ORIGINAL SCIENTIFIC PAPER

Effects of Static Mixing on the Ultrafitration of Milk Whey

Igor Gáspár*, András Román, Gyula Vatai, András Koris, Edit Márki

Corvinus University of Budapest, Faculty of Food Science, Department of Food Engineering, 1118 Budapest, Ménesi út 44. Hungary

Summary

The promotion of efficiency and the reduction of energy consumption are very important tasks in every industrial process as well in food production. Although membrane filtration is a low-energy and environmental friendly separation method it still needs improvement in many fields. In our earlier research it was stated that a static mixer combined with ceramic tube membrane results higher permeate flux and lower specific energy consumption in case separation of oily wastewater. This paper deals with the extension of this combined method to the separation of milk whey. It was found that static turbulence promotion inside a tube membrane during ultrafiltration of whey can increase permeate flux and decrease energy consumption, inside a given spectra of operating parameters, compared to the conventional mode (when no static mixing applied in the process).

Keywords: sweet whey, ultrafiltration, combined method, flux enhancement

Sažetak

Unaprjeđenje učinkovitosti i smanjenje utroška energije vrlo je važna zadaća u svakom industrijskom procesu, pa tako i u proizvodnji hrane. Premda je membranska filtracija nisko energetska i ekološki prihvaćena separacijska metoda još uvijek zahtijeva usavršavanje u mnogim područjima primjene. U našim prethodnim istraživanjima prikazan je statički mikser u kombinaciji sa keramičkom cijevnom membranom koji je doveo do višeg protoka permeata i manjeg utroška specifične energije u slučaju separacije uljevitih otpadnih voda. Ovaj rad je proširenje ove kombinirane metode na separaciju sirutke mlijeka. Pronađeno je da poticanje statičkih turbulencija unutar cijevne membrane za vrijeme ultrafiltracije sirutke povećava protok permeata i smanjuje energetski utrošak unutar zadanog spektra operativnih parametara, uspoređenih sa konvencionalnim načinom rada (pri kojem statično miješanje nije primijenjeno u procesu).

Ključne riječi: slatki proteini, ultrafiltracija, kombinirana metoda, povećanje protoka

1. Introduction

Milk whey is produced in large amounts in the dairy industry; it is the milk serum that is obtained during the manufacture of cheese after separation of casein and fat during milk coagulation and viewed until recently as one of the major problematic disposal. Usually this by-product is discharged into the sewage causing heavy load for the wastewater treatment plants although it contains valuable components like lactose, proteins, vitamin B and C, vitamin B2 and lactoflavin. The major protein fractions in whey are beta-lactoglobulin, alpha-lactalbumin, bovine serum albumin and immunoglobulin (Haug et al., 2007). Whey Protein Concentrates (WPC), sometimes called as muscle protein in some parts of the world, are nothing but powders made by drying the retentates from ultrafiltration (UF) of whey.

The performance of micro- and ultrafiltration can be enhanced through combination with other unit operations. In earlier publications it was reported that the combination of a tube membrane and a static mixer can increase the efficiency of the process. Hiddink et al. (1980) and later Krstic et al. (2004) observed an increase in permeate flux and reduction of operation costs of micro- and ultrafiltration of milk when static turbulence promoter (Kenics-type) was installed in the system. The same results were reached but with different turbulence promoters and membranes by Waal and Racz (1989), Gupta et al. (1995), Bellhouse et al. (2001) and Costigan et al. (2002). The authors of this paper also studied the phenomena with ceramic tube membranes and stable oil-in-water emulsion and published the results as well (Hu et al., 2003; Koris et al., 2007). As a conclusion, all the publications showed that the mass transfer coefficient of the membrane filtration is increased with the insertion of the static mixer. From energy considerations it appeared that, at equal energy input levels, approximately equal permeate fluxes were achieved in both the laminar- and the turbulent-flow regime whether static mixers were used or not. In this paper the effects of static mixing on ultrafiltration of sweet whey was studied from the aspect of flux enhancement and reduction of energy consumption.

2. Materials

2.1. Raw material

The sweet whey was kindly supported by Sole-Mizo ZRt., Hungary. The general composition of sweet whey is shown in Table 1.

Table 1. *General composition of sweet whey.*

Component	Concentration
Water	93 - 94 %
Dry matter	5.6 - 6.5 %
Lactose	4 - 5 %
Lactic acid	traces
Total protein	0.8 - 1.0 %
Whey protein	0.55 - 0.65 %
Citric acid	0.1 %
Minerals	0.5 - 0.7 %
SH Value	app. 4
pH	6.4 - 6.2

Corresponding author: igor.gaspar@uni-corvinus.hu

2.2. Apparatus and Membranes

The experiments were carried out in cross-flow mode using a conventional ultrafiltration set-up with a laboratory tubular single-channel membrane module which can be seen in Figure 1.

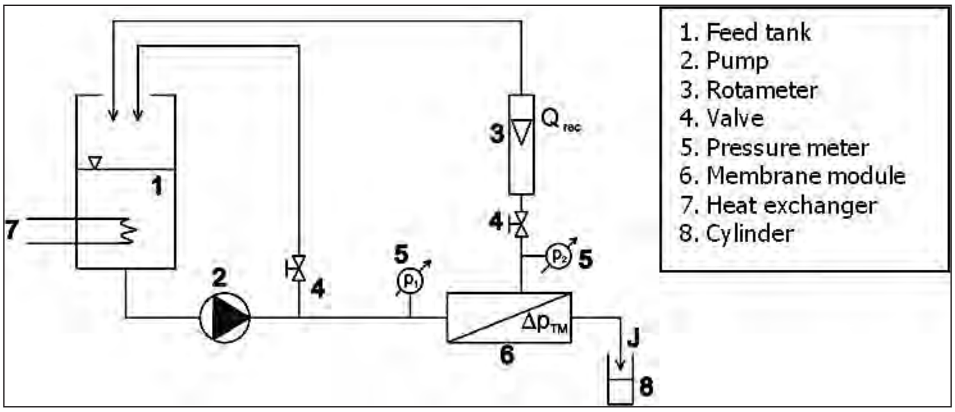

Figure 1. *Scheme of the membrane filtration apparatus.*

The feed is stored and tempered in the feed-tank, fluid recirculation and pressure is ensured by a gear pump. To regulate the transmembrane pressure (TMP) by-pass tube with a valve is installed, to measure the recirculated flow rate (RFR) rotameter is used.

Membralox (Pall Exekia, France) ceramic single tube membranes with nominal pore size of 50 and 200 nm were used in the tests. The material of the active layer on these membranes is ZrO2. The length of the membranes was 250 mm, inner diameter 6.8 mm, with 50 cm^2 effective area. During experiments TMP (1-3 bar) and RFR (50-150 L/h) was modified step by step so permeate flux and pressure drop was measured both with and without the static mixer.

2.3. Static mixer

To intensify the membrane filtration process Kenics-type (Omega, USA) static mixer was used. The mixer was installed in the lumen side of the membrane. The material of the FMX8124-AC static mixer is poly-acetate, the diameter is 6.35 mm and the number of the used mixing elements was 38. From now on the experiments which were carried out in conventional mode (without static mixer) are signed with NSM (non static mixer) and when the static mixer was installed is shown as SM (static mixer) mode.

3. Methods

The work was carried out on focusing two parameters: the permeate flux increase (FI) and energy consumption (EC). The permeate flux (J) was calculated from the time needed to collect 10 mL of permeate (1):

$$J = \frac{V}{A \times t} \left(\frac{L}{m^2 h}\right) \qquad (1)$$

where V is the volume of permeate (L), A is the membrane area (m^2) and t is for measured time (h).

The permeate side was opened to the atmosphere, so TMP could be taken as the average of the gauge readings. The flux improvement (FI) can be calculated as a difference between NSM and SM flux measurements as (2):

$$FI = \frac{J_{SM} - J_{NSM}}{J_{NSM}} \times 100 \quad (\%) \qquad (2)$$

where the dimension of J is $m^3/m^2/s$.

The specific energy consumption (E) defined as the power dissipated per unit volume of permeates. The hydraulic dissipated power is directly related to the pressure drop along the membrane module (p1-p2) and the specific energy consumption can be calculated as (3):

$$E = \frac{RFR \times (p_1 - p_2)}{J \times A} \left(\frac{kWh}{m^3}\right) \qquad (3)$$

where RFR is the retentate flow rate (m^3/s), p is pressure (Pa) and A (m^2) is the effective area of the membrane.

To clearly express the quantity of energy consumption changes (EC) the following equation were used:

$$EC = \frac{E_{SM} - E_{NSM}}{E_{NSM}} \times 100 \quad (\%) \qquad (4)$$

where E_{SM} and EN_{SM} are the specific energy consumptions with and without static mixer.

4. Results

4.1. Experimental results on the 50 nm membrane

The variations of permeate flux with transmembrane pressure (TMP) and retentate flow rate (RFR) during ultrafiltration of sweet whey without using the static mixer (NSM mode) and when the static mixer was used (SM mode) are shown in Fig. 2. It can be seen that the higher is TMP and RFR the flux is higher in both case. However the changes are larger in SM mode. The permeate fluxes were significantly higher in every point when SM mode was applied compared to NSM mode.

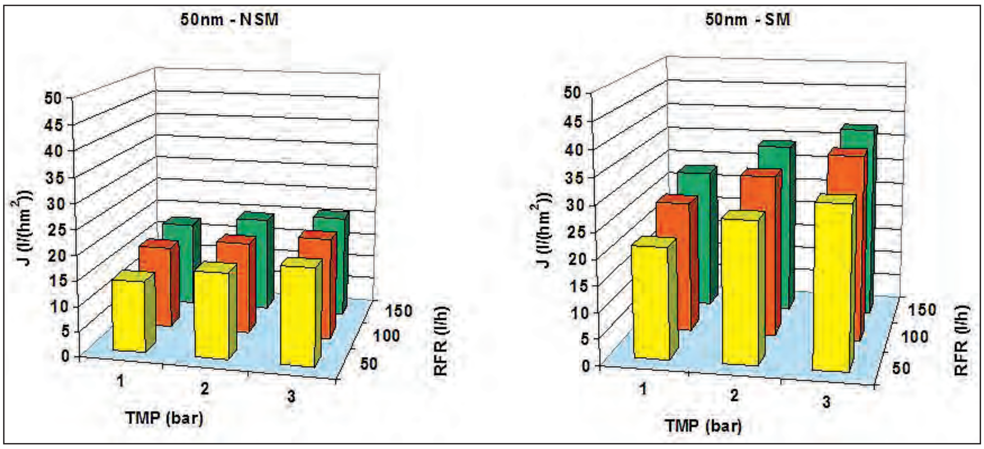

Figure 2. *Measured permeate flux data vs. TMP and RFR in NSM (a) and SM (b) mode (50 nm, T=40^{0}C).*

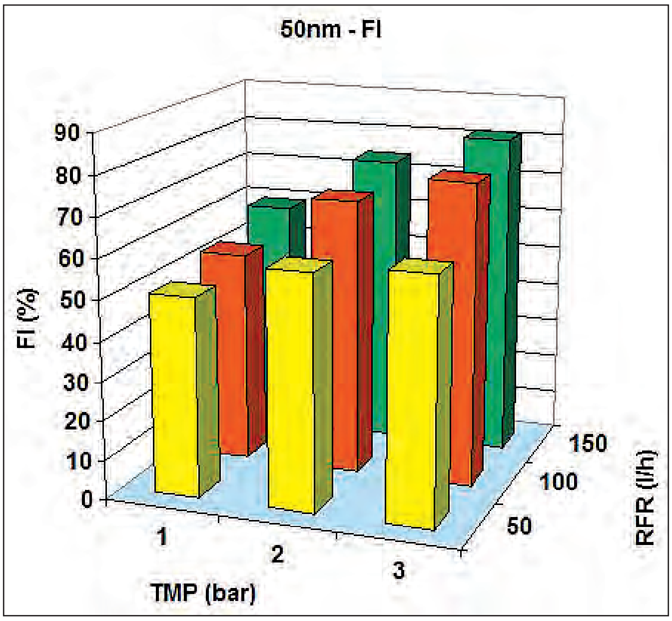

Figure 3. *Calculated FI values vs. TMP and RFR (50 nm, T=40^{0}C)*

The percentages of flux improvements (FI) can be observed even better in Fig. 3. The calculated data with equation (2) shows 50 – 80 % increase in flux after installation of the static mixer (compared to NSM mode). The higher performance is economically acceptable only if energy consumption of the process is not increasing with the flux. To investigate the possible changes in the energy usage of the membrane apparatus equations (3) and (4) was used. Fig. 4 shows the energy consumption (E) of the process in NSM and SM mode. It was found that the presence of static mixer and also RFR has significant effect on the E. The energy usage on RFR 100 and 150 l/h is drastically increased with static mixer, but on 50 l/h the observed increase is acceptable. Fig. 5 shows the percentage of the E change (EC) due to the installation of the static mixer. The explanation of this phenomenon can be explained with the measured pressure drop (p1-p2) along the membrane module (Table 2.). Generally, in NSM mode, the pressure drop is constant and its value is low, but not in case of SM mode. Since the static mixer reduces the cross-section of the tube and because of the intensive contact of the fluid with the edges of left and right handed mixing elements the pressure drop is increasing with large numbers. A more detailed discussion of the phenomena was published by the authors elsewhere (Gáspár et al., 2010).

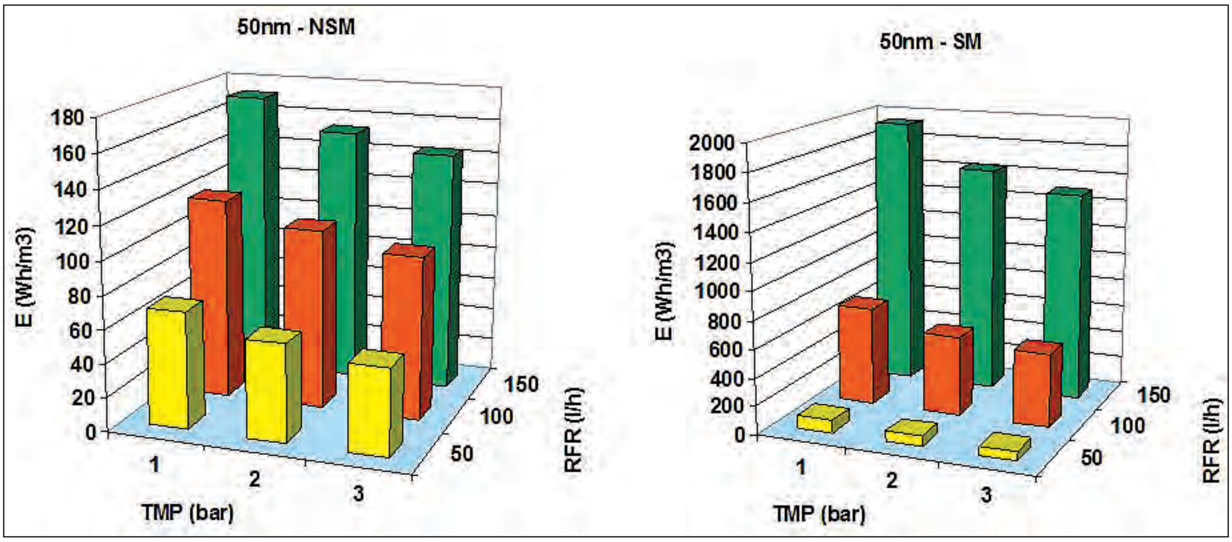

Figure 4. *Specific energy consumption (E) vs. TMP and RFR in NSM (a) and SM (b) mode (50 nm, T=40^{0}C)*

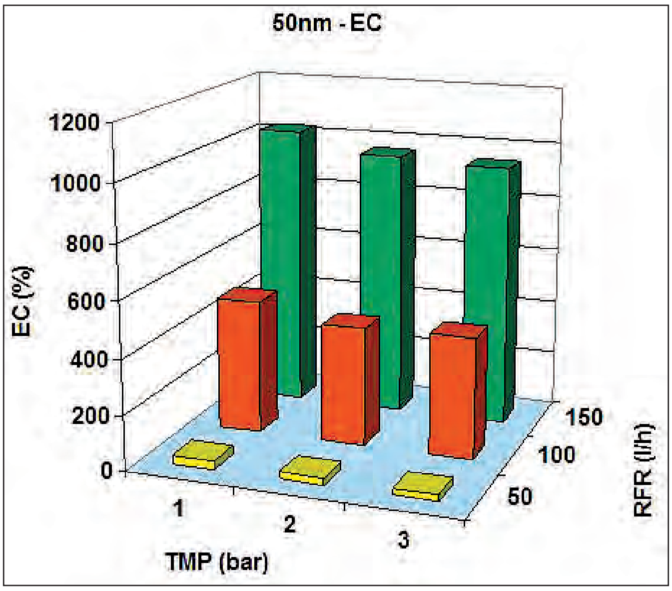

Figure 5. *Specific energy consumption change (EC) in the presence of static mixer vs. TMP and RFR (50 nm, T=40^{0}C)*

Table 2. *Pressure drops on different flow-rates (50nm).*

Mode	50 L/h	100 L/h	150 L/h
NSM	10 kPa	10 kPa	10 kPa
SM	20 kPa	90 kPa	185 kPa

4.2. Experimental results on the 200 nm membrane

In the case of the 200 nm pore sized membrane the same results were gained and similar phenomenon was observed as in case of the 50 nm membrane. However the permeate fluxes were higher on this membrane with an average of 30 % and specific energy consumption decreased due to the higher nominal pore size. The increase in the permeate fluxes are quite the same as it was earlier with the 50 nm membrane (Fig. 6). After taking in account the energy consumption and its change when static mixer was applied it can be stated that the SM mode could be useful with low (50 l/h) flow-rates just like as it was in the case of 50 nm membrane (Fig. 7.). On 50 l/h flow rate the increase of the performance (permeate flux) can equalize the slightly raised energy consumption. From the view of pressure drop the same changes were observed (Table 3.). This is in good coincidence with the statement that says pressure drop in a tube depends only on the length, inner diameter, friction factor of the tube and on the cross-flow velocity.

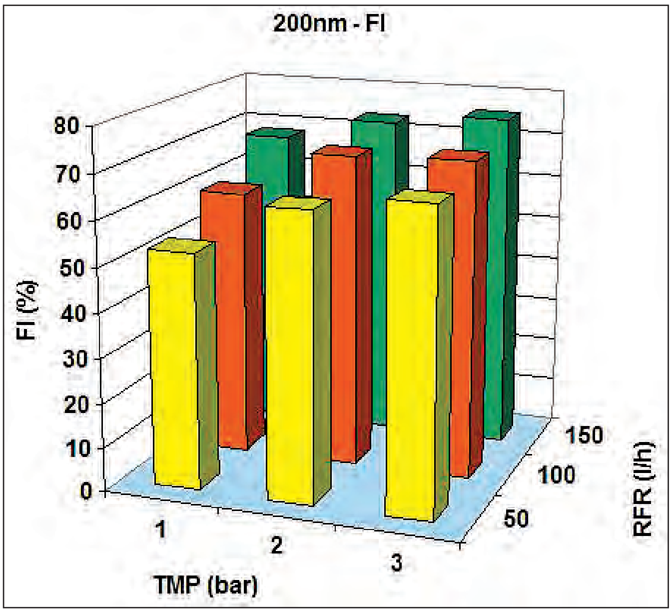

Figure 6. *Calculated FI values vs. TMP and RFR (200 nm, T=40°C)*

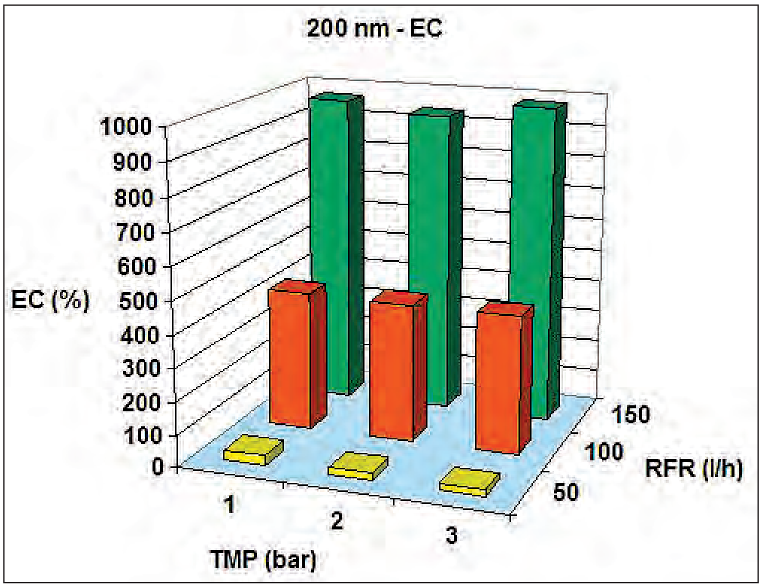

Figure 7. *Specific energy consumption change (EC) in the presence of static mixer vs. TMP and RFR (200 nm, T=40°C)*

Table 3. *Pressure drops on different flow-rates (200nm).*

Mode	*50 L/h*	*100 L/h*	*150 L/h*
NSM	10 kPa	10 kPa	10 kPa
SM	20 kPa	85 kPa	180 kPa

4.3. Efficiency of the separation

However the examination of separation properties was not among the aims of this paper it could be stated that from the aspect of clarification both membranes worked well. All suspended solids, dry matter and proteins, were successfully removed in every laboratory experiment. The feed solution (the whey), is a foggy liquid with high turbidity, but after ultrafiltration treatment very clear permeates were gained.

5. Conclusions

The results of the experiments clearly show that intensification of the sweet whey ultrafiltration is possible through the combination of the membrane filtration apparatus with a simple static mixer. The combined separation method is practically desirable at low retentate flow rate where the increase in the energy consumption due to the static mixer is not serious or the progress in the performance compensates the slightly higher energy usage. The optimal retentate flow rate in this case was 50 l/h and the optimal pressure found to be 3 bars. The average permeate flux increase on optimal operating parameter is around 64 – 65 %. From the aspect of flux the 200 nm pore sized membrane is the better choice; because of its higher initial permeate flux values. But in case of a targeted practical application design the separation of different whey components must be deeply examined before the membrane selection.

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Authors

Igor Gáspár, M.Sc
Corvinus University of Budapest,
Faculty of Food Science, Department of Food Engineering
Menesi ut 44
1118 Budapest, Hungary

András Román, M.Sc
Corvinus University of Budapest,
Faculty of Food Science, Department of Food Engineering
Menesi ut 44
1118 Budapest, Hungary

Dr. Gyula Vatai, Full professor
Corvinus University of Budapest,
Faculty of Food Science, Department of Food Engineering
Menesi ut 44
1118 Budapest, Hungary

Dr. András Koris, PhD
Corvinus University of Budapest,
Faculty of Food Science, Department of Food Engineering
Menesi ut 44
1118 Budapest, Hungary

Dr. Edit Márki, PhD
Corvinus University of Budapest,
Faculty of Food Science, Department of Food Engineering
Menesi ut 44
1118 Budapest, Hungary