Paper No. : 04
Paper Title: Unit Operations in Food Processing
Module-25: Membrane Processing: Reverse osmosis and Ultrafiltration

4.1 INTRODUCTION

Understanding the principle behind membrane filtration is a perquisite to membrane processing. The driving force for solvent/water transport in both reverse osmosis (RO) and ultrafiltration (UF) is pressure gradient. In case of RO, the applied osmotic pressure is much greater than the hydraulic pressure. It is this osmotic pressure that causes the transport of water through the membrane. In UF, the osmotic pressure of the solution is negligible compared to the hydraulic pressure and therefore hydraulic pressure drives water transport across the membrane.

The rejected solute accumulated as a thin layer over the membrane surface. Amount of solute deposition is much greater in dead-end flow compared to cross flow type membrane process. This accumulated solute reduces the flux and gradually leads to fouling of the membrane. The concentration of solute increases from bulk of the solution to near the membrane. This phenomenon is termed as concentration polarization. The consequence of concentration polarization is an increasing resistance to flow. This resistance is less in RO. In UF processes, the effects of concentration polarization are more evident.

Performance of a membrane system needs to be evaluated to monitor the proper functioning of the membrane. It is generally evaluated in terms of permeate flux and rejection.

In this module, we will be discussing about the basic principles of operation of RO and UF systems, their functioning, mass transfer kinetics, process calculation and their applications in the food industry.

4.2 REVERSE OSMOSIS

Osmosis refers to the natural flow of solvent from low solute concentration to high solute concentration. This occurs due to difference in chemical potential. The side having higher solute concentration has a lower chemical potential. Thus the solvent flows to equalize the chemical potential on both sides of the membrane. At equilibrium the hydrostatic pressure difference between the two sides is equal to the osmotic pressure. On application of a pressure greater than the osmotic pressure on the salt side, the chemical potential of the water in the solution is increases and it flows to the other side of the membrane to equilibrate the potential. This phenomenon is known as Reverse osmosis.

The amount of salt removed depends on the magnitude of pressure applied. More is the salt concentration more is the pressure required to cause separation of pure water. The water recovered is termed permeate water and it contains very little contaminants. The other stream obtained from the unit is termed the reject stream and it contains all the contaminants that were not allowed to pass by the membrane.

4.2.1 SOLVENT MASS TRANSFER

For reverse osmosis, the applied pressure on the solution side must overcome the osmotic pressure ($\Delta\pi$) across the membrane. The applied pressure is nothing but the transmembrane pressure difference (TMPD).Thus the net applied pressure (NAP) across the membrane may be given by

$$\mathrm{NAP} = \mathrm{TMPD} - \Delta\pi$$

Solvent flux can be expressed as (Baker, 2004)

$$\mathrm{Jw} = \mathrm{Kw}(\mathrm{TMPD} - \Delta\pi)$$

Osmotic pressure may be defined as

$$\pi = \phi \mathrm{CmRT}$$

Here,

Cm=molar concentration of solution

R=gas constant

T=absolute temperature

Φ=dimensionless constant depending upon dissociation of solute.

Assuming total rejection, concentration ratio is given by

$$\frac{C_{retn}}{C_{feed}} = \frac{\mathrm{Qfeed}}{\mathrm{Qfeed} - \mathrm{Qw}} = \frac{\mathrm{Qfeed}}{\mathrm{Qfeed} - \mathrm{AJw}}$$

Where,

C_{feed} and C_{retn} = Concentration of solute in feed and retentate respectively

Q_{feed} and Q_w=volumetric flow rate of feed and permeate.

Kw=similar to hydraulic pressure permeability.

Overall Mass Balance Equation

(Feed flow x Feed Conductivity) = (Permeate Flow x Permeate Conductivity) + (Concentrate Flow*Concentrate Conductivity) area of the membrane

EXAMPLE: An RO system has the following specifications: Feed flow 8 gpm, Permeate Flow 7 gpm, Feed Conductivity 400 µS, Permeate Conductivity 15 µS, Concentrate Flow 3gpm, Concentrate Conductivity 1400 µS. Check the performance of the unit.

Using the mass balance equation,

(8 x 400) = (7 x 15) + (3*1400)

$3200 \neq 4305$

This inequality is due to losses resulting from membrane resistance etc. So the following is calculated,

$A = Difference/Sum * 100$

$= (4305 - 3200)/(3200 + 4305) * 100$

$= 14.7\%$

An A value less than 10% implies proper functioning of the membrane. In this problem, since A is greater than 10 %, it suggests that the membrane needs servicing.

4.2.2 APPLICATIONS OF RO

A major industrial application of reverse osmosis is desalination of brackish and sea water. Deionized and demineralized water is requisite for many industrial applications.RO can be used to substitute evaporation especially when processing foods with heat sensitive components. This is because of the relatively low operating temperatures involved in RO at which browning reactions, volatile loss and loss of heat labile components is minimized. RO has been used as a pre-concentration step in milk and fruit juices before final evaporation step. Apart from improving sensory quality, RO concentration has also been used to reduce transportation cost (by concentration full cream milk, concentration of cheese whey). Concentration of tomato juice, apple juice, pear, peach and apricot has been successfully accomplished using RO.RO has been used for waste and water recovery in corn-milling processes. Egg white concentration to up to 20% has been achieved using RO.

Dealcoholization of wine is another fascinating application of RO. Wine is concentrated by removing ethanol and water by a selective membrane. This wine when diluted yields dealcoholized wine.

4.3 ULTRAFILTRATION

Hydraulic pressure drives material transport in ultrafiltration. As the feed water moves through the semi-permeable membrane under the influence of hydraulic pressure, the solute particles having size greater than the pore size of the membrane are rejected as retentate and the rest of the solution passes as filtrate. The particles retained on the membrane are of the size range 0.01-0.05μm. usually pressures in the range of 20-200psi are used. Molecular weight cutoff of ultrafiltration membranes is 1000-500000 Daltons. Flow rate of liquid is reduced by fouling of the membrane, concentration polarization and gel polarization.

4.3.1 SOLVENT TRANSPORT

Initial movement of solvent is explained by Darcy's law,

$$J = Lp\Delta Ptm$$

Where,

J=permeate flux

Lp=hydraulic permeability

Hydraulic permeability determines the filtration capacity of a membrane.

4.3.2 SOLUTE TRANSPORT

Solute transport can be measured in terms of sieving coefficient and %rejection.

Sieving coefficient, S is given by,

$$S = \frac{Cperm}{Cretn}$$

C_{perm} and C_{retn}=Concentration of the solute in permeate and retentate resspectively

S=0 for total rejection and S=1 for no rejection

Rejection, R is defined as,

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

Usually an R of 95% is considered as total rejection.

4.3.3 CONCENTRATION POLARIZATION AND GEL POLARIZATION

4.3.3.1 Concentration Polarization

The flux through membrane is affected by two phenomena namely: concentration polarization and gel polarization. Concentration polarization refers to the buildup of solute normal to the membrane surface. Solute concentration decreases as we go away from the membrane i.e. concentration of solute near the wall (C_w) is higher compared to the concentration of solute in the bulk of feed (C_f).The solute accumulation near the membrane causes back flow of solvent due to osmotic back pressure and resistance to flow through the membrane.

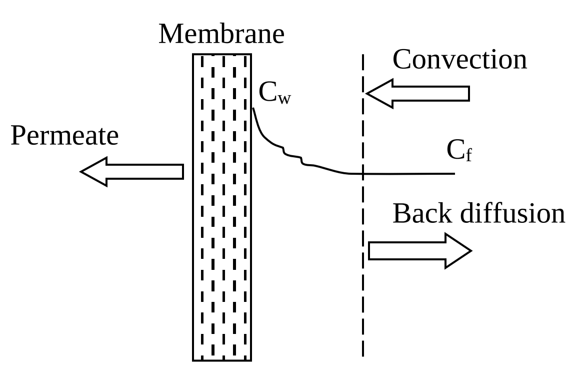

Fig.25.1 Concentration polarization

4.3.3.2 GEL POLARIZATION

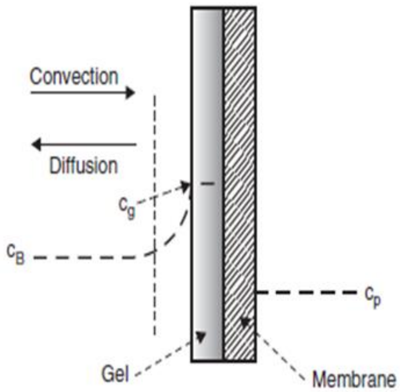

Fig.25.2 Gel polarization (Courtesy: Elsevier Inc.)

The solute concentration in the bulk near the membrane keeps increasing as filtration continues. At certain instant this concentration may attain a maximum value and may not increase further. This phenomenon is called ‘gel polarization’. A maximum value of membrane flux is obtained at this point.

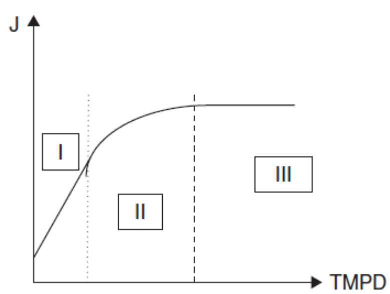

Fig.25.3 Flux as a function of pressure difference (Courtesy: Elsevier Inc.)

The relationship of permeate flux with transmembrane pressure difference can analyzed using the given graph. Phase I depicts the linear(Darcy)region, Phase II represents deviation in ideal behavior due to concentration polarization and phase III is the effect of gel polarization on flux.

4.3.4 APPLICATIONS OF UF

The following applications illustrate the potentiality of ultrafiltration.

In milk industry, Ultrafiltration has been used to concentrate why produced as a byproduct of cheese production. Cheese whey contains 10–12% protein (dry weight). The concentrates are then dried to produce high protein powders (concentrates and isolates) which can be used as supplements for body building foods. UF has also been used for production of yoghurt and fermented products by concentration of milk. Concentration full cream milk by UF has been used as a preprocessing step to cheese making. Ultrafiltration is an extremely valuable method of concentrating and recovering many the minor components, particularly enzymes from raw milk, many of which would be inactivated by pasteurization. UF also finds applications in recovery of heat sensitive components like proteins from milk.

In oilseeds and vegetable industry, UF can be beneficially used improving soy quality by removal of low molecular peptides from soy, removal of toxic components like phytate and trypsin inhibitor from protein,

In meat and poultry industry, UF has been used to commercially concentrate egg white which is used in baking industry. In slaughter houses blood and waste water has been used to concentrate protein which has good functional properties like gelation, emulsification and foaming.

References

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