Paper No. : 04
Paper Title: Unit Operations in Food Processing
Module- 24: Membrane Separation: Introduction

24.1 Introduction

Today membrane separation processes have a wide range of industrial applications like waste water treatment and reuse, recovery of metals, concentration of heat sensitive materials like proteins, desalination of whey etc.

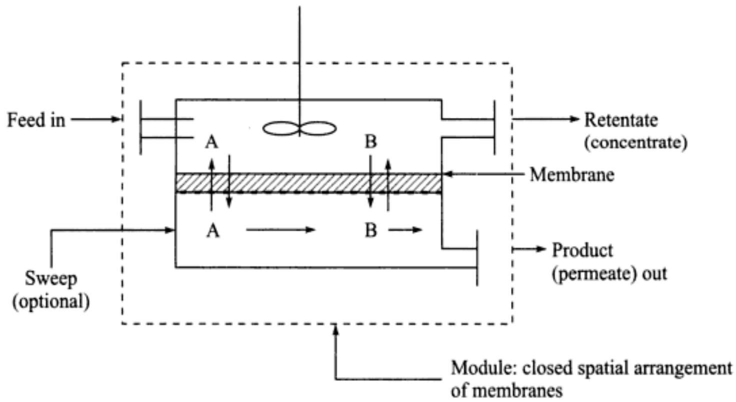

Fig.24.1 Membrane separation process (Courtesy: Marcel Dekker, Inc.)

A membrane is essentially a thin barrier that is able to separate components of a mixture based on its selective permeability. Membrane separation processes utilize the property of a semi-permeable membrane to allow only certain particles to pass through them (depending on their molecular size, shape or charge) and reject the rest. The feed stream is applied to one side of the membrane. On application of appropriate driving force (pressure difference, concentration difference, electric field etc.), this stream passes as filtrate through the other side leaving behind the contaminants or the stream of separated particles termed as retentate/concentrate.

24.2 Types of membrane processes

Membrane processes are broadly classified into four different types of processes based on their separation range namely microfiltration (MF), ultrafiltration (UF), reverse osmosis (RO) and nanofiltration (NF). The driving force for material transport in all these processes is essentially pressure. While MF and UF membranes are generally characterized by their molecular weight cut off (MWCO), RO and NF membranes are characterized by their pore size. Apart from these, electrodialysis and pervaporation are membrane separation techniques of great importance in food industry. The driving force for electrodialysis is electric field and that for pervaporation is concentration difference.

24.2.1Microfiltration

It utilizes differences in sizes of molecules as a criterion for their separation. Microfiltration separates coarser materials present in solutions like fat, microorganisms etc. Its typical applications include clarification of juices, wine, whey in dairy industry, recovery of suspended cells or colloids, concentration of slurries. The MWCO for microfiltration membranes is 0.1-10 μm and typical operating pressures are 10-15 psi.

24.2.2 Ultrafiltration

It has been used extensively for protein recovery, waste water treatment, lactose separation from whey. In combination with Ion exchange, Ultrafiltration has also been used to de-bitter citrus juices (by removal of bitter components limonin and naringin).The MWCO for ultrafiltration membranes is 0.01-0.05µm and operating pressures are at 20-200 psi. In terms of molecular weight Ultrafiltration membranes have a MWCO of 1,000-500,000 Daltons.

24.2.3 Nanofiltration

The separation principle of Nanofiltration and Reverse osmosis is similar i.e. both these processes separate components based on their differences in molecular weights. However nanofiltration membranes have a smaller pore size than RO. MWCO ranges from100-1000 Daltons and operating pressures are at 100-500 psi. Nanofiltration has been used in desalting of whey, removal of pesticides and coloring components from water.

24.2.4 Reverse osmosis

Reverse osmosis has been used extensively in removal of total dissolved solids from water. Reverse osmosis and nanofiltration have been used in the concentrations of aqueous solutions by membrane removal of water. MWCO for RO membranes is not more than 100 Daltons and is operated at pressures of 200-1500psi.

24.2.5 Electrodialysis

Electrodialysis separates electrolytes from non-electrolytes depending on migration of ions through ion selective membranes under the influence of applied electric field. Food applications of electrodialysis include demineralization of whey, deacidification of fruit juices, desalting of water.

24.2.6 Pervaporation

In pervaporation the membrane is selectively permeable to only one component of a liquid mixture. The component diffuses through the membrane and is desorbed into the permeate stream. Pervaporation has applications like ethanol separations, dealcoholization of wines and concentration of aqueous essence of fruit juices.

24.3. Types of flow

Flow of solvent through the membrane can be classified as cross flow filtration and Dead End filtration.

24.3.1 Dead end filtration

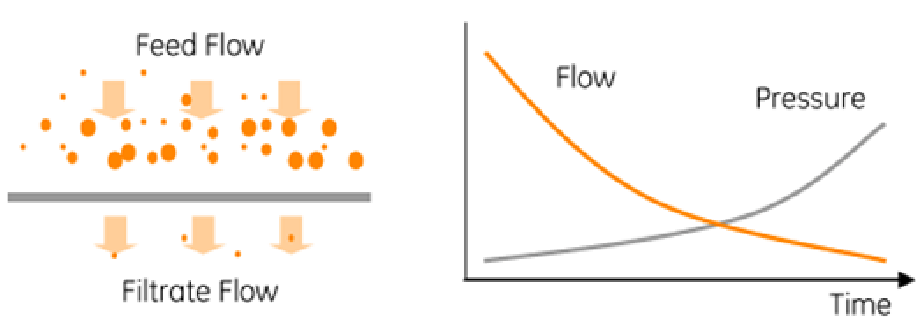

Fig.24.2 Dead end filtration (Courtesy: GE healthcare Inc.)

Flow of feed stream is perpendicular to the membrane surface. The suspended contaminants present in the feed stream accumulate on the membrane surface and form a cake. This reduces feed flux and increases feed pressure overtime.

24.3.2 Cross flow system

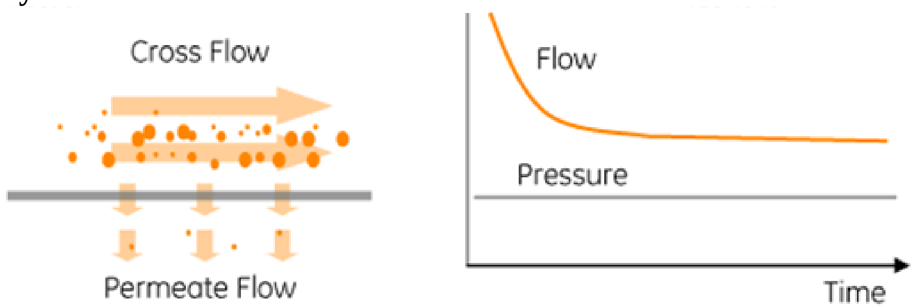

Fig.24.3 Cross flow filtration (Courtesy: GE healthcare Inc.)

Solvent mixture is applied to one side of the membrane and subjected to a pressure. Feed flows parallel to the membrane. The suspended particles accumulate on the feed side as the filtration proceeds. This prevents buildup of particles and aggregates on the membrane thereby maintaining a steadier permeate flux and a relatively low transmembrane pressure. Most industrial applications employ cross flow system for membrane filtration.

24.3 Membrane Classification

Membranes may be classified according to the materials of construction, their structure and their different configurations.

24.3.1 Membrane materials

The materials used in fabrication of synthetic membranes may be metals, polymers or ceramics. Metal and ceramic membranes are suitable for high temperature applications, due to their high thermal resistance. They also find applications when aggressive media like acid are used. Polymeric membranes have advantages like less expensive, versatility, high permeability, selectivity, mechanical strength etc.

24.3.2 Membrane structure

Based on structure membranes can be classified as symmetric or asymmetric membrane. Symmetric membranes are symmetric throughout their thickness. They have limited applications. Expanded polytetrafluoroethylene, polypropelene are examples of symmetric membranes. In asymmetric membranes either a thin microporous of a dense perm selective layer is supported by a more open porous substrate.

24.4.3 Membrane Module Configurations

Commonly used membrane modules include hollow fiber, tubular, spiral wound and plate and frame module.

(a) *Hollow fiber* membranes contain large number of hollow fibers inside tubular casings. They have a high surface area to volume ratio. Surface area can be varied by changing the number of hollow tubes. Most RO (Reverse osmosis) and PV (Pervaporation) utilize hollow fiber systems. High

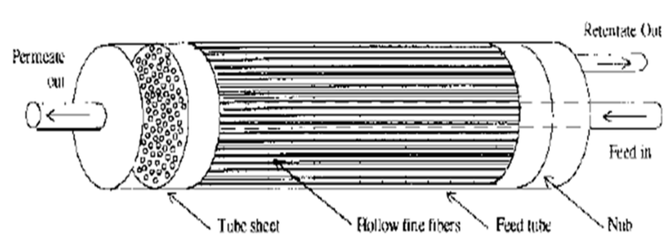

Fig.24.4a Hollow fiber module (Courtesy: Elsevier

pressure liquid enters at one end of the shell side and leaves at the other end. The hollow fibers are closed at one end of the tube bundle. The permeate flows inside the individual tubes and flows out through open end.

(b) *Tubular modules* are larger versions of hollow fiber module with membranes typically 6 to 25mm in diameter packed inside tubes. UF (Ultrafiltration) & MF (Microfiltration) utilize tubular membranes for their operations.

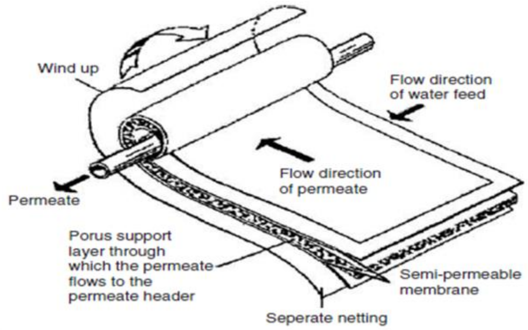

Fig.24.4b Tubular module (Courtesy: Elsevier publ.)

(c) *Spiral wound* membranes are used in virtually all NF and RO, PV systems. These modules are prepared by first making an assembly using two membranes and spacer mesh and then rolling this assembly around perforated permeate collection tube. Spiral wound membranes increase the membrane surface area per unit volume of separator volume and decrease the pressure drop.

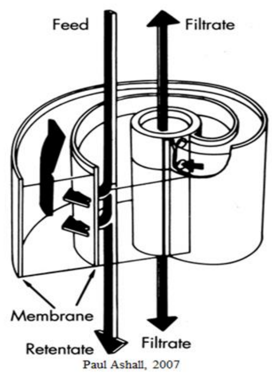

Fig.24.4c Spiral wound module (Courtesy: Elsevier publ.)

(d) *Plate and Frame modules* are a complex plate and frame assembly of layers of membranes separated by corrugated structural sheets, spacers, gaskets. These modules find applications in MF and UF assembly.

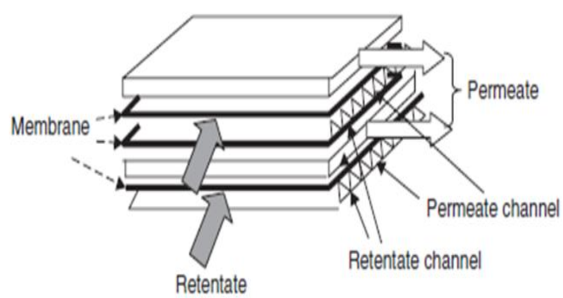

Fig.24.4d Plate and Frame wound module (Courtesy: Elsevier publ.)

24.5 Membrane Performance

24.5.1 Terminologies

All pressure-driven membrane systems are characterized by system flux, recovery, sieving coefficient and rejection.

System Flux (J) is defined as the filtrate flow (Q_p) per unit surface area (A_m).

$$J = Q_p/A_m$$

Percent Recovery (R) is the amount of filtrate flow (Q_p) recovered from the feed flow (Q_f)

$$R = Q_p/Q_f$$

Sieving coefficient (S) is defined as the ratio of concentration of solute in the permeate (S_p) to the concentration of solute in the retentate (S_r).

$$S = \frac{S_p}{S_r}$$

Rejection (R) refers to the percentage of contaminants rejected by the membrane.

$$R\% = (1 - S) * 100$$

Operation of a membrane systems refers too monitoring the permeate flow rate and rejection within specific limits to allow for the proper functioning of the membrane. There is a considerable decrease in the flow rate of permeate as compared to the flow rate of pure water. This reduction maybe attributed to factors like fluid transport properties, concentration polarization, membrane response and membrane fouling.

24.5 .2 Fouling Phenomena

Fouling is initiated by the deposition of particles on the membrane thereby blocking the flow of solvent. This results in a decline in solvent flux and an increase in pressure drop across the membrane. A concentration polarization layer sets on the membrane surface. This is reversible. The flux can be increased by decreasing pressure, increasing velocity or decreasing concentration. Overtime, the solutes that accumulate on the membrane surface undergo irreversible changes and form resistant layers. On further standing, smaller sized solutes enter the membrane pores and block the same. The final stage of fouling occurs when solute particles are absorbed by the membrane. For instance protein absorption by ultrafiltration membranes

24.6 Conclusion

Separation processes have many applications in food processing starting from dairy industries to fruit processing industries. However, the efficiency of separation is very low. Membrane separation processes thus are gaining popularity for their higher separation and retention rate. Among the membrane separation processes microfiltration, ultrafiltration, reverse osmosis and nanofiltration. There are two types of filtration methods viz. dead end and cross flow filtration. Cross flow filtration is preferred over dead end filtration because the pressure drop is less thus yield is good. There are different configurations of membrane materials viz. hollow fiber, tubular module, spiral wound and plate and frame modules. The modules have selective applications. Membrane performance is determined and characterized by system flux, percent recovery, sieving coefficient and rejection percent.

References

1. *Food process engineering and technology*, Zerki Berk, Elsevier Inc.,1st ed.,2009
2. *Handbook of Food Engineering Practice edited*, Kenneth J.Valentas, Enrique Rotestein, R Paul Singh, CRC Press,1997