MEMBRANE FILTRATION

Introduction

Membrane processing is used in the dairy industry for non-thermal processing, to retain most of the nutrients and is mainly used for manufacture of health and functional foods, through concentration and fraction of various components. This involves, Ultra Filtration, Reverse Osmosis, Micro Filtration and Electrodialysis.

Uses of Membrane Filtration

1. Changing pattern of milk consumption is stressing on individual use of its components.
2. Whey which has high BOD value is being efficiently concentrated form protein. Then, the lactose in the permeate solution can also be handled by RO.
3. It saved energy in transportation, due to concentration.
4. Cheaper method of drying. Pumping is involved, as against evaporation of moisture.
5. Possibility of incorporating whey proteins into cheese.
6. Pollution due to whey is controlled, as whey contains lactose.
7. Milk also can be concentrated without damage to protein or changing flavour unlike in concentration and drying.
8. Other industrial uses, like water purification, fractionation & concentration in Food and Pharmaceuticals, recovery of various components of waste for further use.

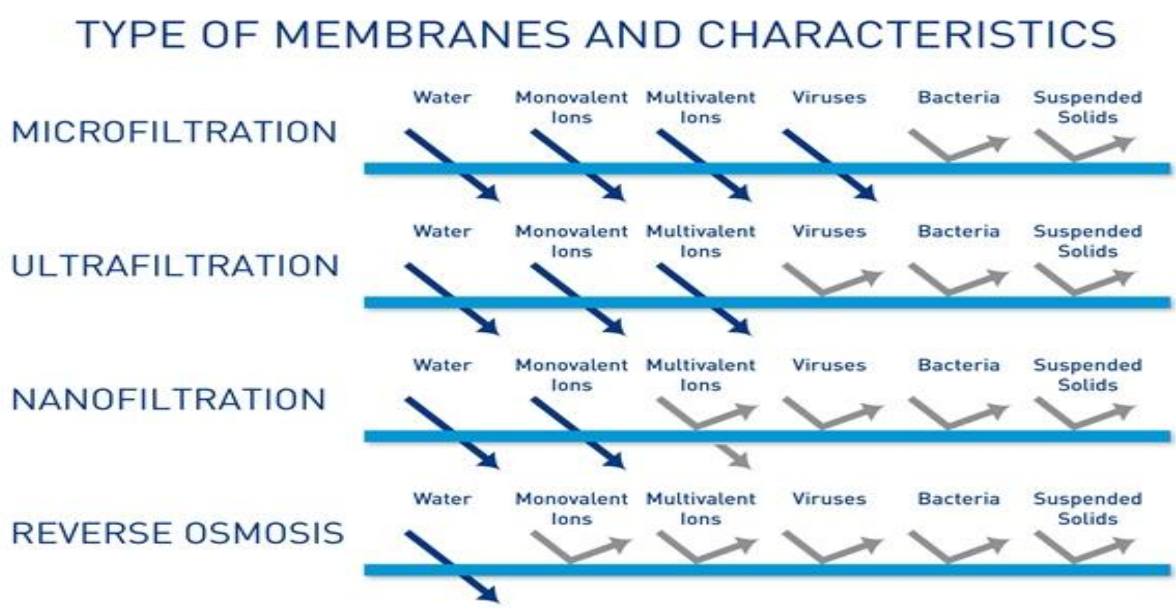
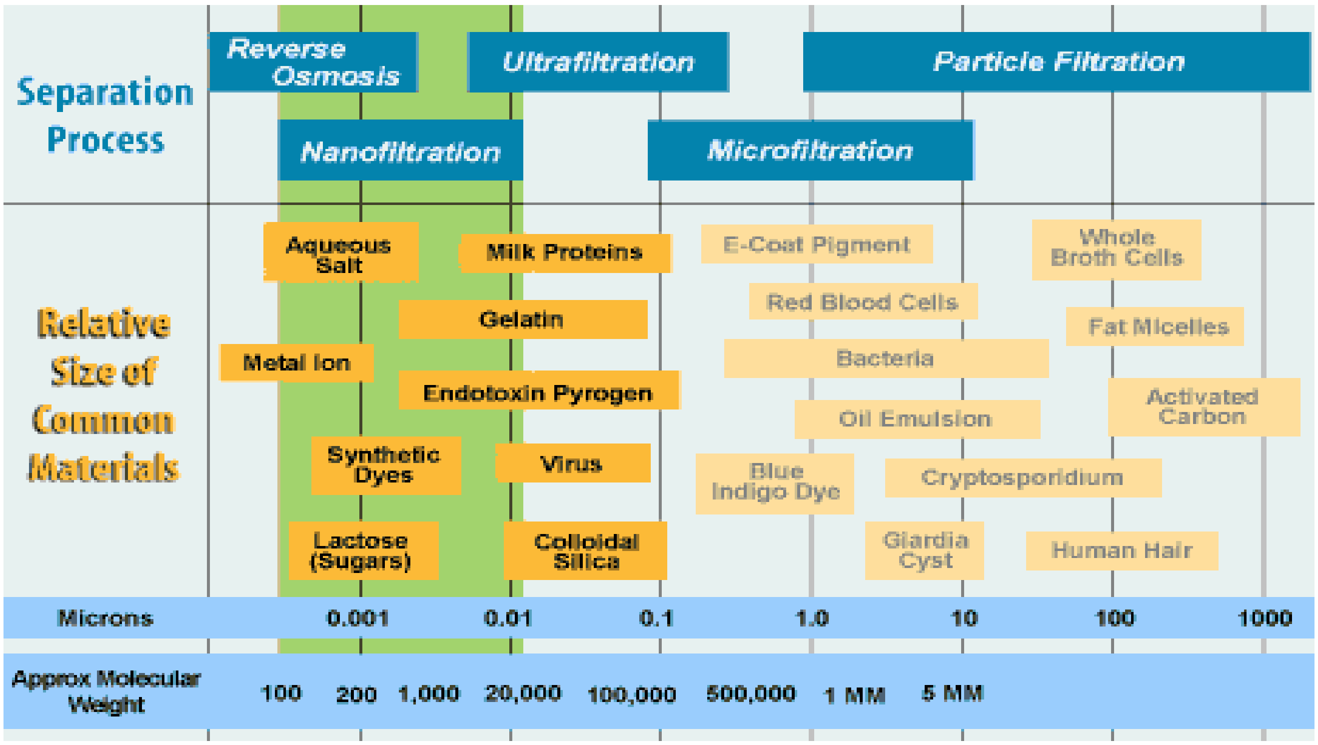


Fig. 1 Types of membrane separations

The various membrane processes have different range of conditions under which they operate as well as the basic principle of drive. However, the heart of the membrane process is the membrane itself. The over view of the various membranes are shown below:

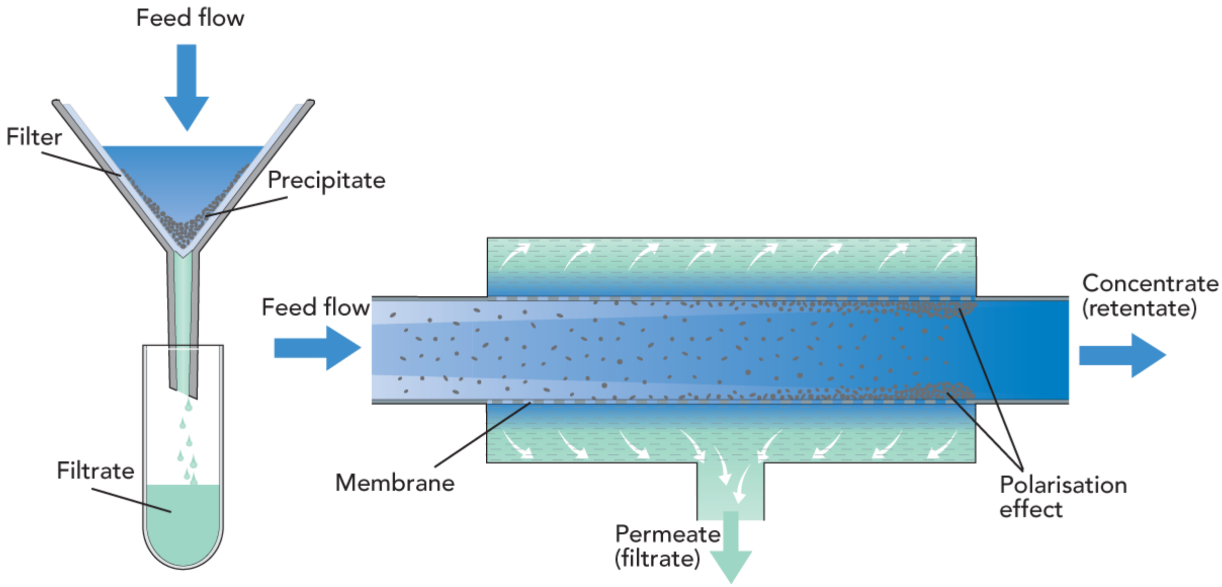


(Table of operating pressure to be given here)

The membrane processing has certain basic terminology, which is common across the various ranges of membrane processes. The important terms are given below:

Membrane: A membrane can be defined as a phase which acts as a barrier to flow of molecular or ionic species between other phases that it separates. It is dry solid, a solvent swollen gel, or a liquid that is immobilized.

Semipermeable membrane: A membrane which allows some molecules to pass and retains other according to their size.



Composite membrane or thin film: Thin filtering layer built on to the support layer and the two layers are of different materials.

Asymmetric Membrane: Chemically of the same material throughout but physically is of different structure on its two sides.

Membrane cut off: Molecular weight above which 100 % (in practice 95%) of a solute is retained by the membrane.

Permeate: The filtrate, the liquid passing through the membrane.

Concentration Factor: The volume reduction achieved by concentration.

Initial volume of feed Final conc. of component retained
---------------------- OR ------------------------------------
Final volume of concentrate Initial conc. of component retained.

Retention Factor: It specifies the ability of a membrane to retain that molecule

$$R= (Cf – Cp / Cf)$$

Where, Cf = Conc. of molecule in feed
Cp = permeate

In Batch process where the concentrations are continually changing, R varies and then the realistic value can be,

$$\mathrm{Ln}\,(C/C_o) = R \ln (V_o/V)$$

Where, C_o = Initial concentration at V_o

C = Conc. at any other volume V

Separation Factor (s) a measure of performance of the membrane in separating solvent and solute.

$$S = C_f / C_p \text{ and } R = 1 - (1/S)$$

S is a concept more appropriate to water purification than milk concentration.

Concentration Polarization: Increase in concentration of solids in the direction towards the membrane due to the extraction of permeates through the membrane.

The rediffusion of concentrated solids back into the feed is governed by Fick's law. This law describes molecular diffusion.

$$J_{AB} - D_{AB}\,(dc_A / dz)$$

Where, J_{AB} = Molar flux of component A in the direction of Z of mixture of AB (kg mol of A/m2 s)

D_{AB} = Molecular diffusivity of component A in component B (m2 / s)

c_A = Concentration of component A (kg mol / m3)

z = distance (m)

Flux: Rate of extraction of permeate, measured in litres/sq. h

The flux or the flow rate in the membrane under laminar flow is governed by Hagen Poiseuille equation. This equation relates the pressure drop, path geometry and viscosity of fluid flowing through membrane under laminar condition.

Where average velocity, pressure drop , D is diameter of μ , viscosity, L length of the pipe

Microfiltration (MF)

Microfiltration is the oldest membrane technology, having been used several decades before the first industrial use of reverse osmosis. However, subsequent development of the technology has been slow. MF is pressure-driven employing pressures considerably lower than others especially reverse Osmosis. In fact the distinction between UF and MF is somewhat arbitrary and there is no distinction on purely theoretical grounds. The distinction lies in the size ranges of the materials which are separated. Particle Size ranges 0.05 – 10 microns in MF. UF is considered to involve the processing of dissolved macromolecules, while MF involves separation of dispersed particles such as colloids, fat globules or cells. MF can be considered to fall between UF and conventional filtration, although there is overlap at both ends of the spectrum.

MF can be useful in:

a. Refining petroleum
b. Treating water for portability
c. Treating wastewater
d. Separating oil/water emulsions
e. Processing dairy products while allowing protein through
f. Sterilizing beverages and pharmaceuticals without sacrificing flavor
g. Microfiltration can also be used to harvest cells from fermentation broth, and, as mentioned above, pretreat water for RO.

Ultra Filtration (UF)

Ultra filtration can be defined as a pressure driven membrane process that can be used in the separation and concentration of substances having a molecular weight between 10^3 – 10^6 Dalton. UF is a process where the high molecular weight component, such as protein, and suspended solids are rejected, while all low molecular weight component pass through the membrane freely. There is consequently no rejection of mono and disaccharides, salts, amino acids, organics, inorganic acids or sodium hydroxide.

Characteristics

Membrane	Asymmetrical
Thickness	150 – 250 μm
Thin film	1 μm
Pore size	0.2 – 0.02 μm
Rejection of	Macro molecules, proteins, polysaccharides vira
Membrane materials	Ceramic, PSO, PVDC, CA, thin film
Membrane module	Tubular, hollow fibre, spiral wound, plate-and-frame
Operating pressure	1-10 bar
Typical flux	30 – 300 lit/m2h

Membrane modules

1. Tubular module

● 18 x12.5 mm perforated stainless steel tubes
● Tubes assembled in a shell-and-tube like construction and connected in series.
● A replaceable membrane insert tube is fitted inside each of the perforated stainless steel pressure support tubes.
● Permeate is collected on the outside of the tube bundle in the stainless steel shroud.

In tubular module with ceramic membrane, the filter element is a ceramic filter. The thin walls of the channels are made of fine-grained ceramic and constitute the membrane. The support material is coarse grained ceramic.

2. Hollow fibre

● Cartridges each having bundles of 45 to over 3000 hollow-fibre elements.
● The fibres are oriented in parallel.
● Fibers are potted in a resin at their ends and enclosed in the permeate-collecting-tube of epoxy.
● The membrane has an inner diameter ranging from 0.5 to 2.7 mm.
● The active membrane surface is on the inside of the hollow fibre.
● The outside of the hollow-fibre wall, has a rough structure and acts as a supporting structure for the membrane.
● The feed stream flows through the inside of these fibres, and permeate is collected outside and removed at the top of the tube.

3. Spiral wound

● Contains one or more membrane envelopes, each of which contains two layers of membrane separated by a porous permeate conductive material.
● *Permeate channel spacer* allows the permeate passing through the membrane to flow freely.
● The two layers of membrane with the permeate channel spacer between them are sealed with adhesive at two edges and one end to form the membrane envelope.
● The open end of the envelope is connected and sealed to a perforated permeate collecting tube.
● The feed channel spacer is placed in contact with one side of each membrane envelope.

4. Plate and frame design

●It consist of membranes sandwiched between membrane support plates arranged in stacks.

●The feed material is forced through very narrow channels that may be configured for parallel flow or as a combination of parallel and serial channels. Polymers used in membrane manufacturing

- Cellulose Acetate
- Polyamide membranes
- Polysulfone membranes
- Ceramic membranes

Fouling of membrane

Fouling is termed as decline in flux when all operating parameters like pressure, flow rate, temperature and feed concentrations are kept constant. It can be avoided by:

- Pretreatment of feed.
- Maintain minimum axial velocity.
- Dynamic pressure of flow should be higher.
- For proteinaceous feed, pH far away from iso- electric point is maintained.

Terms

1. Rejection = 1- (solute conc. in Permeate / solute conc. in Retentate)
2. Volume concentration ratio (VCR) = Initial feed volume / Retentate volume
3. Weight concentration ratio (WCR) = Initial feed weight / Retentate weight
4. Volume reduction % = {1- (1/ VCR)} x 100
5. Flux: The quantity of permeate liquid(Kg or L) per membrane area unit(sq. m) and time unit (h).
6. Transmembrane Pressure: Pressure gradient between Retentate side and permeate side.
7. Retentate: Fraction of feed stream not passing through the membrane.
8. Permeate: Fraction of feed stream passing through the membrane.
9. Hold up volume: volume of concentrate remaining in the module.
10. Concentration polarization (CP): A higher concentration of retained solute species adjacent to the membrane surface than in the bulk stream.

U.F. membrane preparation methods

- Phase inversion
- Thermal inversion
- Dynamic membrane
- Ultrathin composite membranes
- Track – etched membranes

Disadvantages

● As the surface of membrane is not smooth, building of scale leads to idle environment for
bacterial growth.
● The voids provide space for growth of micro-organisms.
● Disassembly of the UF equipment for manual cleaning is not practical due to high surface area involved.
● Membrane materials like cellulose acetate have high sensitivity to several cleaning and sanitizing solutions.

Applications of UF

● Separation and fractionation of individual milk proteins from lactose and minerals.
● Enzyme recovery in various operations like lactose hydrolysis using lactase.
● Fractionation of cheese whey
● Pre – concentration of milk for cheese manufacturing.
● Sugar refining
● Vegetable protein processing. e.g. soy protein
● Animal products industry. e.g. gelatin
● Biotechnology applications
● Fruit juices & other beverages.

REVERSE OSMOSIS

Reverse Osmosis (RO) is the tightest possible membrane process in liquid/liquid separation. Water is in principle the only material passing through the membrane; essentially all dissolved and suspended material is rejected. The more open types of RO membranes are sometimes confused with nanofiltration (NF). Reverse osmosis is a process which separates small molecules and ions (molecular weight less than 1000; molecular size less than 0.001μm) from the solvents. It is a pressure driven membrane system essentially used for dewatering of fluid foods.

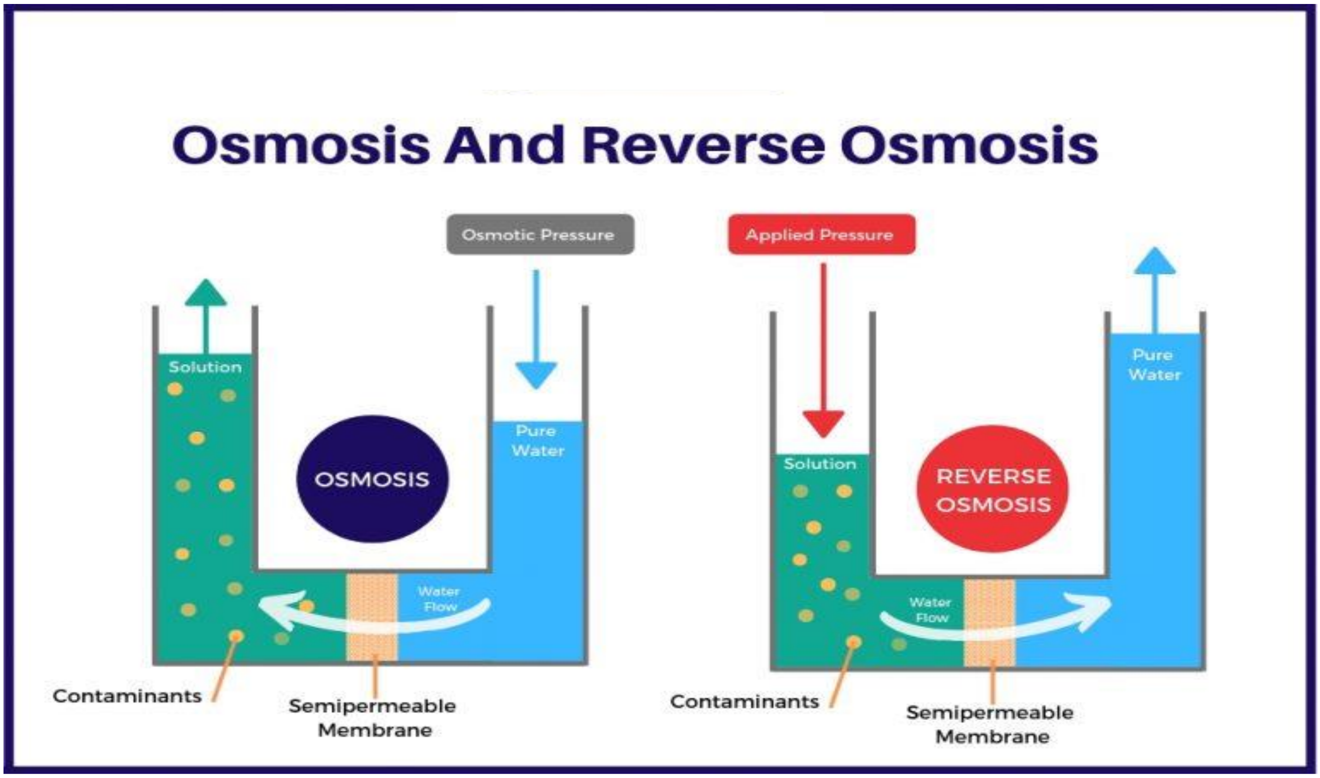


Fig 2 Principle of RO

membrane	asymmetrical
thickness	150 µm
Thin film	1µm
Pore size	< 0.002µm
Rejection of	High molecular weight component Low molecular weight component, Nacl, glucose, amino acid
Membrane materials	CA, thin film
Membrane module	Tubular, spiral wound plate and frame
Operating pressure	15-150 bar
Mechanism of membrane retention	Diffusive transport
Typical flux	3-30 lit/m^2 h

Table 1 Characteristics

Materials for membrane manufacturing

Cellulose acetate

Polymers (polysulphones, polyamides, PVC, polystyrene, polycarbonates, polyethers).

Composite or ceramic membranes (porous carbon, zirconium oxide, alumina).

Terms

● the pressure difference across the membrane (the trans-membrane pressure) is found using:

$$P = \frac{P_f - P_r}{2} - P_p$$

where *P* (Pa) is trans-membrane pressure, *P*f (Pa) is pressure of the feed (inlet), *P*r (Pa) is pressure of the retentate (outlet) (high molecular weight fraction) and *P*p (Pa) is pressure of the permeate (low molecular weight fraction).

• Water flux is measured as:

$$J = KA\ (\Delta P - \Delta\pi)$$

Where, *J* (kg /h) is flux, *K* (kg m-2 h -1 Pa-1) is mass transfer coefficient, *A* (m2) is area of the membrane, Δ*P* (Pa) is applied pressure and ΔΠ (Pa) is change in osmotic pressure.

● Osmotic pressure

$$\Pi = MRT$$

Where, *T* (ºK) is absolute temperature, *R is* universal gas constant, *M is* molar concentration and ΔΠ (Pa) is osmotic pressure.

Advantages

1. The removal of water is accomplished without a change in phase or state of the solvent.
2. The process can be operated at ambient or up to 50°C temperature. Thus thermal degradation of nutrients is minimum.
3. There is negligible loss of volatiles and eating quality.
4. Complicated heat transfer or heat generating equipments are not required.
5. Lower labour and operating costs.

Limitations

1. Variation in the product flow rate when changes occur in the concentration of feed liquor
2. Higher capital costs than evaporation
3. A maximum concentration to 30% total solids

4. Fouling of the membranes (deposition of polymers), which reduces the operating time between membrane cleaning.

Applications

1. Concentration of milk, whey & UF permeate.
2. Preparation of indigenous dairy products like khoa, chakka etc.
3. Concentration and purification of fruit juices, enzymes, fermentation liquors and vegetable oils.
4. Concentration of wheat starch, citric acid, egg white, coffee, syrups, natural extracts and flavours.
5. Clarification of wine and beer.
6. Demineralization and purification of water from boreholes or rivers or by desalination of sea water.

NANOFILTERATION

A nanofiltration filter has a pore size around 0.001 microns. Nanofiltration removes most organic molecules, nearly all viruses, most of the natural organic matter and a range of salts. Nanofiltration removes divalent ions, which make water hard, so nanofiltration is often used to soften hard water.
Nanofilteration membranes reject ions that are divalent such as Ca, Mg and sulfates while allowing passage of monovalent ions such as sodium and chloride. Since NF membrane compositions are less tightly meshed than reverse osmosis membranes, the permeate flow is higher and the pump pressure is lower, thus saving energy.