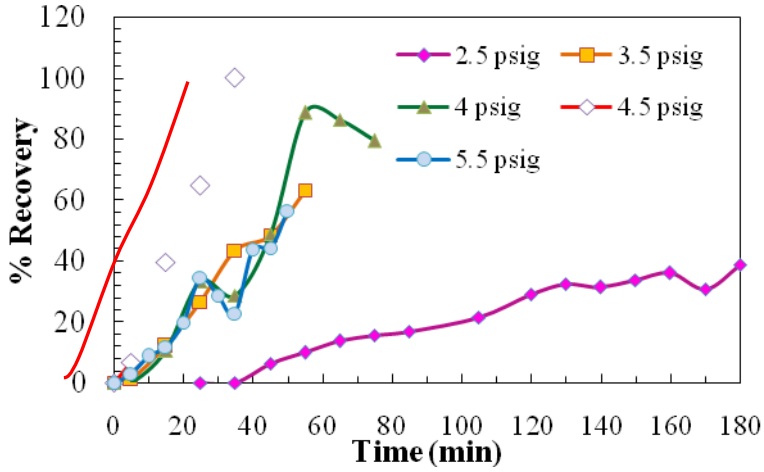

Figure 3. % recovery of lactose in permeate at different transmembrane pressure.

Table 1. Effects of transmembrane pressure on lactose and protein rejection.

Transmembrane pressure (psig)	% rejection	
	lactose	protein
2.5	48.7	99.7
3.5	22.1	100
4	20.0	100
4.5	13.1	100
5.5	15.5	100

Effects of feed flow rate

Feed flow rate is another major parameter affecting the membrane performance. The rate of membrane fouling depends upon flow rate, thus making it difficult to compromise between the membrane rejection and membrane capacity. The effects of feed flow rate on permeate flux and rejections of protein and lactose were thus studied. Figure 4 represents the permeate flux at different feed flow rates. The transmembrane pressure, however, cannot remain constant because the transmembrane pressure increased with increasing the feed flow rate. As a result, the permeate fluxes in these experiments were also affected by both the transmembrane pressure and feed flow rate. As shown in Eq. 5, the permeate flux (J) is affected by the transmembrane pressure difference (ΔP) and the osmotic pressure difference ($\Delta\pi$) between the retentate and permeate sides, the membrane resistance (R_m), and the deposited cake resistance (R_c) [9].

$$J = \frac{(\Delta P - \Delta\pi)}{(R_m + R_c)} \quad (5)$$

As can be seen from Figure 4, the permeate flux increased with increasing the feed flow rate. The high flow rate could reduce the deposition of cakes or other clogs that may affect the permeate flux, resulting in the higher permeate flux. Therefore, the concentration polarization effect could be minimized by operating at high feed flow rate. The % lactose recovery in the permeate was also reported as shown in Figure 5. The high recovery of lactose is obtained at the feed flow rate of 1.72 L/min. Table 2 presents the lactose and protein rejections at different feed flow rates. There was no significant milk proteins lost in the permeate. Therefore, the feed flow rate of 1.72 L/min was considered as the recommended flow rate because it gave high permeate flux and high lactose recovery.

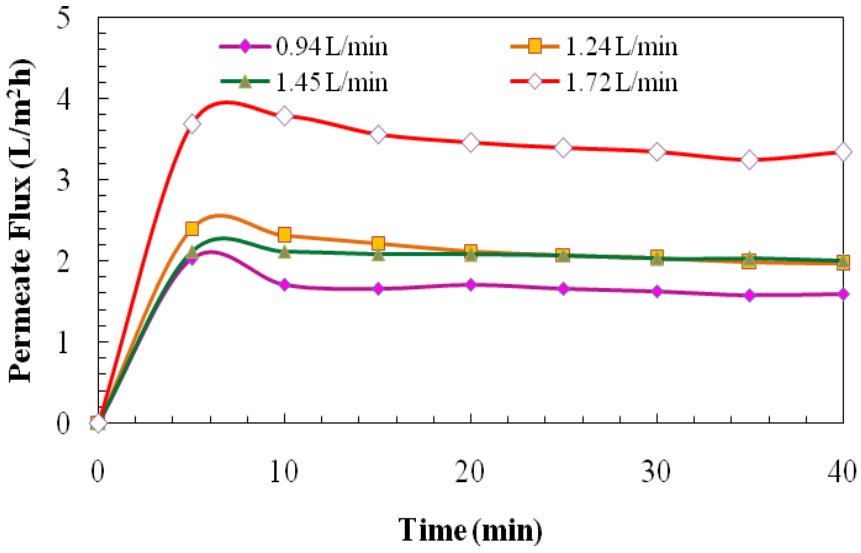

Figure 4. Effect of feed flow rate on permeate flux.

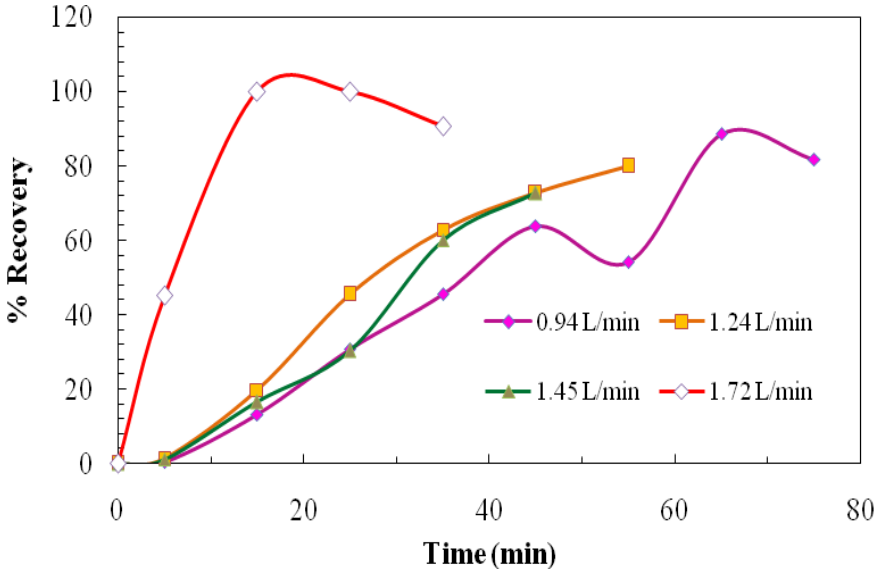

Figure 5. % recovery of lactose in permeate at different feed flow rate.

Table 2. Effects of feed flow rate on lactose and protein rejection.

Feed flow rate (L/min)	% rejection	
	lactose	protein
0.94	30.2	99.9
1.24	18.2	99.7
1.45	11.3	99.8
1.72	12.2	100

Conclusion

Both transmembrane pressure and feed flow rate affected the permeate flux, lactose rejection and % lactose recovery. A high degree of removal of lactose from milk could be achieved by UF with a minimal or no lost of protein in the permeate. Therefore, the low lactose milk and milk products can be obtained by this technique and the separated lactose can be used as substrates for functional food production.

Acknowledgment

This work was financially supported by the Faculty of Engineering and Industrial Technology, Silpakorn University.

References

1. Novalin S., Neuhaus W. and Kulbe K. D. (2005). A new innovative process to produce lactose-reduced skim milk. **Journal of Biotechnology**, 119, 212-218.

2. Vyas H. K. and Tong P. S. (2003). Process for calcium retention during skim milk ultrafiltration. **Journal of Dairy Science**, 86, 2761-2766.

3. Kulkarni S. S., Funk E. W. and Li N. M. (2001). Ultrafiltration: Introduction and definitions, pp.393-397. In W. S. Ho and K. K. Sirkar, (Eds.). Membrane Handbook. Norwell. Massachusetts.

4. Chen C. S., Hsu C-K. and Chiang B-H. (2002). Optimization of the enzymic process for manufacturing low-lactose milk containing oligosaccharides. **Process Biochemistry**, 38, 801-808.

5. Kosikowski F. (1979). Low lactose yoghurts and milk beverages by ultrafiltration. **Journal of Dairy Science**, 62, 41-46.

6. Grano V., Diano N., Rossi S., Portaccio M., Attanasio A., Cermola M., Spiezie R., Citton C. and Mita D. G. (2004). Production of low-lactose milk by means of nonisothermal bioreactors. **Biotechnology Progress**, 20, 1393-1401.

7. Alvarez F., Arguello M., Cabero M., Riera F. A., Alvarez R., Iglesias J. R. and Granda J. (1998). Fermentation of concentrated skim-milk. Effects of different protein/lactose ratios obtained by ultrafiltration-diafiltration. **Journal of the Science of Food and Agriculture**, 76, 10-16.

8. Aydogan N., Gurkan T. and Yilmaz L. (1998). Effect of operating parameters on the separation of sugars by nanofiltration. **Separation Science and Technology**, 33, 1767-1785.

9. Kulkarni S. S., Funk E. W. and Li N. M. (2001). Ultrafiltration: Theory and mechanistic concepts, pp.398-407. In W. S. Ho and K. K. Sirkar, (Eds.). Membrane Handbook. Norwell. Massachusetts.