Chapter 2

The Application of Membrane Separation Technology in the Dairy Industry

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Abstract

Dairy industry is considered as an important food industry that provides various kinds of nutritionally rich dairy products for all age groups. Beside these nutritive values, dairy industry is contemplated as a good source of raw materials for other industries. Most importantly, dairy industry employs environment-friendly and energy-saving technologies. Membrane separation technology being one of those also focused on a cost-effective and environment-friendly manner, which can be widely applied in dairy industry for many useful purposes. In this chapter, we first define and classify the membrane separation technology and then comprehensively describe its applications, for instance, component separation, filtration, removal of bacteria, and wastewater treatment in dairy industry.

Keywords: membrane separation, milk concentration and component separation, milk sterilization, dairy wastewater treatment

1. Introduction

Milk is a complete food, and its products are a good source of essential nutrients for human health and raw materials for other industries. Dairy industry is a predominant part of food industry that has rapid growth and stability in emerging markets. With the increase of dairy industries, to control cost and make it sustainable, it is necessary to adopt new energy-efficient and eco-friendly technologies. In new technologies, membrane separation is an emerging technology with suitable properties for dairy products in which solution is passed through a membrane of microscopic pores and pressure applied to separate the components [1].

Membrane separation technique	Principle	Driving force (kPa)	Intercept component	Application
Microfiltration	Sieving	20–100	0.1–20 um	Clarification, separation, removal of bacteria, and filtration [2, 3]
Ultrafiltration	Sieving	100–1000	5–100 nm	Concentration, grading, and purification of macromolecular solution [4]
Nanofiltration	Dissolving diffusion, Donnan effect	500–1500	>1 nm	Separation, purification, and enrichment process of food, medicine, and biochemical industries [5]
Reverse osmosis	Dissolving diffusion	1000–10,000	0.1–1 nm	Concentration of low-molecular-weight components and removal of dissolved salts in aqueous solutions [6]
Electrodialysis	Ion exchange	Electrochemical potential—penetration	Large ions and water	Removal of salt and deacidifcation of solutions containing neutral components [7]
Pervaporation	Dissolving diffusion	Concentration difference	Insoluble or nonvolatile components	It is mainly used for volatile organic pollutants in the product separation and enrichment [8]

Table 1. Classification and characteristics of membrane separation techniques.

Most commonly used membrane separation techniques are microfiltration (MF), ultrafiltration (UF), nanofiltration, reverse osmosis, and electrodialysis. Their characteristics and applications are shown in **Table 1**. As these techniques have a good economic performance and are eco-friendly and uncomplicated to use, they are widely used in dairy industry for removal of bacteria, concentration, component separation, and wastewater treatment.

2. Applications of membrane separation technology in the dairy industry

2.1. Milk concentration and component separation

The removal of water from milk is known as milk concentration that reduces the cost of the packaging, storage, and transportation of milk and its products. To concentrate the milk, on the principle of heat exchange, flash [9] and falling film evaporation [10] methods are developed. However, these methods may change the composition, rheological characteristics, and heat stability and are energy consuming. As a result, the properties of final products are influenced [11]. Membrane separations are not phase separation technologies. They have advantages of having lower cost, being environment friendly, and having a simple operation [12]. Kelly [13] and Jevons [14] applied ultrafiltration and reverse osmosis in preconcentration of quarg, soft cheese, and yogurt, respectively. The results showed that output of cheese significantly improved.

Besides milk concentration, milk components such as casein, whey proteins, mineral substance, lactose, and saccharides can also be isolated by membrane separation techniques. Milk proteins are whey protein (average diameter < 20 nm) and casein micelles (average diameter of 200 nm) that can be isolated by using membranes of 0.05 to 0.2 nm diameter [15]. Whey protein consists of lactoferrin, β-lactoglobulin, α-lactalbumin and immunoglobulins that demonstrate a range of immune-enhancing properties [16]. These components can be separated by permeation and phage retention by using one filtration process at the same time that gives approximately 60% α-lactalbumin and 40% β-lactoglobulin [17]. Al-akoum et al. [18] reported that slightly higher transmission rates, 65% for α-lactalbumin and 25–30% for β-lactoglobulin, were obtained by using vibratory shear enhanced processing. Rotating ceramic membranes are more suitable because they offered a better compromise between flux and whey protein transmission [19].

Casein is a major protein found in mammalian milk (80% of cow's milk proteins and 20–45% of human milk proteins) [20] that provides amino acids, carbohydrates, calcium, and phosphorus. Membrane separation processes do not affect the micellar structure of casein as compared to traditional methods such as acidification and rennet coagulation [21]. The temperature in membrane filtration is 45 to 50°C that is beneficial for high flux and growth control of mesophilic bacteria [22]. β-Casein exists in the serum phase that requires low temperature [23, 24]. Therefore, new separation techniques are developed such as polyethersulfone (PES) and polyvinylidene fluoride (PVDF) membrane that applied in β-casein enrichment at refrigeration temperatures (<20°C). The final casein has same composition, physicochemical properties, and protein profile. Moreover, PES membrane has a higher flux and a lower fouling [25]. Chai et al. [26] applied the transverse vibrating membrane filtration system of 0.04 μm PVDF membrane at 10°C to separate and concentrate the milk protein, and the structure of obtained protein was preserved better.

It is notable that membrane fouling is a serious problem and becomes more severe when protein concentrated and viscosity increased during protein separation. Therefore, effective methods for fouling removal are developed. High cross-flow velocities can effectively increase the shear force that controls the membrane fouling and maintains the productivity [27]. Dynamic membrane systems such as vibratory shear enhancing process are also helpful to control the fouling problem. The sugar present in milk is lactose that is a functional ingredient used in food and pharmaceutical products. It is used in bakery goods to reduce sweetness and enhance browning and as a protective carrier for sensitive proteins and peptides. But high amounts of lactose content lead to undesirable grainy texture and cause dyspepsia [28]. The wastewater of dairy industry contains high amount of lactose that increases the level of chemical and biochemical oxygen and causes pollution. To control this pollution, it is necessary to adopt membrane separation techniques to remove lactose before draining the wastewater [29–31].

The combination of microfiltration and ultrafiltration was applied to produce protein-enriched yogurt from fractionated skim milk. Results showed that the lactose content of final product also decreased up to 50% [32]. Morr and Brandon [33] evaluated that when MF in combination with UF membrane was applied to fractionate lactose and sodium from skim milk, 90–95% of lactose and sodium fractionated without affecting the consumer acceptance, product appearance, and flavor. When the lactose is separated from goat's milk by ultrafiltration membrane, some particular components such as serum proteins, casein, and fat globules are retained. The optimization of parameters usually involve transmembrane pressure and cross-flow velocity [34].

Lactose recovery from wastewater with ultrafiltration, nanofiltration, and reverse osmosis was also reported in many previous studies [35–37]. In general, nanofiltration and reverse osmosis are more efficient in terms of lactose recovery, but they require a higher operating pressure as compared to ultrafiltration [38–41]. Chollangi and Hossain [42] found that membranes with molar weight cutoff 3, 5, and 10 kDa provided 70–80%, 90–95%, and 100% recovery rate of lactose in permeate, respectively. In addition, lactose hydrolysis was applied in a continuous stirred tank-ultrafiltration (CSTR-UF) with β-galactosidase enzyme to produce galactose and glucose [43].

Human milk oligosaccharides (HMOs) play an important role in the growth and development of infants [44]. Animal milk also contains oligosaccharides with similar structure and function as human milk oligosaccharides that can be a functional food ingredient [45]. Sialyllactose is N-acetylneuraminic acid (sialic acid) bound to β-lactose, and Luo et al. [46] showed that high permeation of 3′-sialyllactose is obtained by using an integrated UF/NF membrane system for the valorization of dairy by-products with engineered sialidase. Continuous production of sialyllactose, as a typical sialylsaccharide, was also examined with a membrane reactor by Masuda et al. [47].

2.2. Removal of bacteria in milk

Milk contains particles with different sizes such as somatic cells (15–6 um), fat globules (15–0.2 um), bacteria (6–0.2 um), and casein micelles (0.3–0.03 um) [48]. Microbial and somatic cells of milk affect quality, flavor, and shelf life of final dairy products. Milk is treated with heat to remove microbial cells [49]. However, the heat treatment change the nutritional and flavor profile of the products [50, 51]. Membrane separation techniques are operated at low temperature, which remove bacteria effectively without affecting the nutritional and flavor profile. It also reduces the processing and transportation cost; that's why microfiltration is widely used for the removal of bacteria [52–55]. Cross-flow microfiltration (CFMF) has emerged as an industrial separation technique in the dairy industry [56–58].

Sterilization with inorganic ceramic membrane not only keeps the flavor of milk but also prolongs the shelf life of product. This processing technology is combined with slight heat treatment and applied in cold pasteurization. The products are called as extended shelf-life (ESL) milk [59]. ESL milk has a shelf life of 3 weeks, longer than HTST-pasteurized milk (10 days, typically), and sensory profile analysis shows that ESL milks have no appreciable difference from the pasteurized milk during storage. It fills the gap between high-temperature short-time (HTST) pasteurized milk and ultrahigh temperature (UHT) milk [60].

2.3. Wastewater treatment

Dairy industry is the major source of wastewater in the food processing [61] that contains large amount of organic matter and nutrients [62]. Common treatments include primary treatment and secondary biological treatment. Membrane separation usually plays an important role in secondary biological treatment as it is simple and energy saving and has wastewater zero emissions [63, 64]. In this processing, protein and sugar are also recycled from the wastewater. Membrane with different molecular weight cut off plays different roles in wastewater treatment. **Table 2** shows the applications of different membrane separation technologies for wastewater treatment.

2.4. Application of electrodialysis and pervaporation in dairy industry

Apart from above mentioned membrane separation technologies, electrodialysis and pervaporation are also used in dairy industry. Electrodialysis is a unit operation applied for the separation or concentration of ions in a solution, based on their selective electromigration through semipermeable membranes under the influence of a potential gradient. Nowadays, this operation has been widely used for demineralization in the dairy industry [66] and has successfully applied electrodialysis for desalination of skimmed milk and showed that the technique is useful in demineralization of dairy products. Demineralization is helpful for better use of milk protein such as application in infant formula. Laurent et al. [67] used electrodialysis for demineralization of skim milk with rate up to 75%. This is much better than their previous study (30–40% demineralization rate) [68]. Chen et al. [69] also successfully applied electrodialysis to remove the lactate ions from acid whey in order to solve operational problems in downstream spray drying operations. Alternatively, electrodialysis has been successfully demonstrated to recover lactic acid from fermentation broths [70, 71], as well as to demineralize sweet whey prior to whey powder production [72, 73]. However, ED applications are still in their infancy, and its potentialities have not been completely exploited probably because of the high specific electromembrane costs or their short lifetime [74].

Pervaporation is a selective membrane separation process in which some feed components are concentrated to a greater degree than others with the selectivity controlled by the membrane type [75]. It can be used to concentrate certain compounds in a mixture. In hydrophobic

Membrane separation technique	MWCO	Application
Microfiltration	100–500 kDa	Remove almost all pathogenic bacterial species and mold as well as a certain amount of halogenated salt [48]
Ultrafiltration	2–150 kDa	Remove almost all of the protein, fat, and some insoluble compounds and minerals in dairy wastewater, and only lactose, soluble salts, and ash content will be allowed to pass [65]
Nanofiltration	0.2–2 kDa	Intercept the lactose in the dairy wastewater, and recover more than 90% of the acid and alkali wastewater from clean in place (CIP)
Reverse osmosis	<0.2 kDa	Intercept almost all pollutants in dairy wastewater.

Table 2. Application of different membrane separation technologies in dairy wastewater treatment.

pervaporation, volatile hydrophobic compounds such as flavors pass through the polymeric membrane more readily than water and are thereby concentrated in the permeate [76]. In previous reports, it was used to concentrate acids, esters, and ketones in model flavor mixtures, and the characteristics of the feed mixture (pH and presence of dairy ingredients) were found to alter the pervaporation behavior of the flavor compounds [77].

3. Conclusion

The applications of membrane separation technology in dairy industry are wide. These are used in milk concentration, component separation such as protein and lactose, filtration, and bacteria reduction as well as play an important role in dairy industry wastewater treatments. All these applications fully demonstrate the advantages of membrane separation: simple operation, environment-friendly, and energy saving. However, there are still some problems such as membrane fouling that limit its further application. Therefore, more attention should be paid on the mechanism and control methods.

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