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A REVIEW

Membrane separation technology in food and allied industry

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SUMMARY :

Membrane filtration is a technique that uses a physical barrier, a porous membrane or filter, to separate particles in a fluid. Particles are separated on the basis of their size and shape with the use of pressure and specially designed membranes with different pore sizes. Although there are different membrane filtration methods (reverse osmosis, nanofiltration, ultrafiltration and microfiltration, in order of increasing pore size), all aim to separate or concentrate substances in a liquid. Developments in novel membrane processes, including electrodialysis and pervaporation, increased the array of applications in combination with other technologies for alternate uses in fruit juices and beverages. Food industry applications make use of four basic module designs: spiral-wound, tubular, hollow-fibre and plate-and-frame styled systems. The technology can be applied to several production methods, including milk-solids separations in the dairy industry, juice clarification and concentration, concentration of whey protein, sugar and water purification and waste management.

KEY **W**ORDS : Membrane, Beverages, Dairy, Water, Sugar, Fouling, Economics

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The current food industry has come about through generations of cultural and technological developments, involving many aspects from food production to processing to retail before reaching the consumer. In this day and age, the highest level of quality and safety are expected from food products, and the market for value-added foods is ever-increasing (Lotek, 2008). Membrane separation technology is a prominent figure in ensuring that food meets those requirements. Membrane technology has become a dignified separation technology over the past decennia. The technology can be applied to several production methods, including milk-solids separations in the dairy industry, juice clarification and concentration, concentration of whey protein, sugar and water purification and waste management (Stratton, 1999). Membrane filtration utilizes a pressure driving force to separate. The membrane separation process is based on the presence of semi permeable membranes. The principle is quite simple: the membrane acts as a very specific filter that let water flow through, while it catches suspended solids and other substances. There are two factors that determine the affectivity of a membrane filtration process; selectivity and productivity. Selectivity is expressed as a parameter called retention or separation factor (expressed by the unit l/m^2h). Productivity is expressed as a parameter called flux (expressed by the unit l/m^2h). Selectivity and productivity are membrane-dependent.

Membrane construction:

The membranes are symmetrical, where the properties

Process	Membrane	Species retained
MF	Porous, 0.1 – 5 mm	Cells, bacteria, yeasts, starch granules, oil globules, etc.
UF	Porous, 5 – 100 nm	Polysaccharides, proteins, tannins, virus, etc.
NF	Porous, 1 – 5 nm	Sugars, organic acids, polyphenols, aroma compound, etc.
RO	Non-porous	Salts

(Dornier; 2006)

of the membrane do not change throughout the cross-section of the membrane and are homogenous (Reif, 2006; Ramakrishna *et al.*, 2011). Symmetrical membranes are usually made of sintered metal. Asymmetrical membrane is composed of a thin selective layer and a strong supportive layer giving mechanical strength and may be either homogeneous or heterogeneous. It is typically characterized by a thin skin on the membrane surface with small pore size and a thickness of 0.1 to 0.5 μm. Asymmetric membranes rarely get plugged (Ramakrishna *et al.*, 2011). Asymmetrical membranes are usually made of polysulfone. A composite membrane is comprised of more than one material and structure. Like the asymmetric skinned membranes, composite membranes also have a thin, dense layer that serves as the filtration barrier but skin differs in cast (Pirnie, 2005). Composite membrane can be achieved by dip-coating, interfacial polymerization, *in-situ* polymerization or plasma polymerization (Reif, 2006; Ramakrishna *et al.*, 2011). Track-etch membranes offer distinct advantages over conventional membranes due to their precisely determined structure. There are two basic methods of producing latent tracks; the first method is based on the irradiation with fragments from the fission of heavy nuclei such as californium or uranium (Fleischer *et al.*, 1964). The second method is based on the use of ion beams from accelerators (Luecket *et al.*, 1990). Track-etch membranes are manufactured of particular product based on polyethylene terephthalate (PET) or polycarbonate (PC) films. Chemical etching is a process of pore formation. During chemical etching the damaged zone of a latent track is removed and transformed into a hollow channel (Fleischer *et al.*, 1964).

Comparision of various membrane modules

	Tubular	Plate-and-frame	Spiral-wound	Hollow-fibre
Packing density	Low			Very high
Cost	High			Low
Fouling tendency	Low			Very high
Cleaning	Good			Poor
Membrane replacement	Yes/No	Yes	No	No

(Ramakrishna *et al.*, 2011)

As required by other processing equipment in the food industry, all membrane surfaces, backings, spacers and support structures that make contact with food products must meet Title 21, Part 177, of the Code of Federal Regulations, generally recognized as safe (GRAS), or otherwise approved by the FDA for food contact (Short, 1995). Materials also are chosen for their cleanability and ability to withstand a variety of conditions under which it might perform.

Membrane technology in juice industry:

To achieve high-quality products in a cost-effective way, manufacturers are looking for means to improve and optimize juice processing. Membrane filtration can both replace the traditional clarification process as well as complement evaporation used in the concentration of juice, resulting in high energy saving (Wenten, 2002). Membrane technology for the processing of fruit juices has been applied mainly for clarification using ultrafiltration (UF) and microfiltration (MF), and for concentration using reverse osmosis (RO). Developments in novel membrane processes, including electrodialysis and pervaporation, increased the array of applications in combination with other technologies for alternate uses in fruit juices and beverages (Girard and Fukumoto, 2000). The purpose of beverage clarification is to remove proteins, suspended colloids, polyphenolic compounds, starch, pectin and microorganisms from natural fruit juice. After clarification/fining, the fruit juice is concentrated to reduce costs for transportation and storage. Gomes *et al.* (2005) defrosted the acerola pulp and treated it with 100 ppm of Citrozym Ultra L enzyme at 45^0C for 1 hr and then ultrafiltrated (UF) at 3 bar using 0.1 μm ceramic membrane and concentrated it by reverse osmosis (RO) using a spiral membrane of a compound film. The pressures on the reverse osmosis were 20, 30 and 40 bar at environmental temperature and resulting juice had concentration of 9.76, 14.56 and 17.36 ^{0}Brix, respectively. The physicochemical characteristics of the juice and public acceptability showed that 75 per cent of the consumers liked the juice. Thin film composite polyamide membrane was used for ultrafiltration (UF) of sucrose and pectin solutions, their mixtures and enzymatically treated mosambi [*Citrus sinensis* (L.) Osbeck] juice. The nature of the flux decline and the values of the permeated TSS of enzymatically treated mosambi juice showed similar behavior as compared with that of the UF of the sucrose–pectin mixture. Moreover, the permeate of the enzyme-treated mosambi juice contains almost all the soluble solids and acids (citric acid) with a remarkable improvement in juice clarity (Rai *et al.*, 2005). UF and powdered activated carbon was applied in clarification of apple and grape juice, an improvement in taste and odour was observed and in specific cases, residuals of pesticides and fungal toxins were removed (Norit, 2006). Fresh depectinised kiwi fruit juice was clarified using UF and it was observed that juice retained maximum nutritional value (Cassano *et al.,* 2006).

After pre-concentrate with microfiltration (MF) and reverse osmosis (RO) it was found that yields of the longan juice were 71.63 ± 1.31% and 37.69 ± 2.72%, respectively, under optimal operation parameters. Results also showed that the product had 25.87 ± 1.63% TSS, pH 5.16 ± 0.09 and 0.42 ± 0.03% acid (citric acid). Furthermore, the MF retained protein, sucrose, glucose, fructose, some vitamins and minerals in longan juice pre-concentrate compared to the dried longan (Yunchalad *et al.,* 2008). The applicability of reverse osmosis (RO) for the concentration of blackcurrant juice by polyamide tubular membrane that has a salt rejection > 80% was examined. The fresh juice had a TSS content of about 16.58^0 Brix. It was concluded that the applied RO membrane is suitable for concentration of blackcurrant juice up to 28.68^0 Brix, which was achieved with the juice that had been treated with pectinase enzyme preparations (Panzym Super E) (Pap *et al.,* 2009). Grape juice was concentrated by reverse osmosis (RO) at three different temperatures at 60 bar of pressure. The temperature of 30ºC resulted in an adequate value for the permeate flux besides maintaining the physico-chemical and nutritional characteristics of the concentrated product when compared to the single strength juice (Santana *et al.,* 2011). Pervaporation of apple juice was done to recover any lost juice solution during evaporation. The recovered, concentrated apple juice can be combined with the product solution to help the apple juice retain it's aromatic and taste qualities (Lipnizki, 2010). Pervaporation process was used to recover volatile aroma compounds from lemon juice using a poly octyl methyl siloxane membrane; three compounds (α-pinene, β-pinene and limonene) that make contribution to lemon juice aroma were studied. It was found that membrane was selective towards α-pinene, β-pinene and limonene and thus, pervaporation was considered attractive technology for the recovery of lemon aroma compounds as it yields good separation and operates under mild conditions (Rafia *et al.,* 2011).

Membrane technology in wine and beer industry:

Winemaking is a complex and delicate process and has to take into consideration the perfect balance between aroma, colour and taste of a particular wine. In wine treatment oxidation and browning is reduced in healthy way. Innovative and proven technology enhancing the quality of wine and help in specialize CO_2 and O_2 management, quality control and wide range of process valves, activated carbon, microfiltration membranes for wine are used.

In an experiment white and red grape-juice samples were used for must preparation. Samples were clarified and sterilized by microfiltration (MF). During filtration the sugar content remained in the retentate. Very low anthocyanin content was measured in the red grape juice permeate, which proves good anthocyanin retention of the membrane. With the combination of the two processes a new complex method was established that resulted in a sterile concentrate with higher sugar content. This method gave a possibility to handle must excess and to develop a new product without preservatives (Rektor *et al.,* 2004).

Wine clarification (remove suspended material and colloids) done by UF and MF is effective, decrease the turbidity, no need for additives and does not produce solid waste and filtration media (De Pinho and Semiao, 2010). Electrodialysis is used for wine tartaric stabilization (removal of potassium hydrogen tartarate) in order to avoid the formation of precipitates and as such there is no generation of huge amounts of solid, no effect on the organoleptic wine characteristics and competitive costs (De Pinho and Semiao, 2010). Moreover electrodialysis has been approved by the International Wine Board (OIV) as well-suited for tartarate stabilization of wine. Membrane technology can control the permeation of oxygen into wine. It is used by the wine industry in pre-bottling micro-oxygenation techniques and more recently it is being used post-bottling, by a number of leading premium and large wineries, in innovative membrane cork technology. Membrane technology can also be used to inhibit taint and flavour transmission into wine (Tran *et al.,* 2007). Micro filtration (MF) with a maximum pore size of 0.2 μm (average = 0.1 μm) provides a wine quality that is low in microbiological activity and reduces yeast and bacteria count to < 1 cell/100 ml. The turbidity level is also reduced to < 1 NTU (Norit). Alcohol can be removed from wine using hydrophilic membranes (Lee *et al.,* 1991).

Conventional beer clarification process employs filter press or pressure vessel filters, which are commonly pre-coated with porous particles of diatomaceous earth as filter aids (Gan, 2001). Environmental pressure on the use of diatomaceous earth has forced the industry to investigate new and alternative technologies. One such technology, crossflow filtration, has been studied in detail (Taylor *et al.,* 2001). In beer industry MF can combine clarification, stabilization and sterile filtration in one single continuous operation (Czekaj *et al.,* 2000). Using alfa laval membrane filtration technology, recovery of about 60 per cent of excellent quality, volume as beer and at the same time, increase income by selling excess yeast with a higher dry matter content (Nielsen, 2009) Osmotic distillation (OD) is used to preserve the beer and to obtain a dense foam head. Cross-flow MF with plate-and-frame cassettes has been adopted to remove yeast, micro-organisms and haze without affecting the taste of the beer. RO is used to reduce the alcohol concentration 8–10 times, while maintaining the beer flavour. Operated at temperatures of 7–8^0C or lower, resulting in a high quality beer, the flavour of which is not affected by a heating process (Lipnizki, 2010).

Membrane technology in dairy industry:

The dairy industry has used membrane processing since its introduction in the food industry in the late 1960s to clarify, concentrate and fractionate a variety of dairy products. With membrane processes in the dairy industry it is possible to separate virtually every major component of milk, increase of cheese manufacturing yield development of new products and effluent minimization (Lipnizki, 2010; De Pinho and Semiao, 2010) and preparation of egg white and egg yolk (Wenten, 2002).

In dairy industry membrane technology can be used in standardization of milk by UF offers the possibility of increasing or decreasing the protein content in milk without the need of adding milk powders, casein and whey protein concentrates (WPC). The resulting dairy products have superior quality and sensory characteristics compared to those produced from milk concentrated by conventional methods (Rosenberg, 1995). MF and/or UF are used in the production of milk protein concentrates (MPC), which are products containing 50–58 per cent of protein. The fractionation of milk proteins using membrane technology enables the recovery of value-added protein ingredients β -lactoglobulin and α –lactalbumin has great potential markets. β -lactoglobulin can be used as a gelling agent and α -lactalbumin, which is very rich in tryptophan, can be used in the production of peptides with physiological properties. The production of WPC with 35–85 per cent protein in the total solids can be achieved by a combination of UF and DF (Difiltration). MF can be used as a pretreatment to remove both bacteria and fat and allows the production of WPI with 90 per cent protein in the total solids (Lipnizki, 2010). UF and RO can be applied for the isolation of K-casein glycomacropeptid (GMP) from cheese whey. GMP can find several applications in the pharmaceutical industry. In the dairy industry, the NF process is used to concentrate and partially demineralize liquid whey (35% reduction of the ash content) (Maubois and Ollivier, 1992). UF and RO plays a major role in the lactose manufacture from whey using and in the production of low carbohydrate beverages with high dairy protein content. UF of milk for the production of cheese is the most widespread application of membranes in the dairy industry. UF is used in cheese manufacturing for production of feta cheese, quark and cream cheeses (Rosenberg, 1995) and brine treatment. RO is used for condensed and powder milk production, dewatering, concentration of whey or skimmed milk and polishing of NF permeates (De Pinho and Semiao, 2010).

Other application of membrane technology:

Very few large-scale membrane separation processes have been applied in the sugar industry worldwide despite the encouraging results of numerous investigations published in the literature (Chou, 2002; Lipnizki *et al.*, 2006). Cross-flow microfiltration (MF) membranes can be used to remove non-sucrose compounds, or to fractionate the retentate rich in colourants. Ultrafiltration (UF) membranes can be applied to concentrate the relevant juices in sugar industry and to remove non-sucrose compounds. The purification of raw beet juice, the use of microfiltration and ultrafiltration for the purification of cane juices was investigated (Hamachi *et al.*, 2003). Decolorization of sugar can be achieved by nanofiltration (NF). UF / MF process in cane sugar production acts as a pretreatment prior to other separation technologies by removing impurities from the raw juice, including starch, dextran, gums, waxes, proteins and polysaccharides. Concentration of raffinate from beet molasses can be achieved by chromatographic separators using reverse osmosis (RO) (Anonymous, 2002). Forward osmosis is a viable membrane process for concentration of sucrose solutions (48^0Brix), increased temperature leads to an increase in the draw and feed solute diffusion coefficient and a decrease in water viscosity (Esperanza *et al.*, 2009).

In a very short duration, cross flow membrane filtration has become a mainstream process unit operation in the starch and sweetener industry. MF is used in saccharification of liquor tank to remove unliquified starch, polysaccharides, proteinaceous matter and other impurities. MF is also used for clarification of maltodextrins, depyrogenation of dextrose, final filtration of dextrose and fructose syrups (Kumari and Chandra, 2008).

The food industry is one of the largest water-using industries. Application of membrane processes in the drinking water industry are desalination using RO, softening using NF, and production of drinking water from surface water, backwash water and nitrate removal using ED (Saxena and Bhardwaj, 2001a). Membrane for potable water production commonly made from organic polymer (Manem and Sanderson, 1996.) but ceramic materials also can be used (Bottino *et al*., 2001). PVDF (polyvinylidenefluoride) as one of fluorocarbon material is suitable to use as membrane-produce potable water because of its resistance against various oxidants (Saxena and Bhardwaj, 2001a and 2001b). Gandhi (2003) reported that ultrapure de-ionized water required for orange juice preparation can made using dialysis. Membrane processes play an important role in both the pretreatment of the water before usage and post-treatment of the water before recycling or discharge.

The clarification of vinegar by UF is positioned directly after the fermentation step and can substitute many steps in the traditional production. Additionally, proteins, pectins, yeast, fungi, bacteria and colloids are removed and thus the filtration /sedimentation and the clarification are substituted and the storage time reduced (Lipnizki, 2010).

Proanthocyanidins (PAs) are natural antioxidants that protect against reactive oxygen species involved in arthritis and cardiovascular diseases. PAs, a poly-phenolic compound modify their structure, being hydrolyzed when temperature increases. Conventional techniques such as evaporation are not suitable to concentrate them MF, UF and NF are alternative processes (Santamaría *et al.,* 2002).

EDI (electro deionization) can be used for starch processing (Widiasa *et al.,* 2002), recovery of citric acid from fermentation broth (Sutrisna *et al.,* 2002). Lipnizki (2010) reported, UF is used for concentration of agar (4–5% TS) and agarose (2% TS) by removing more than 50 per cent of water. Apple and citrus pectin concentration up to 4–7 per cent and purification by removing low molecular components, e.g. salt and sugars.

Conclusion:

The use of membrane filtration offers a wide range of advantages for the consumer as well as for the producer. On the one hand, filtration technology offers an efficient way to gain superior quality and safety without destroying the fundamental sensory qualities of the product. On the other hand, it may reduce some production steps and increase yield, has a high degree of selectivity, improves control over the production process and has low energy costs. The development of filtration techniques and their distribution is not yet complete. There is continuing development of new applications based on the technique. New methods, in particular development of better and longer lasting membranes, offer new perspective.

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