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Application of Membrane Processes in the Dairy Industry: A Review

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***Abstract*:- The application of membrane technology has revolutionized the dairy industry since 1970s. The major pressure-driven membrane technology includes microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and Reverse Osmosis (RO). The key applications of Membrane technology in milk processing includes pre-concentration of milk prior to manufacturing of cheese, demineralization, alternative technology for extension of shelf life of milk, standardization of milk constituents for formulation of novel products and enhancement of yield and quality of the dairy products. Apart from that membrane technology has also been utilized in concentration, fractionation and purification of milk constituents in valuable milk proteins, besides resolving the separation challenges. Moreover, the production of valuable products from milk constituents signifies the most potential applications of membrane technology in dairy sector.**

Key Words: Membrane Technology, Purification, Dairy, Pre-Concentration, Milk proteins

INTRODUCTION

Milk holds a significant place in human vegetarian diet, and is considered ideal and wholesome food (Shekhar and Kumar, 2011). India is the leading producer and consumer of milk apart from milk being the main source of revenue generation for rural sector. Since 2000, the milk production and consumption has reported to grow annually by 4.2 percent (GoI, 2014). The Dairy industry of India has established its position in world from producing 17 million tons of milk in 1951 rising to 187.7 million tons in 2019 (NDDB, 2020).

Membrane technology is considered as the essential processing approach in food industries of agricultural sector, for the treatment of food products and by-products or waste (Daufin et al., 2001). Since 1970, there has been significant increase in development and effective utilization of membranes for milk and milk product processing. This evolution of membrane technology has resulted in advancement of novel applications, benefiting milk and dairy product processing, consisting of unit operations such as water removal, liquid–liquid separation or solid–liquid (Pouliot, 2008).

One major reason for membrane separation technology to be suitable for milk for fractionating and other functions, is the broad particle size distribution range of milk (Saxena et al., 2009; George et al., 2019), somatic cells with size range 15–6 µm, fat from 15 to 0.2 µm, bacteria (6–0.2 µm) and casein micelles (0.3–0.03 µm) (Pierre et al., 1998). At present in the milk processing industry, membrane technology is well integrated. Over 2/3rd of membrane technology that is, Ultra Filtration and Reverse Osmosis are reserved by whey processing, while milk processing industry accounts for 1/3rd of Ultra Filtration membranes (Timmer and Van der Horst 1998).

MEMBRANE PROCESSES IN DAIRY INDUSTRY

The membrane technology applications in milk processing industry can be categorized into three major parts (Fig. 1), i.e. (1) alternatives to some unit operations (2) means to resolve separation challenges such as recovery of protein and separation, milk fat globule fractionation (Goudedranche, Fauquant, & Maubois, 2000) and spore removal, and (3) Creation of new dairy products such as UF cheeses (Ras, Pave´ d’Affinois, Domiati, etc.), whey-based beverages and other dairy products. Apart from the above classification, there are two important membrane processes, that are standardization of milk products (using milk Ultra Filtration permeate) (Puhan, 1991) and on-farm Ultra Filtration for milk transportation cost reduction (Zall, 1987a, 1987b). The membrane technology has acquired broad range of applications and versatility in the dairy industry, as displayed in the classification.

The development and manufacturing of dairy-based proteins from milk and whey have utilized membrane technology. The widespread filtration spectrum of membrane processes applied in dairy industry is reviewed in Table 1, that includes Micro Filtration, Ultra Filtration, Nano Filtration and Reverse Osmosis membranes. These four membranes are classified by pore sizes that vary between >0.1 µm and <0.1 nm and operating pressures from 0.01 to 5 MPa. Nano Filtration (NF) and Reverse Osmosis (RO) membranes require higher operating pressures compared to other membranes. This high operating pressure can be attributed to the membrane porosity and small pore sizes, where to allow permeation of feed, applied pressures must be higher than the osmotic pressure of the feed.

Fig.1: Applications of membrane processes in dairy industry (Pouliot, 2008)

Classification of Applications of Membrane processes in Dairy Industry

Alternatives to unit operations	Creation of new products	Resolving separation challenges
• Water removal (evaporation) • Control over bacteria (heating) • Demineralization (electrodialysis) • Centifugal separation (Skimming)	• Textured milk products • UF-cheeses • Beverages • Extended Shelf Life Milk (ESL) • Fermented milk	• Removing spores from skim milk and whey • Extracting whey proteins (WPCs) • Seprating proteins • Defatting whey • Removing casein from milk • Recycling cleaning solutions

Ultra-Filtration (UF) offers broad range of configuration of modules, in addition to Hollow Fibre, Tubular, Plate and Frame, and Spiral Wound. The membrane materials like polymeric and inorganic materials are available for the complete range of membrane technology. The complete separation of milk constituent domain from casein micelles to monovalent ions, is fulfilled by RO, NF, UF and MF technology. The separation mechanism for separation of milk constituents that occurs in most of these membrane processes is molecular sieving/size separation. The initiation/introduction of steric effects is resulted due to surface morphology and internal structure of UF and NF membranes, affected by pH and ionic strength. Moreover, most NF membranes and some UF membranes are electrically charged and predomination of phenomena such as electrostatic interactions and Donnan effects can be observed over their separation mechanisms. Numerous technological options for concentrating and purifying milk or whey proteins using membranes have been comprehensively described in various reports (Mehra & Kelly, 2004; Zydney, 1998).

Table 1: Filtration spectrum for the separation of milk components (Pouliot, 2008)

	MF	UF	NF	RO
Pore Size	>0.1 µm	1-500 nm	0.1-1 nm	<0.1 nm
Separation Mechanism	Sieving	Sieving & Charge	Sieving & Charge	Sieving & Diffusion
Operating Pressure (MPa)	0.01-0.2	0.1-1.0	1.5-3.0	3.0-5.0
Module Configuration*	T, MC	T, HF, SW, PF	T, HF, SW, PF	SW, PF
Separation domain	Somatic cells, bacteria, spores, Fat globules Casein micelles	Soluble proteins	Indigenous peptide salts (divalent cations)	Salts (monovalent cations) Lactose
Membrane based commercial dairy ingredient	Micellar Casein, Native whey protein	Whey Protein Concentrate, Whey Protein Isolate, Milk Protein Concentrate	Bioactive milk, Whey protein hydrolysates, Glycomacropeptides	Deproteinized whey, Delactosed whey permeate

Data in rows 2–5 were brought together from reference books on membrane separations (Mulder, 1996; Cheryan, 1998).
* T, tubular; MC, multichannel; HF, hollow fiber; SW, spiral wound; PF, plate and frame.

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APPLICATION OF MEMBRANE IN DAIRY PROCESSING

There are numerous types of membrane filtration technology with different properties commonly used in the milk industry, available in market. Membranes have been applied in different fields of dairy technology that includes removal of bacteria and extended shelf life of milk, whey processing, cheese industry, milk protein processing, fractionation of milk fat and desalting or demineralization (Kumar et al., 2013).

Removal of bacteria and extended shelf life of milk

Traditionally, heat treatment such as High Temperature Short Time pasteurization or Ultra High Temperature, was extensively used for the removal of microbial load from milk and other dairy fluids whey and brine (Rosenberg, 1995). Even though heat treatment effectively eradicates most of the microorganisms, the dead cells (with their potentially active enzymes) remain in the milk. The metabolic activity caused due the growth of the remaining thermoduric bacteria in addition to the active enzymes of dead cells, results in reduction of shelf life, due to changes in milk during storage (Saboya and Maubois, 2000).

The particle size of bacteria and fat globules are significantly high compared to other constituents. Therefore, a membrane with pore size of 0.3–1.0 mm can be utilized to filter the bacteria and fat globules from other milk constituents. Such membranes are anticipated to have uniform pore size distribution and suitable physicochemical properties in order to minimize fouling. The applications of MF for processing milk products and skim milk have advanced due to advancement in Micro Filtration (MF) membranes (inorganic ceramic). Furthermore, for bacterial removal processes, MF membrane is an appropriate pretreatment process compared to Ultra Filtration (Wang et al., 2011).

Pedersen, 1992, reported that the application of combination of MF followed by High Heat Treatment (HHT) can decrease somatic cell count up to 100%. Whereas, Damerow (1989) reported that the similar combination of MF and HHT extended shelf life of refrigerated milk (8°C) from 12 d to 18 d by decreasing the psychrotrop number, without compromising sensory attributes.

Whey Processing

Whey is a dairy by-product which is obtained during the preparation of milk products viz. cheese, paneer and casein. Paneer is an Indian dairy product similar to soft cheese prepared by coagulating casein with citric acid, lactic acid or tartaric acid (Kumar et al., 2011). The traditional methods applied for concentration or separation of whey nutrients are cumbersome and time consuming. The purification, concentration and fractionation of whey constituents can yield significant products such as whey protein concentrate or isolates, α-lactalbumin, β-lactoglobulin, lactose and salt, by application of membrane filtration technology. The combined application of UF and DF results in increase of the protein content of the whey protein concentrate from 35 to 85% of the total solids. Similarly, the protein content of whey protein isolates can be increased to 90% of the total solid content, by eliminating bacteria and fat globules, through application of MF (Lipnizki, 2010).

Cheese Industry

The UF technology has been extensively utilized in various technological versions for pre-concentration of milk prior to production wide variety cheese (Henning, Baer, Hassan, & Dave, 2006). In addition, UF membrane technology in cheese processing is lucrative, as milk is concentrated by a factor of 1.2 to 2.0 times (Rosenberg, 1995) and rise in the casein: protein ratio (Guinee et al., 2006; Johnson and Lucey, 2006) thus reducing the requirement of processing equipment, offering better yield, composition and quality of the cheese.

The casein concentrated milk through application of MF is suitable for various types of cheese production due to its superior quality and microbial elimination by removing bacteria, somatic cells and spores from milk, with enhancement of major milk constituents. The MF pre-treated of cheese milk optimizes the stability/texture of curd and accelerates ripening (Maubois, 2002), reduces the requirement additives such as $CaCl_2$ (Schafroth et al., 2005), in addition to that it facilitates heating at higher temperature. Thus, MF membrane technology has future prospectus in standardization of protein in cheese milk and fortification with casein micelle powder (Mistry and Maubois, 1993).

CONCLUSION

The advancement of membrane technology has unlocked new prospects in milk processing sector. The application of membrane processes enhances the quality of milk and milk product; besides, it fosters new product development, and improves process efficiency and profitability. Whereas, the dairy industry is offered with new possibilities due to membrane processes that provide benefits such as standardization both the nutritional and functional properties of milk and milk derived products and preparation of functional ingredients. The membrane processes and combination of these technologies enable specific functional characteristics of milk constituents to be highlighted and have unfolded new markets for milk-derived products. Other applications include removal of bacterial and somatic cells with their endogenous thermoduric enzymes, resulting in extended shelf life to milk. The diversified prospect has been opened to dairy industry, by separation of micellar casein and fat globules, consequently, enhancing overall quality of products and creating novel milk products and byproducts, thus, resolving to the globally persisting needs of dairy consumers.

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