Chapter 12

MEMBRANE SEPARATION

(Membrane processing methods and equipment, RO, NF,UF,MF, Applications of membrane separation, Membrane techniques, Membrane materials, Membrane modules)

Membrane separation is a process of separating food components by using semi-permeable membranes, basing on the molecular size and molecular weight of the components. The driving force of the separation process is, for example, differences in concentration or pressure between the two sides of the membrane.

Membrane separation processes can remove much smaller substances, such as viruses and dissolved ions, from the water.

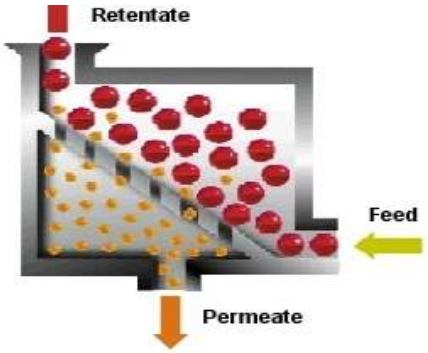

Fig. 12.1 Principle of operation in membrane separation

MEMBRANE PROCESSING METHODS

The different membrane processing methods are as follows.

Reverse osmosis (RO). Concentration of solution by removal of water

Nanofiltration (NF). Concentration of organic components by removal of part of monovalent ions like sodium and chlorine (partial demineralization).

Ultrafiltration (UF). Concentration of large and macro molecules

Microfiltration (MF). Removal of bacteria, separation of macromolecules

The difference in application of these technologies is shown in Fig. 12.2.

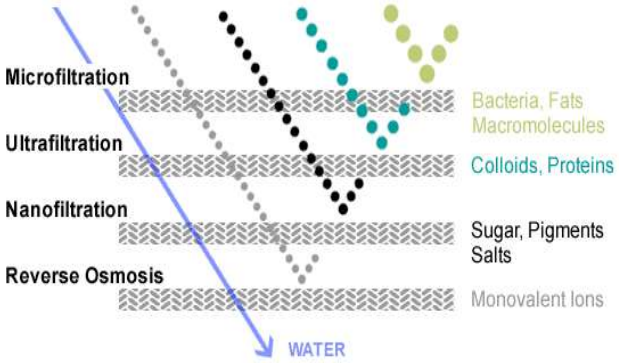

Fig. 12.2 Application of different membrane processing technologies

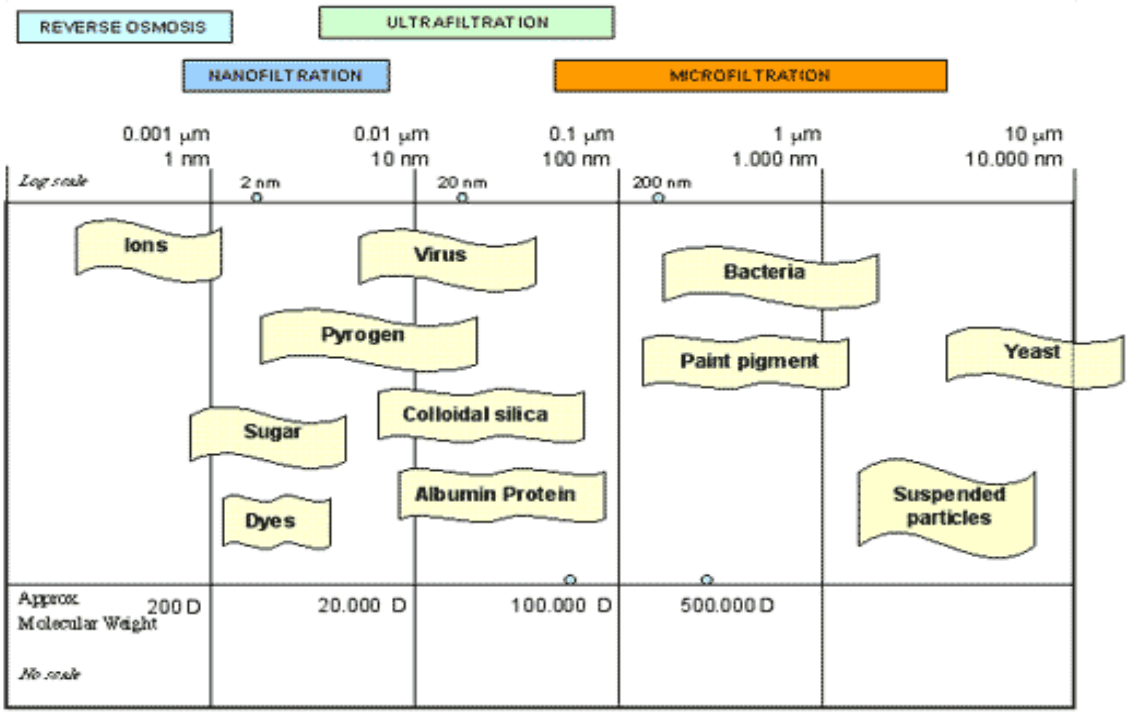

Fig. 12.3 Range of concentration in various filtration systems

There are also other methods for selective separation as follows.

- Pervaporation
- Ion exchange
- Electro-dialysis

REVERSE OSMOSIS

It is a membrane separation process, driven by a pressure gradient, in which the membrane separates the solvent (generally water) from other components of a solution. The solvent flow is opposite to the normal osmotic flow.

The membrane pore size is very small allowing only small amounts of very low molecular weight solutes to pass through the membranes.

Applications

Broadly used to separate water from low molecular weight solutes (salts, aroma compounds etc.), which have high osmotic pressure.

- Concentrate and purify fruit juices, enzymes, fermentation liquors and vegetable oils; pre-concentrate juices and dairy products before evaporation.
- Concentrate wheat starch, citric acid, egg white, milk, coffee, syrup, natural extracts and flavors.
- To clarify wine and beer (De-alcoholization for low alcohol wines and beers)
- To determine and purify water from boreholes or rivers or desalination of sea water.
- Water and waste water purification.
- Concentration of whey during cheese manufacture.

RO materials and equipment

- Polymer having high permeability for water, high rejection for soluble salts and durability.
- Cellulose acetate is outstanding being inexpensive.
- Polyacrylonitrile, polyamides, polyurethanes are also used, but they have low temperature resistance and low pH range.
- Polysulphones and ceramic materials can withstand high temperature and wider pH range.
- Operating pressure ranging from 40 to 80 bar @ 450 to 2400 lit/h of flux.

NANOFILTRATION (NF)

- New class of pressure-driven membrane processes that lies between RO and UF
- Pressure range: 10-50 bar (lower pressure than RO)
- Rejects ions with more than one negative charge (such as SO42-, CO32-)
- Also known as loose reverse osmosis

Applications

- Removes materials having molecular weight between 300 to 1000 Da.
- Employed for pre concentration for RO.
- Removal of inorganic salts Na, K, Cl, urea, lactic acid
- Partial demineralization
- Membranes that leak particle species with a radius in the nanometer range
- Reduction of salty taste as well as reduction of salt from cheese making

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- Pretreatment for electro dialysis, ion exchange
- Acid removal
- Separation of dispersed particles such as colloids, fat globules etc.

ULTRAFILTRATION

Ultra-filtration is similar to reverse osmosis with low pressure of operation. In UF, the membrane pore size is larger allowing some components to pass through the pores with the water. It is a separation/ fractionation process.

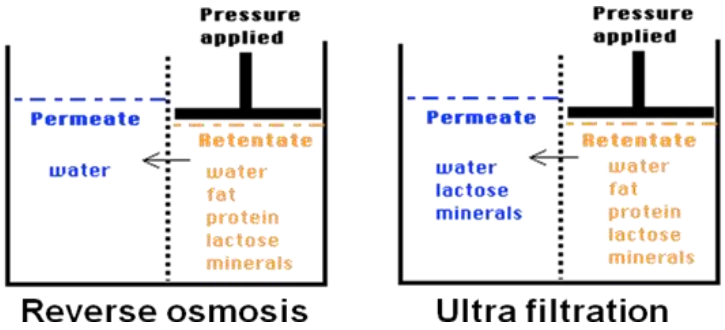


Fig. 12.4 Difference between RO and UF

Dia-filtration is a specialized type of ultra-filtration process in which the retentate is diluted with water and re-ultra filtered, to reduce the concentration of soluble permeate components and increase further the concentration of retained components.

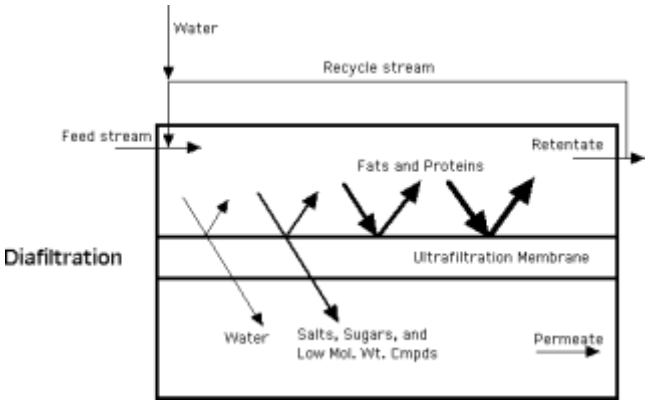


Fig. 12.5 Diafiltration process

Equipment

- U.F. membranes have higher porosity.
- They operate under low pressure (0.05 to 10 bar @ 2400 lit/hr of flux).
- Polymers like polysulphones, polyamides, PVC, polystyrene, polycarbonates and polyethers are normally used.

Applications of ultrafiltration

- Most commonly used to pre concentrate milk prior to preparation of other range of dairy products
- Concentration of sucrose and tomato paste.
- Separation and concentration of enzymes, other proteins or pectin.
- Treatment of water to remove bacteria and contaminants greater than 0.003 µ dia.
- To selectively remove lactose and salts from the whey.
- Removal of protein hazes from honey & syrups.
- Pretreatment for RO to prevent fouling by organic and colloidal material

Fig. 12.6 Integrated membrane filtration system comprising UF plant for WPC & RO plant for lactose concentration

Fig. 12.7 Module filters for food and beverages

Fig. 12.8 Filter to remove microbiological impurities from cheese brine

MICROFILTRATION

- Microfiltration (MF) designates a membrane separation process similar to UF but with even larger membrane pore size allowing particles in the range of 0.2 to 2 micrometers to pass through.
- The pressure used is generally lower than that of UF process.
- MF is used in the dairy industry for making low-heat sterile milk.

Table 12.1 Applications of membrane filtration

		Permeate	**Concentrate**
RO	dyeing effluent	clean water	BOD, salt, chemicals, waste products
	water	low salinity water	salty water
	whey	low BOD permeate	whey concentrate
NF	antibiotics	salty waste product	desalted, concentrated antibiotics
	dyeing effluent	clean, salty water	BOD/COD, color
	water	softened water	water product
	whey	salty waste water	desalted whey concentrate
UF	antibiotics	clarified fermented broth	waste product

	bio gas waste	clarified liquid for discharge	microbes to be recycled
	carrageenan	waste product	concentrated carrageenan
	enzymes	waste product	high value product
	milk	lactose solution	protein concentrate for cheese production
	oil emulsion	oil free water (<10 ppm)	highly concentrated oil emulsion
	washing effluent	clarified water	dirty water (waste product)
	water	clarified water	waste product
	whey	lactose solution	whey protein concentrate
	xantan	waste product	concentrated xantan

Membrane techniques

- Counter diffusion
- Osmotic distillation
- Electro dialysis
- Ion-exchange

Counter diffusion

- Separate small ions from large molecules.
- Hollow fiber cellulose diffusion tubes.
- Counter diffusion can produce 50 per cent demineralization.
- which may represent 70 per cent removal of monovalents.

Osmotic distillation

- Low pressure and low temperature separation
- Hollow fiber or spiral wound hydrophobic membrane

Electro dialysis

- Similar to Ion exchange separation.
- Used to separate electrolytes from non-electrolytes and to exchange ions between solutions.
- Direct current is passed through a solution having number of ion exchange plates/membranes.
- The ion selective membranes act as barriers to either cations or anions.

- Anions and cations are attracted towards anodes and cathodes, respectively.
- The membranes are arranged alternatively to form ion diluting cells and ion concentrating cells.
- Electro dialysis is used for demineralization of milk products.
- It is also used for desalination of water.
- Also used to de-mineralize whey, to remove potassium and tartaric acid from wines and to de acidify fruit juices.

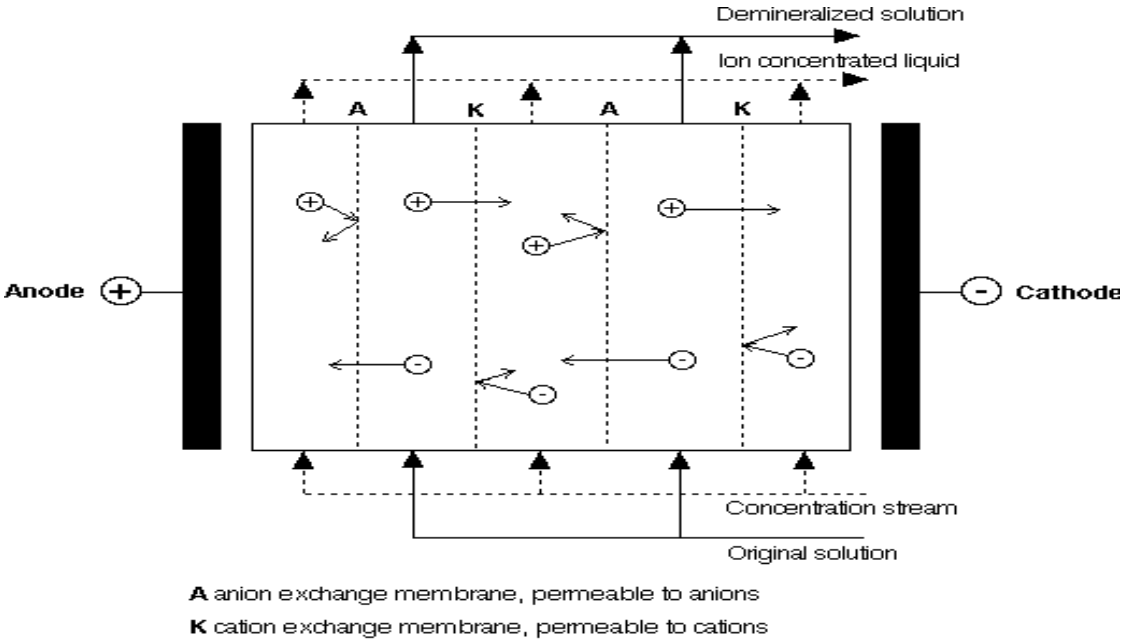


Fig. 12.9 Electro dialysis process

Ion- exchange

- Food components are separated basing on their electrical properties.
- Metal ions, proteins, amino acids and sugar are transferred from the feed and retained on a solid ion exchange material.
- Two types of ion exchangers (having fixed electrical charges) namely cation exchanger that attracts cations and anion exchanger that attracts anions by a process called electro static adsorption.
- The components are then separated by washing off the ion exchangers.
- They are constructed using porous matrix made of polyacrylamides, polystyrenes, dextrans or silica.
- Generally employed for de-colorization of sugar syrup, protein recovery from whey, softening & demineralization of water and separation of enzymes.

Membrane material

- Membranes may be composed of natural (e.g. modified natural cellulose polymers) or synthetic polymers (plastic materials) or inorganic ceramic materials.
- They should be good film formers ,manage high permeate flows and have high selectivity.
- They should have good chemical and bacteriological resistance, be resistant to detergents and disinfectants.
- Be inexpensive.

Table 12. 2 Advantages and limitations of different membranes used in R.O. and U.F.

Type of membrane	Advantages	Limitations
Cellulose acetate	High permeate flux, good salt rejection, easy to manufacture	Operates below 30^0C and pH range 3 to 6, broken down by chlorine
Polysulphones, polyamides, PVC, poly styrene, poly carbonates, poly ethers	Better temperature resistance Better pH resistance Better chlorine resistance, easy to fabricate	Don't withstand high pressure-restricted to UF, Poly amides are more sensitive to chlorine than cellulose acetate
Composite or ceramic membranes (porous carbon, zirconium oxide, alumina)	Inert, very wide range of operating temperature and pH, resistant to chlorine and easily cleaned	Expensive

MEMBRANE MODULES

The different types of plate modules are as follows.

The tubular type

Hollow fibre

Wide tube design

The flat plate type

Plate and frame type

Spiral wound cartridges

The flat plate type

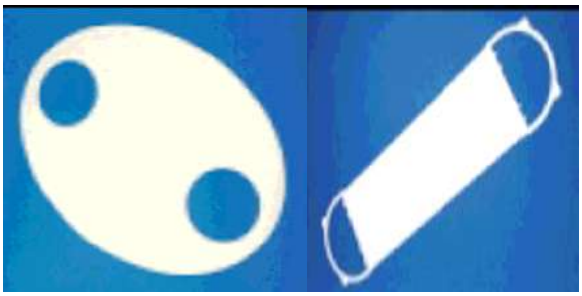
- Plate and frame design is similar to plate filter press.

- Have membranes stacked together with intermediate spacers and collection plates to remove permeate.
- Either laminar or turbulent flow.
- The feed can be passed in either series or parallel.
- High surface area to be fitted in a compact space.
- Individual plates can be replaced easily, hence less expensive.

Plate and frame design

- Membrane sandwiched between membrane support plates which are arranged in stacks similar to a plate heat exchanger
- Typically polymers (e.g. polyethersulfone) with polypropylene or polyolefin support
- UF (<1 to 1000 kDa MWCO)
- MF (0.1 to 0.16 um diameter)

Fig. 12.10 Plate and frame module in waste water system



Oval shaped Rectangle shaped

Fig. 12.11 Types of plates

Spiral wound system

- In the spiral wound system, alternating layers of polysulphone membranes with polyethylene supports are wrapped around a hollow central tube, separated by channel spacers and drains.
- The cartridge is about 12cm in diameter and 1m long.
- Feed liquid enters the cartridge and flows tangentially to the membranes.

- The permeate flows into the central tube and the concentrate flows out of the other end of cartridge.
- Separator screens cause turbulent flow and hence more flux.
- Low cost and popularly adopted.

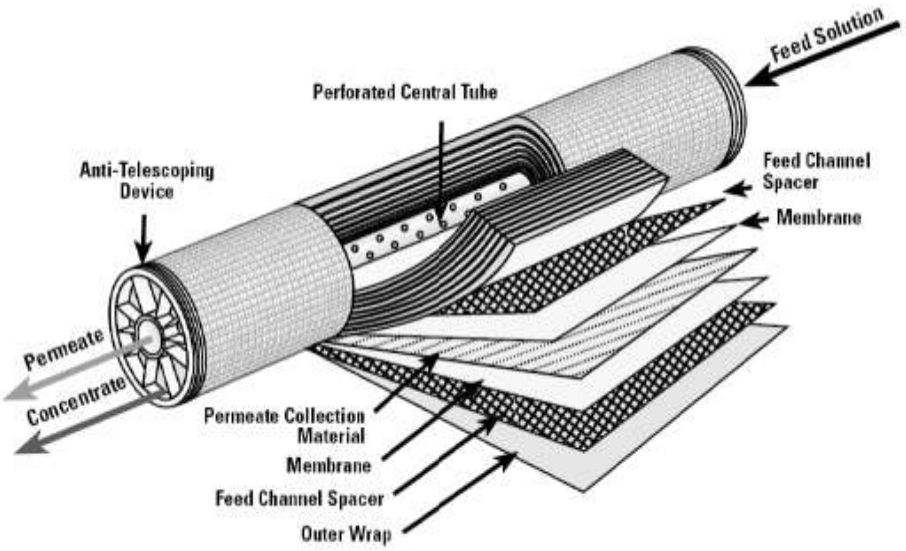


Fig. 12.12 Spiral wound membrane

The tubular type

- *Hollow fibre systems* are usually a narrow tube made of a non-cellulosic polymer, have 50-1000 fibres, 1m long, 0.001-1.2 mm diameter.
- Attached to each end of a tubular sheet.
- Having large surface area, generally employed for R.O.
- Comparatively expensive as whole cartridge is changed in case a single fibre is damaged
- They are easy to clean and don't block easily.
- In *Wide tube design*, a number of stainless steel tubes having lined membranes are fabricated.
- Give rigid support to membranes.
- About 20 tubes, each 1.2-3.6m long & 12-25mm diameter are fitted in parallel or series.
- Operate under turbulent flow conditions with higher flux, hence can handle more viscous fluids.

Fig. 12.13 Hollow fibre membrane

Advantages of Membrane separation

- Basically membrane concentrations occur at ambient temperatures.
- Loss of heat sensitive nutrients and characteristics are insignificant.
- Sensory and nutritional qualities of foods remain unaltered.
- Simple installation with low operation costs and labor.
- In contrast to conventional concentration by evaporation, no requirement of steam boilers.

Limitations

- Change in concentration of feed affects the flux.
- Higher capital cost involvement than evaporation,
- Limited to maximum concentration to 30 per cent total solid.
- Fouling of membranes may adversely affect the efficiency and time of operation.

Pervaporation

It is another separation technique which has the following characteristics.

- Liquid feed mixture is separated by partial vaporization through a non porous selectively permeable membrane.
- Produces vapor permeate and liquid retentate.
- Partial vaporization done by decreasing pressure of the permeate side.
- Two types of membranes used.
- Hydrophilic polymers (polyvinyl alcohol or cellulose acetate) permit water permeation.
- Hydrophobic polymers (polydimethyl siloxane or polytrimethyl silylpropyne) permit permeation of organic materials.
- Hydrophilic membranes are used to de-alcoholize wines and beers.
- Hydrophobic membranes are used to concentrate aroma compounds like alcohols, aldehydes and esters.

CHECK YOUR PROGRESS

1. Write short notes on the equipment specifications and applications of reverse osmosis, nanofiltration, ultra filtration and microfiltration.
2. Explain the different membrane techniques.
3. What are the different membrane modules?
4. Write short notes on pervaporation, electro dialysis, ion exchange methods of separation.