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Alternative Thermal Processing Technique for Liquid Foods-membrane Processing

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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Review Article

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ABSTRACT

Liquid foods are sensitive to temperature and concentration by conventional methods results in product deterioration. Alternative processes, such as freeze concentration, have the drawback with respect to the maximum achievable concentration (only up to 40 to 45°Brix). In recent years membrane processes such as Microfiltration, Ultrafiltration and reverse osmosis are gaining importance for the concentration of liquid foods. Since heat is not involved in this process, it is also called Alternate thermal processing technique. This process can be employed as a pre-concentration step to reduce water load on subsequent processing steps and can be easily scaled up. Liquid foods such as fruit juices are of high nutritive value as they are naturally enriched with minerals, vitamins and other beneficial components required for human health. When extracted from their sources fruit juices have low solid content, color strength and high-water load. Recent advances and developments in this membrane processing used for the concentration of liquid foods are discussed here.

Keywords: Liquid foods; membrane processing; types; Modules.

1. INTRODUCTION

Membrane processing is a technology that allows macro and micro molecules to be concentrated and separated based on their size and structure. It is the fast emerging among various unit operations available for separation processes, especially in the field of food processing. Better

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process economy, higher yield, improved product quality, utilization of byproducts and a solution to some environmental problems, can all be achieved by using membrane processing [1].

Dhineshkumar, V., & Ramasamy, D. [2] explained that the separation science is essential to manufacturing food and beverage products. Evaporation, centrifugation, media filtration, distillation, and solvent extraction are just a few of the traditional processes used in solid/liquid and liquid/liquid separations needed in the sector. Since their debut in the food industry about 30 years ago, membranes have found both large-volume and niche applications across a range of food and beverage industries, including fluid milk, cheese, and other dairy products; grain and oilseed products; beer, wine, and soft drinks; frozen, canned, preserved, and juiced fruit and vegetables; sugar and other sweeteners; meat, poultry, and seafood products; and various miscellaneous foods and food additives.

1.1 Reasons for Concentration

1. To increase the solid concentration.
2. Removal of large amount of water reduces storage and transportation costs.
3. Removal of water helps to reduce the microbial load, thereby favoring an increase in the shelf-life of the liquid foods.
4. In the sugar industry, concentration is used as a pretreatment in to crystallization of sugar.
5. In the wine industry, concentration is sometimes used to raise the alcohol content to a prescribed level.

1.2 Membranes

Membranes are of either isotropic or anisotropic. An isotropic membrane has uniform pores all the way across the membrane thickness, while anisotropic membrane consists of a thin layer of selective material on the surface of a porous backing. Microfiltration membranes are isotropic, while the selective, high flux membranes are used in Ultrafiltration and Reverse Osmosis which are often anisotropic. The manufacturing processes result is a number of different membrane structures such as, microporous, asymmetric, composite, etc. Some of the structures are illustrated in Fig. 1. [3].

1.3 How Pores are Formed

Membranes are formed by casting the sheets using a polymer solution in a volatile solvent followed by evaporation of the solvent. Removal of solvent leaves a porous structure in the membrane. Large pore membranes are produced by subjecting a non porous polymeric membrane to high energy radiation. (Cui, Z. F., & Muralidhara, H. S. [4].

1.4 Membrane Characteristics

a. Mean pore size
b. Range of pore size distribution
c. Membrane thickness
d. Pore configuration.

1.4.1 Commercially available membranes

- Cellulose acetate
- Polyvinyl chloride
- Polycarbonate
- Polyamide
- Polysulphone
- Polyacrilonitrile
- Alumina
- Zirconium oxide

1.5 Membrane Separation Process

A form of filtration which employs selective membranes as the filter medium is used to separate solute, macro molecules, and small suspended particles in liquids. A thin membrane having small pore size and with selectivity for passing solute or solvent is used. The solvent and small molecules pass through the membrane and other solutes, macro molecules or suspended solids are retained. There are two types of filtration. They are Dead end filtration and Cross flow filtration.

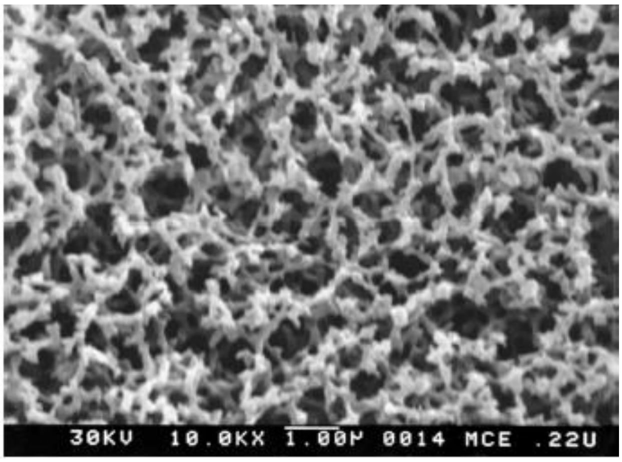
In traditional dead-end filtration, particles collected by the filter form a cake layer over time, resulting in increasing filtration resistance. This necessitates filter cleaning or replacement on a regular basis [5].

In cross-flow filtration, the bulk phase is pushed to flow along the membrane's surface under pressure, washing the trapped particles away, results in a thin cake layer and minimal filtering resistance. This enables for the maintenance of relatively high fluxes over lengthy periods of time. The difference between these two filtration mechanisms is depicted in Fig 2.

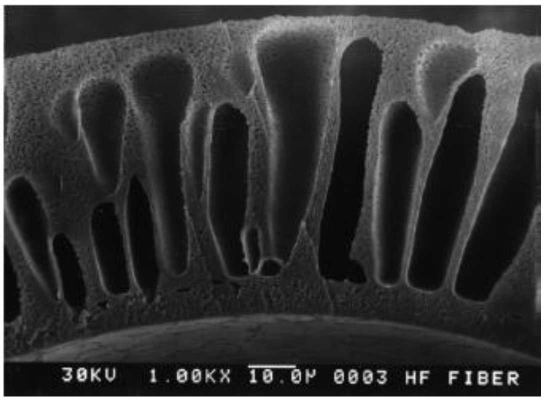
Cross flow filtration is the most efficient method used to obtain high solids concentration in the product. The liquid passing through the membrane is called Permeate and the fraction retained is called retentate (concentrate). The fluid entering the membrane is the feed [6].

1.6 Principle of Separation and Forces Involved

In all the three processes hydraulic pressure (through a pump) is used to provide the force for permeation. The process is simple, involving only the pumping of the liquid mixture across the appropriate membrane. This is depicted in the Fig.3. The difference in the thermodynamic activity on either side of the membrane is the driving force for the permeation of solutes and solvent. Pure solvent is withdrawn as permeate, leaving a concentrated solution (retentate) on the high pressure side of the membrane [7].

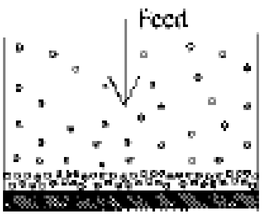


Cross Section of Symmetric microporous membrane. (courtesy of Poretics)

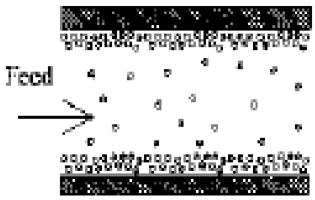


Cross section of Hollow fiber membrane (courtesy of Romicon)

Fig. 1. Different membrane structures [3]



Dead end Filtration



Cross flow Filtration

Fig. 2. Dead-end and cross-flow filtration

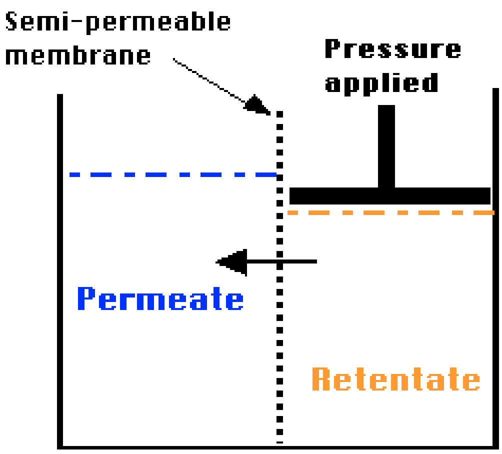


Fig. 3. Principle of membrane separation process

1.6.1 Membranes used for different Separation Process

Plyproylene	Microfiltration (MF)
Polysulfone	Ultrafiltration (UF), Gas Separation (GS)
Polyimide	Gas Separation
Polyamide	Reverse Osmosis (RO)
Polyacrylonitrile	Ultrafiltration
Cellulose	Microfiltration, Ultrafiltration, Reverse Osmosis

Matsuura, T. [8]

1.6.2 Different types of separation process

The different types of membrane separation processes in practice are

1. Microfiltration (MF)
2. Ultrafiltration (UF)
3. Reverse Osmosis
4. Electrodialysis

In recent years, above processes is gaining importance for processing liquid foods. These processes normally operate at ambient temperature, thereby reducing the thermal damage to the product and retaining the color, flavor/aroma and nutritive components of the product. Studies have shown that membrane applications can be less energy intensive than evaporation and freeze concentration [9].

1.7 Microfiltration

In this process, large molecules (e.g. fat globules) and suspended particles are held by the membrane while the remaining components of the solution pass through the membrane. MF resembles conventional coarse filtration and can selectively separate particles with molecular weights greater than 200 kDa. The pore sizes of microfiltration membranes are in the range of 0.05 to 10 μm and the porosity of the membrane is about 70 per cent. Membrane thickness is in the range of 10 to 150 μm. In microfiltration the applied pressure is in the range of 0.1 to 2 bar. Microfiltration finds application in cell harvesting, clarification of fruit juice, wastewater treatment, separation of casein and whey protein and separation of oil–water emulsions [10].

1.8 Ultrafiltration

This process is mainly used for clarification, concentration and purification of fruit juices, natural colors etc. The membranes are made up of polysulphone, polyvinyldene fluoride and cellulose acetate of pore size 1–100 nm. The applied pressure is in the range of 1–10 bar. Ultrafiltration is also used for the separation of high molecular components from low molecular components having applications in the food, dairy, pharmaceutical, textile, chemical, paper and leather industries. The various applications in the food and dairy industry are concentration of milk, recovery of whey proteins, recovery of potato starch and proteins, concentration of egg products and clarification of fruit juices and alcoholic beverages.

Diafiltration is a form of ultrafiltration in which the retentate is diluted with water before being re-ultrafiltered to reduce the concentration of soluble permeate components while increasing the concentration of retained components [11].

1.8 Reverse Osmosis

In this process the concentration of solute in the solution (feed) will increase by the flow of water (or solvent) across the membrane to a dilute solution. This can be accomplished by applying the pressure in excess of the osmotic pressure (10 to 100 bar) of the solution. RO removes most of the organic compounds and up to 99 per cent of all ions. This process achieves rejection of 99.9 per cent of viruses and bacteria and was the first cross flow membrane separation process to be widely commercialized. The RO involves dense membranes having pore size of **<**2 nm. The porosity of the membrane is about 50 per cent. The separation mechanism is based on solution diffusion across the membrane. Rastogi, N. K. [12]. Membranes are made up of cellulose triacetate, polyether urea and polyamide. RO finds application in the concentration of liquid foods such as fruit juices, milk, etc. and desalination of brackish and seawater. Hyperfiltration is the same as RO [13].

The separation through three processes can be shown by means of Fig. 4.

1.9 Electrodialysis

Demineralization of milk products and whey for newborn formula and special dietary items is done using electrodialysis. Desalination of water is another application.

1.9.1 Principles of operation

Ions move in an aqueous solution under the influence of an electric field. The number of molecules in solution is inversely proportional to ionic mobility and directly proportional to specific conductivity.

Synthetic polymer membranes with ion exchange groups can remove charged ions from a solution. Cation exchange membranes include anionic groups that repel cations and are only permeable to cations, whereas anion exchange membranes contain cationic groups that repel cations and are only permeable to cations. Polymer chains - styrene-divinyl benzene made anionic with quaternary ammonium groups and made cationic with sulphonic groups - make up electrodialysis membranes. After that, 1-2V is applied across each pair of membranes. [14,15].

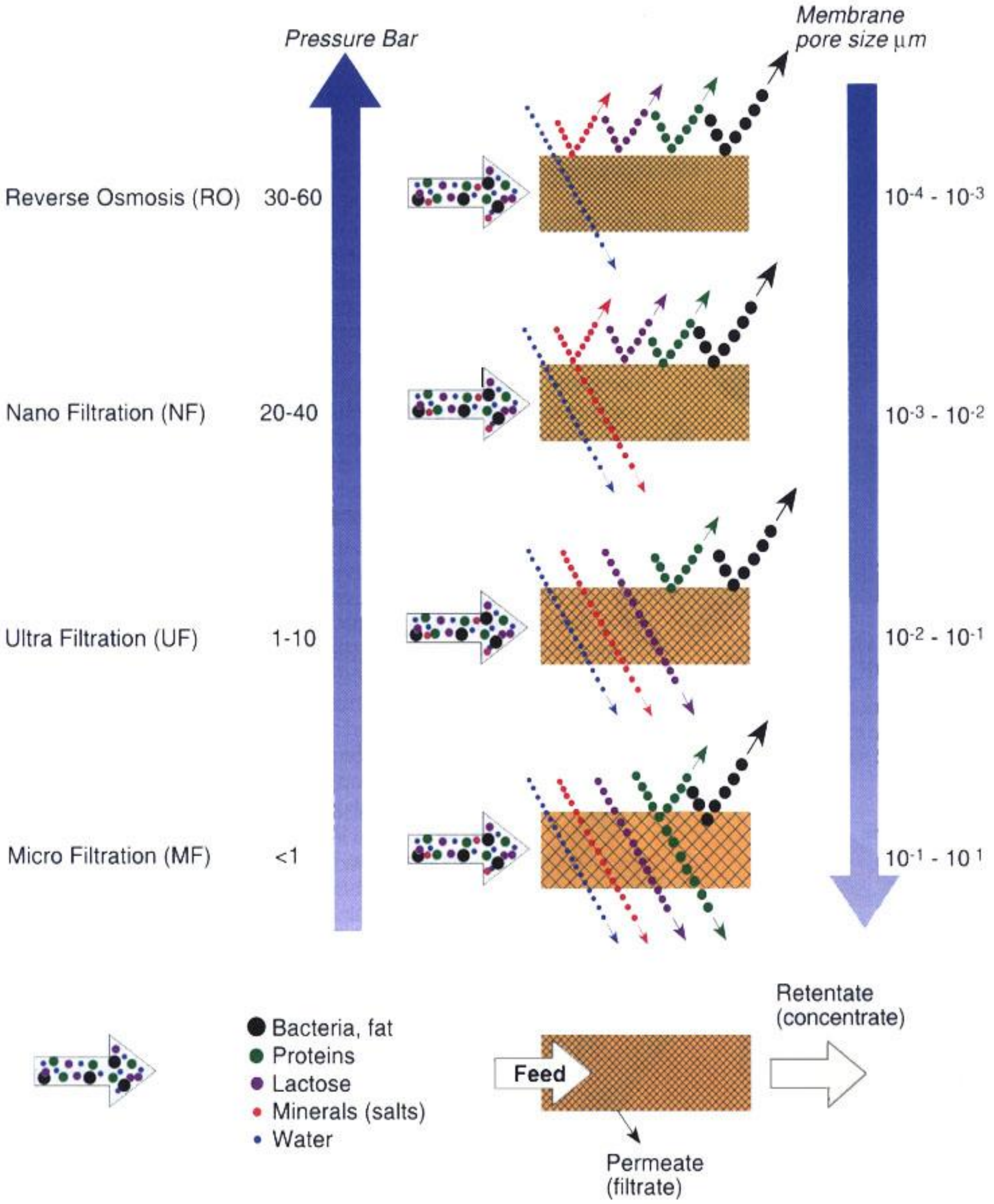


Fig. 4. Different membrane separation processes [13]

1.10 Process

Between an anode and a cathode, anion and cation exchange membranes are placed alternatively in parallel. The membranes are separated by 1mm or less. A plate and frame arrangement is used, similar to that of a plate heat exchanger or a plate filter. The demineralized solution passes through the gaps between the two types of membranes. Only one type of ion can pass through each type of membrane. As a result, anions exit the gap in the anode's direction, while cations leave in the cathode's direction. After that, a focusing stream absorbs both of them [15].

1.11 Membrane Modules

Membranes are built as modules that can be simply plugged into systems with hydraulic components. The primary goals of module design are to fit large membrane areas into tiny spaces, to sustain filtration pressures, and to maintain clean membrane surfaces at high cross-flow velocities. Module configurations include plate and frame, tubular, hollow fibre, and spiral-wound.

1.11.1 Plate and frame module

A support plate separates two flat sheets of membranes in flat plate modules, which also holds the permeate channels. A spacer plate, which also contains the feed-flow channels, separates the membrane sandwiches. Bolts connect and hold together alternate layers of membrane sandwiches and spacer plates. Although this module can sustain high pressures, it is prone to fouling by suspended particles.

In Fig. 5. The arrows show the upstream and permeate paths. The upstream leaves as the retentate and is enriched in non-permeate. Permeates is collected from channels in support plates and leaves enriched in the most permeable component [16].

Advantages: Easy to clean and replace membranes.
Disadvantages: Low membrane area per volume

1.11.2 Tubular module

A schematic diagram of tubular membrane is shown in Fig. 6. Tubular modules are made up of membranes that are produced inside tubes that are typically 6 to 25 mm in diameter and come in three different forms.

- Self supporting tubular modules
- Externally supported tubular modules
- Monolithic tubular modules

A self-supporting tubular module is made up of multiple membrane tubes connected to common headers and permeate vessels in a pack. Modules with 1, 7, or 19 tubes are common. Because of its structural strength, this kind is only suitable for low-pressure applications [17].

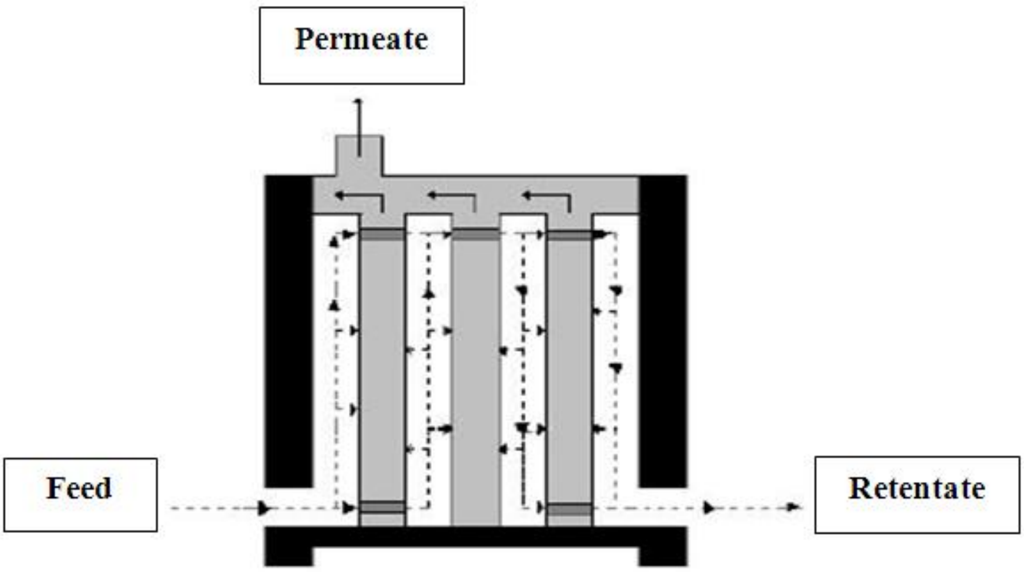


Fig. 5. Schematic view of Plate and Frame module

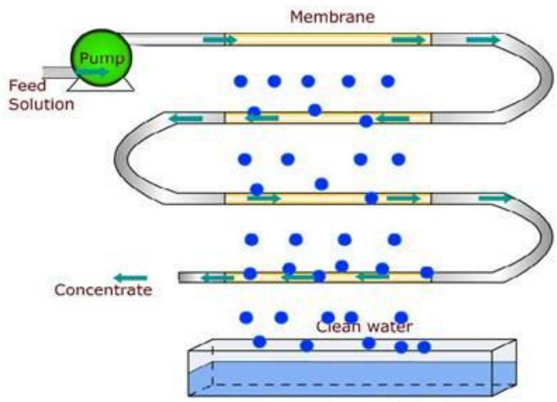


Fig. 6. Schematic view of Tubular module (courtesy of Paulsingh)

Tubular membrane modules with external support are made up of tubular membranes held inside separate porous support tubes. To construct a module, several of these tubes are connected to common headers and permeate containers. Because this type can sustain high pressures, it's commonly utilised in reverse-osmosis systems.

Several tubular channels are produced in a porous block of material in monolithic tubular modules, and the membrane layer is formed inside the tubes. Suspended particles can be accommodated in any tubular module.

1.11.3 Hollow fiber

Bundles of hollow fibres with a diameter of 0.5 to 3 mm are sealed into plastic headers and joined in permeate casings to form hollow fibre modules. Permeate collects in the outer casing as the feed travels through the central bore. Because hollow fibres are self-supporting, these modules are only suitable for low-pressure applications. Moderate quantities of suspended particles can be accommodated in these. Fig.7 and 8 show an illustration of a hollow fibre membrane and its flow patterns [18].

1.11.4 Spiral-wound module

Spiral modules are manufactured by sandwiching a permeate channel made of plastic mesh between two membrane layers and closing three sides. The fourth side of the sandwich is joined to the permeate tube, and the assembly is wrapped around the central permeate tube with another plastic mesh that serves as a feed channel. Although this module can sustain high pressures, it is prone to fouling by suspended particles [19]. Nano filtration and reverse osmosis (RO) are the only applications for spiral membranes. The spiral-wound module is depicted in Fig. 9.

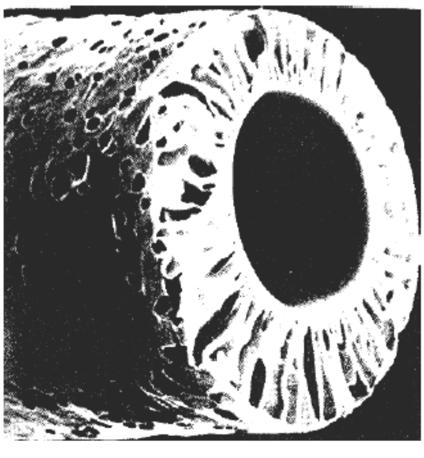
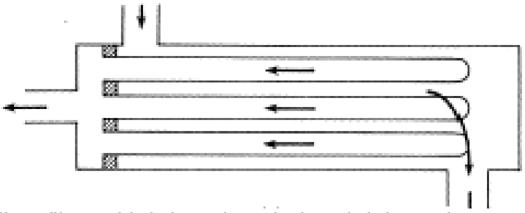
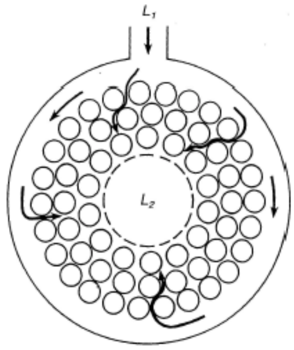


Fig. 7. Magnification of hollow fiber membrane
(Outer diameter between 50 to 200 microns)



Hollow fiber with left end sealed and right end open to exit manifold



(end view)
Flow pattern inside the bundles

Fig. 8. Flow pattern of hollow fiber

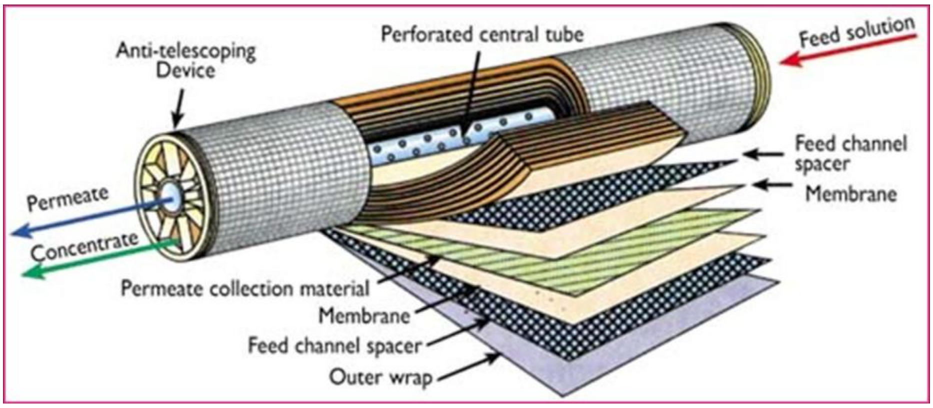


Fig. 9. Spiral - Wound Module

Table 1. Application of membrane processing in dairy, juice, and sugar industry [9]

Industry	Application	Process	Module	Membrane
Dairy	Milk Concentration	RO	Spiral	CA, TFC
	Whey Concentration	RO	Spiral	CA, TFC
	Whey Fractionation	UF	Spiral	PS, PVDF, PES
	Lactose Concentration	RO	Spiral	CA, TFC
	Milk Pasteurization	MF	Tubular	Ceramic
	Desalting	NF	Spiral	TFC
Juice	Clarification	MF	Tubular	Ceramic
		MF	Hollow fiber	PS, PE
		UF	Hollow fiber	PS
		MF/UF	Tubular	PVDF, PS
	Concentration	RO/NF	Spiral	TFC
		RO/NF	Tubular	TFC
		RO/NF	Hollow fine fiber	TFC
	Caustic recovery	MF	Tubular	Ceramic
Gelatin	Concentration	UF	Spiral	PS
Corn Sweetener	Dextrose clarification	MF	Spiral	PS/PES
Sugar	Clarification	MF/UF	Tubular	Ceramic
	Pre concentration	RO	Spiral	TFC

Note: RO = reverse osmosis; UF = ultrafiltration; MF = microfiltration; NF = nanofiltration; CA = cellulose acetate; TFC = thin film composite; PS = polysulfone; PVDF = polyvinylidine difluoride; PES = polyethersulfone; PE = polyester

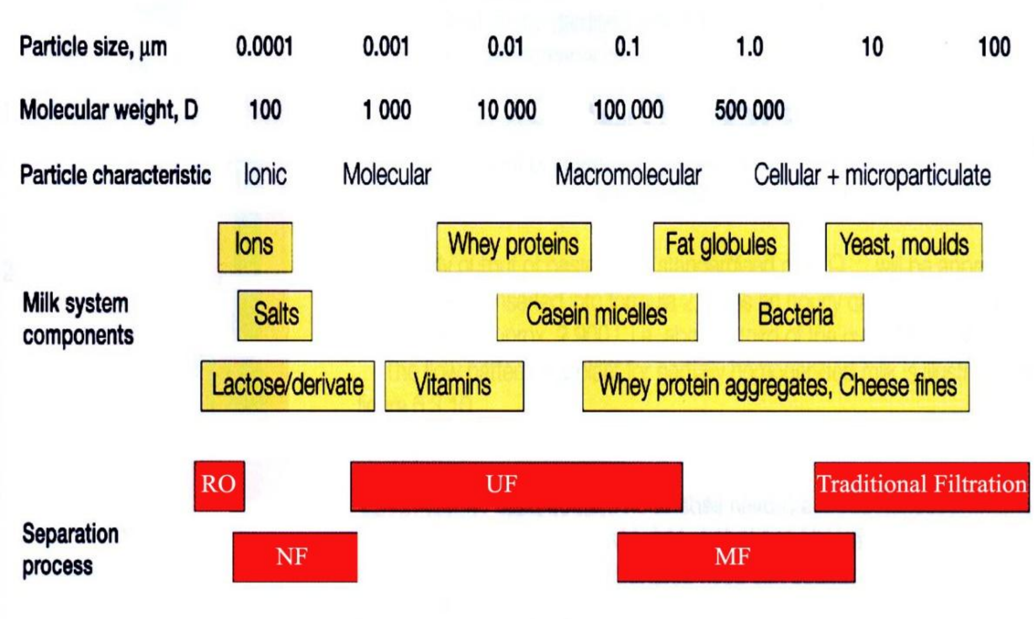


Fig. 10. Spectrum of application of membrane separation processes in the Dairy Industry

1.11.5 Applications of different types of membrane processing technique in food industries

The various application of membrane processing in dairy, juice and sugar is shown in Table 1. Some of the other applications of membrane processing are wine, brewery, waste water treatment etc.

1.12 Wine and Brewery

In the clarifying process, diatomaceous earth filters and pad filters are being phased out in favour of tubular and hollow fibre microfiltration membranes. To a limited extent, ultrafiltration has been successful in replacing fining. The tartrate precipitation process in cold stabilisation is accelerated when wines are concentrated using reverse osmosis. Low alcohol wine is made using reverse osmosis.

Cold sterilised beer is made by microfiltration through ceramic membranes. Low-alcohol beer is made using reverse osmosis. To reduce air pollution and recover thermal energy, vapours from beer stills are condensed and processed by reverse osmosis membranes [20].

1.13 Animal Products

Blood is a high-volume slaughterhouse waste product. Ultrafiltration separation and purification of blood cells, ultrafiltration concentration of plasma, and ultrafiltration concentration of homogenised blood are all examples of byproduct recovery from waste blood utilising membranes. Tubular, spiral, and flat plate modules are used in these applications.

Gelatin is a result of the hydrolysis of collagen that contains colloidal proteins. To make gelatin powder, a hydrolysate containing 3 to 15% solids is concentrated and dried. Steam evaporation and drum drying were the typical methods. Due to reduced heat damage and lower cost, ultrafiltration was shown to be better to steam evaporation. Ultrafiltration also allows for salt loss, resulting in a superior product. Tubular microfiltration devices have replaced diatomaceous earth filters in gelatin clarifying [21].

1.14 Ultra sound Assisted Membrane Processing

In membrane filtrations, power ultrasound (US) transmits large volumes of tiny mechanical vibrations that aid particle detachment. US has also been proven to improve food quality by altering physical qualities and altering enzyme and microbial activity. The use of US in food membrane processing enhances flow, but the lack of consistency in terms of experimental settings makes it impossible to make meaningful comparisons. In this regard, the ultrasonic intensity (UI), membrane configuration and kind of transducers, as well as the volume of the treated solution, must all be carefully considered. The most researched use of membrane food processing in the United States is dairy products. The use of US in conjunction with membrane processes like as reverse osmosis (RO), forward osmosis (FO), and enzyme membrane bioreactors (EMBR) could be beneficial in the manufacture of value-added meals [22].

1.15 Process Effluents

Large amounts of water containing suspended and dissolved particles are discharged from food processing plants. Food manufacturers have been pushed to explore for sophisticated wastewater treatment technology due to rising effluent disposal expenses in urban areas. Reverse osmosis becomes the method of choice when the wastewater disposal problem is related to dissolve organic matter or salts. Microfiltration has been used in the brining and pickling business to clarify brines for reuse, as well as reverse osmosis to concentrate brining trash for alternate disposal. Biological treatment is used on effluent that contains dissolved organic materials. For dilute effluents, aerobic treatment is the optimum option, while anaerobic treatment is better for more concentrated effluents. Membrane treatment can be used to concentrate dilute effluents for anaerobic treatment, as well as recovering water [23].

1.15.1 Advantages of membrane processing

- ❖ Simple in operation. It involves only a bulk fluids using mechanical energy.
- ❖ Does not involve phase change.
- ❖ Can be done at ambient temperate.
- ❖ Requires low energy compared to other dewatering method.

1.15.2 Limitations of membrane processing

- Cannot be dried
- Cost of the membrane
- Concentration polarization
- Constraints on the maximum attainable concentration (only up to 25 to 30°Brix).

2. ECONOMIC FEASIBILITY

The use of membranes cannot be justified solely on the basis of disposal cost savings. Byproducts, chemicals, and heat recovery can help round out the benefits while also lowering the cost of the application. The recovery of sugars from rinse fluids and the recovery of chemicals from cleaning water have both been proved to be economically possible using membrane devices.

Newer membranes have been shown in studies to be capable of making efficient and precise separations without consuming a lot of energy. Membranes were developed by researchers and membrane firms to recover sediments, fractionate nutrients, and generate clean water that could be reused in the process. Processors would be able to recover more solids from process streams, develop novel coproducts, and minimise the load on the environment and wastewater treatment as a result of this capability. Electrical, thermal, and overall cost requirements for the membrane-based system were 30, 40, and 33% of the conventional steepwater concentration method, respectively. Currently, research is required to evaluate long-term cleaning procedures as well as the economic viability of specific membrane applications [24, 25].

3. CONCLUSION

For many years, and to a significant part now, applications in the treatment of milk and whey dominated the usage of membrane technology in the food and beverage sectors. Juice and wine clarity, as well as protein processing, are becoming more popular. Food and beverage industries will continue to prioritise wastewater treatment as a means of reducing pollution. Converting food byproducts to value-added products is another industry trend for reducing waste and increasing profits. Membranes can be used in a variety of conversion processes, such as converting waste salts to useful acids and bases, recovering blood proteins from abattoir wastes, or fermenting maize starch to ethanol, corn oil, and other corn co-products.

Recent advances in membrane filtering technology are being utilised to concentrate nutraceuticals and functional food ingredients to improve the quality of food products, in addition to the conventional food and beverage processing applications. Concentration of soy isoflavones from soybean water extracts and concentration of green tea leaf extracts are two examples. The benefits of membrane-based processing include the preservation of tastes and functional food components due to the lack of thermal processing.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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