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Membrane Filtration Technology

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Abstract: Membrane technology has revolutionized the dairy sector. Membrane separations can be used either as alternatives to conventional techniques or as novel technology for processing new ingredients and foods. Different types of membranes are used in the industry for various purposes like extending the shelf life of milk without exposure to heat treatment, standardization of the major components of milk for tailoring new products as well increasing yield and quality of the dairy products, and concentrating, fractionation and purification of milk components especially valuable milk proteins in their natural state. With the advancement of newer technology in membrane processes, it is possible to recover growth factor from whey. With the introduction of superior quality membranes as well as newer technology, the major limitation of membranes, fouling or blockage has been overcome to a greater extent. Pressure-driven membrane processes, namely MF, UF, NF and RO facilitate separation of components with a large range of particle sizes.
Keywords: Membrane separations, filtration, microfiltration, ultrafiltration, Nano filtration, reverse osmosis, dairy, milk, cheese, whey.

Introduction

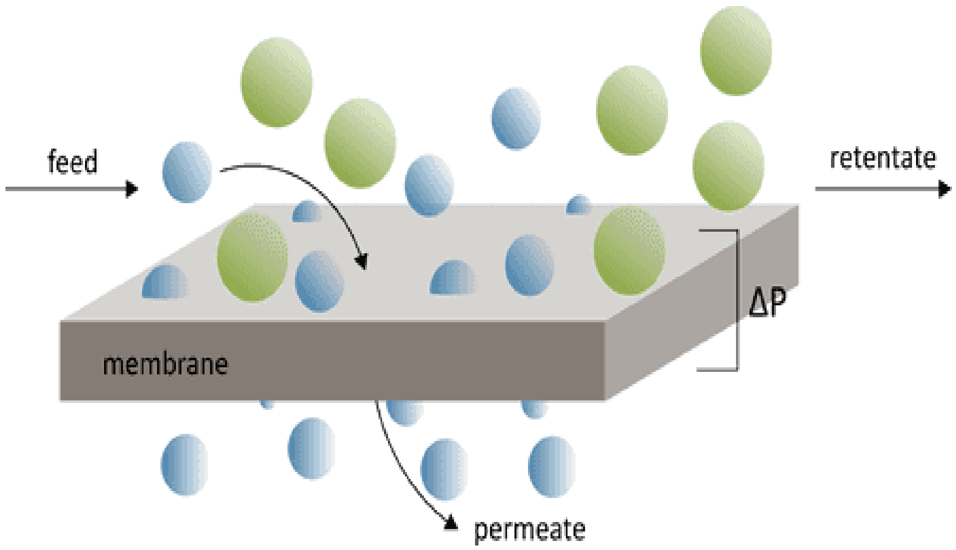
The term “membrane technology” is used to collectively represent the separation processes by employing specific semi-permeable membrane filters to concentrate or fractionate a liquid into two liquids of different compositions. (Strathmann, H., *at el*, 1992). Membrane Filtration technology encompasses the scientific processes used in the construction and application of membranes. (Baker, 2023). Membranes are used to facilitate the transport or rejection of substances between mediums, and the mechanical separation of gas and liquid streams. In the simplest case, filtration is achieved when the pores of the membrane are smaller than the diameter of the undesired substance, such as a harmful microorganism.

Membrane technology is a proven separation method used on the molecular and ionic levels. Since the beginning of the 1970s, this technique has been adopted by the dairy industry (Tamime, 2013). Membrane filtration of milk is a separation technique using a semi-permeable membrane to separate the feed stream of the liquid into permeate and retentate streams, or the milk that passes through the membrane and the liquid containing the retained substances.

Mechanism:

Membrane filtration process is a physical separation method characterized by the ability to separate molecules of different sizes and characteristics (NATH, 2017). Its driving force is Pressure, Concentration, Temperature or Electrical potential. Membrane separation is based on the difference in permeability of materials and substance.

The feed stream is divided into two stream Retentate (concentrate) stream and Permeate stream. Either the concentrate or permeate stream is the product of our interest.



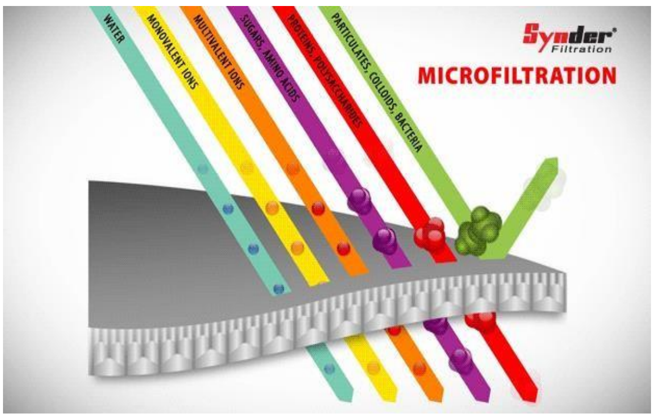
Source: (Introduction to Membrane Science from the Open Membrane Database, n.d.

Classification

Depending on the desired end product, membrane filtration in the milk and dairy industry separates components of milk and whey to concentrate, remove or reduce particles within the milk feed stream and according to the molecular size of the retained solutes Membrane filtration is subdivided into four classes.

1. Micro filtration (ME)
2. Ultrafiltration (UF)
3. Reverse osmosis (RO)
4. Nano filtration (NF)

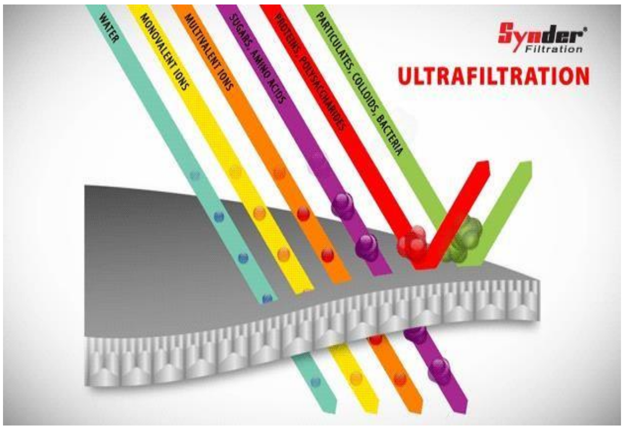
I. Microfiltration:



Microfiltration is a pressure-driven membrane separation process which uses porous membranes Microfiltration membranes have the most open pore sizes of all polymeric membranes with a pore size range of 0.1 to 2μm. Microfiltration filters can be made with both organic materials, such as polymer based membranes, as well as inorganic materials, such as ceramic or stainless steel (Singh & Purkait, 2019). Microfiltration membranes are capable of separating large suspended solids Such as colloids, particulates, fat, and bacteria, while allowing sugars, proteins, salts, and low molecular weight molecules pass through the membrane. MF is a pressure driven membrane processusually operating at trans-membrane pressures of less than 1 bar (ISMAIL, A. A., & Giorno, L. 2021).

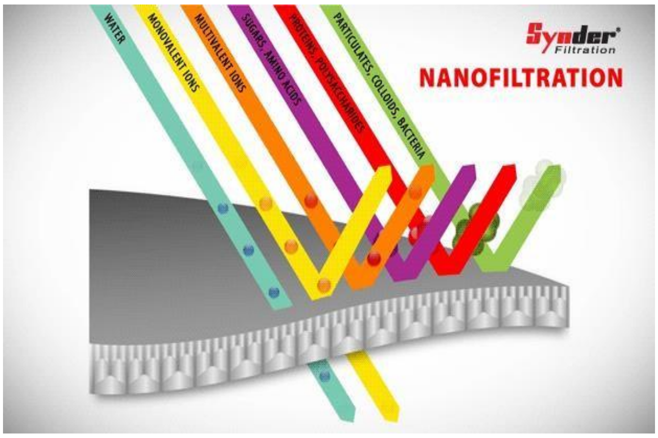
The term 'cross flow' or tangential flow' microfiltration has been used to signify that the fluid flow is tangential to the membrane surface and perpendicular to the permeate flow. In this process, typical operative pressures are somewhat lower and fluxes about 1 order to magnitude higher than for the classical UF. The process may also be described as a 'loose UF' (Michaels *et al*., 1995). Microfiltration filters can be made with both organic materials, such as polymer based membranes, as well as inorganic materials, such as ceramic or stainless steel (Gul *et al.*, 2021).

II. Ultrafiltration:



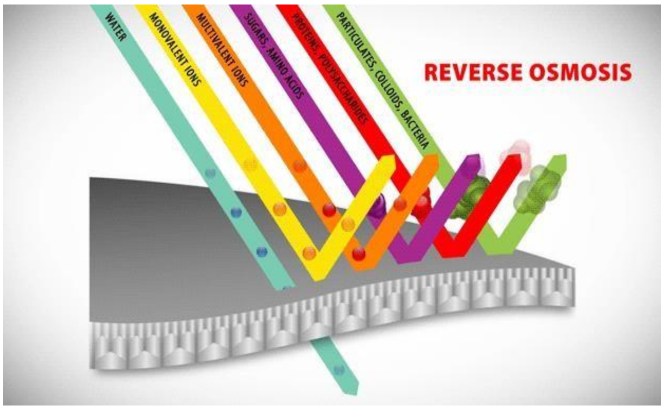
Ultrafiltration (UF) can be defined as a pressure driven membrane process that can be used in the fractionation, purification and concentration of the substances, having a molecular weight between 10^3 to 10^6 Daltons (Schuster & Sleytr, 2021). Ultrafiltration membranes are capable of separating larger materials such as colloids, particulates, fats, bacteria, and proteins, while allowing sugars, and other low molecular weight molecules to pass through the membrane. With a pore size range between 0.1 to 500µm, ultrafiltration membrane pore sizes fall between that of Nano filtration and microfiltration. UF membranes typically operate between 50 – 120 PSI (3.4 – 8.3 bar)

III. Nano filtration:



NF is a high to medium pressure driven membrane separation process which is capable of reversing the osmotic effects of liquids (Wang & Wang, 2019) (Yadav *at el*.,2022) In addition to concentration NF membrane are also partially permeable to mineral ions and other low molecular weight constitute. Nano filtration is a separation process characterized by organic, thin-film composite membranes with a pore size range of 0.1 to 5nm and operating pressure 20-40bar.Unlike reverse osmosis (RO) membranes, which reject all solutes, NF membranes can operate at lower pressures and offer selective solute rejection based on both size and charge. It Allows-Monovalent ions Rejects-Divalent ions. The operating pressure employed are generally lower than the pressure used by RO due to the larger pore size of the membranes. Which is sufficient to retain most of the lactose. In this manner, the process could alsobe viewed as an ultra-tight UF as well as loose RO.

I. Reverse Osmosis:



RO uses high pressure and a highly dense membrane that allows only water to cross through it, concentrating solids and rejecting dissolved and suspended materials.

The tight nature of the membrane calls for the highest operating pressure compared to the other membrane separation processes with operating pressure of 100 bar(Wang & Wang, 2019). The membranes used are called Diffusion membranes. They are unsymmetrical or have extremely thin, symmetrical layers. There is no membrane that can separate all materials and only allow the solvent to pass. The efficiency for desalination is 87-99%, depending on the filter material used (Kavitha *et al*., 2019).

Table 1. Commonly used membrane techniques in dairy industry

Type	**Pore size**	**Molecular weight cut off**	**Pressure and principle**	**Compounds in retentate**	**Application in the dairy industry**
Microfiltration	0.2-2 µm	>200 kDa	Low pressure (below 2 bar) driven membrane process	Low retentate. separation of protein, bacteria and other particulates	Skim milk and cheese Dextrose clarification Bacteria removal
Ultrafiltration	1-500 µm	1-200 kDa	Medium pressure (1- 10 bar) pressuredriven process to overcome the viscosity	Large retentate with casein micelles, fat globules, colloidal minerals, bacteria and somatic cells	Standardization of milk, reduction of calcium and lactose - Protein, whey, milk concentration
Nanofiltration	0.5-2 nm	300-1.000 Da	Medium to high pressure (5-40 bar), mass transfer phenomena	Low productivity, separate monovalent salt and water	Desalting of whey, lactose-free milk, volume reduction
Reverse osmosis or hyperfiltration	No pores	100 Da	High pressure. 10-100 bar	Based on the principle of solubility, low productivity	Volume reduction, recover. of total solids and water

(Source: Kumar et al., 2013)

Application in the Dairy Industry

Membrane technology is essential to dairy processing because it allows for value extraction, component concentration, and milk clarity.

1. Membrane application in extending the shelf life of milk: Microfiltration (MF), a type of membrane filtration, has been identified as a key technology for increasing the shelf life of dairy products. It offers a non-thermal substitute that minimizes bacteria without compromising flavor or sensory aspects. Cold MF preserves milk quality and minimizes microbial contamination. Milk can be made bacteria-free through structural advancements in membrane design without affecting its content. Heat treatment and membrane filtration are combined to create ESL milk, which

Significantly lowers the bacterial burden. (Rysstad and Kolstad, 2006). Heat treatment is still necessary, though, in order to eradicate harmful bacteria. High heat treatment (HHT) in conjunction with MF effectively lowers the quantity of somatic cells and increases the shelf life of milk. Micro sieves with small pore sizes have also showed promise in terms of increasing selectivity and permeability, as well as lowering fouling and number of microbes. (Kumar *et al*., 2013)
(Henning *et al*., 2006)

2. Membrane applications in 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). Important products such whey protein concentrates, -lactalbumin, -lactoglobulin, lactose, and salts are produced by the concentration, fractionation, and purification of whey components via membrane filtration. Such as reverse osmosis (RO), ultrafiltration (UF), and microfiltration (MF) are utilized to enhance the concentration, protein content, and quality of whey. When compared to classical evaporation, RO can save up to 60% on fuel. The protein content is increased by UF and MF, while lipid removal by membrane processes results in high-quality whey protein concentrates and isolates with improved functional characteristics. Because of their higher functional qualities and biological significance, these proteins are used in the food industry s (Lipnizki, 2010).

3. Membranes used in cheese manufacturing: Membrane filtration technique is used in the cheese industry to improve nutritional quality, composition, and yield. It lowers rennet and starter culture requirements, increases the amount of total solid content in cheese, and makes it easier to use whey. Using membranes to concentrate milk before cheese manufacture is a cost-effective and efficient method (Henning *et al*., 2006). Different-sized membrane filters efficiently eliminate bacteria, spores, and contaminants from cheese brine while maintaining chemical equilibrium, producing cheese with a richer flavor and a longer shelf life (Hoffman, 2018).

4. Membrane applications in milk protein processing: The milk protein concentrate (MPC) containing 50 to 58% proteins of good functionality are prepared by application of MF, UF and diafiltration (DF) technologies either alone or in combinations. Separating out the various milk components of different sizes from milk by applying membrane technology will transform dairy industry into very efficient and profitable enterprises. Membrane pore size homogeneity, concentration polarization phenomena and membranes fouling as main factors determining the fractionalization of milk components (Jimenez-Lopez *et al*. 2008). The milk protein concentrates (with 50 to 85% protein in the products) and milk concentrates (with more than 85% protein in the products) are increasingly prepared by using MF (Novak, 1992). Native casein can be concentrated in retentate employing MF with a pore size of 0.2m, yielding up to 90% casein concentration for a variety of applications. A membrane technique followed by heat treatment permits the extraction and purification of -lactoglobulin from whey proteins, giving prospects in the industrial, medicinal, and edible sectors.

5. Membranes used in the processing of milk fat: Cream is traditionally separated from whole milk using an energy-intensive centrifugation process, in which the centrifugal force pushes heavier skim milk toward the periphery and lighter fat globules into the center. Energy-saving membrane Technology also makes it feasible to separate cream, resulting in skim milk with better cream sensory qualities and good storage quality without compromising the integrity of fat globular membranes. The application of membranes with a size of 2 m to fractionate fat globules. The texture and sensoryqualities of a cream are greatly influenced by the size of its fat globules; creams with smaller fat globules have finer texture and better flavor than those with larger fat globules. (Goudedranche *et al*. 2000).

6. Role of membranes in desalting or demineralization: The removal of minerals from whey increases its value (Kelly et al., 1991). Cheese whey contains a high concentration of salt and acids; therefore, it must be reduced or demineralized before usage in order to reduce environmental risks (Greiter et al., 2002). In the dairy industry to get up to 60% reduction of minerals (Kelly et al., 1991). The efficiency of electrodialysis can be increased by pre-concentrating by RO or evaporation up to 20% dry matter. For demineralizing whey, NF membranes with molecular weight cutoffs (MWCO) of 200–1,000 Daltons work best because they are impermeable to organic molecules yet porous to salt and monovalent ions. The mineral contents of the whey is reduced by 35% and ash content by 3 to 4 times in addition to increase concentration of whey by applying Nano filtration (NF), making it suitable for the people having cardiovascular diseases.

Conclusion

Introduction of membrane technology into dairy science witnesses phenomena of mutual benefit for membranes as well as for dairy industry. Membrane types like UF, NF, RO, and MF play diverse roles, enhancing milk processing, extending shelf life, revolutionizing whey utilization, optimizing cheese production, and refining milk fat separation. The implementation of membrane technology allowed for the development of various novel dairy products as well as a notable improvement in the sensory qualities and nutritional value of the current dairy products with better yields.

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