Lecture 5: Membrane Processes Technology in water treatment (Part II)

Water Treatment Technology

Water Resources Engineering
Civil Engineering
ENGC 6305

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Reverse Osmosis Treatment (RO)

1. Principles of Reverse Osmosis

A. Osmosis:

Osmosis is the natural passage or diffusion of a solvent such as water through a semi-permeable membrane from a week solution to a stronger solution. This natural phenomena is explained in many ways as follows:

- The movement is due to the difference in the vapor pressure of the two solutions separated by the membrane. The vapor pressure of the pure solvent is higher than that of the solution with dissolved solids. Thus the solvent moves from the higher pressure to the lower pressure side.
- Others say that the solvent moves from the less concentrated (higher-potential) solution to the more concentrated (lower-potential) one to reduce the solution concentration.

Reverse Osmosis Treatment (RO)

§ The solvent continues to move and water rises in the concentrated solution side to a level with a hydrostatic pressure ($\Delta\pi$) equivalent to the difference in vapor pressure of two solutions. At this level the system is said to be at equilibrium.

§ ($\Delta\pi$) is called the Osmotic Pressure. Osmotic pressure is the driving force for osmosis to occur. The osmotic pressure of a solvent depends on many factors such as the characteristics of the solvent, the dissolved solids concentration, and temperature.

§The osmotic pressure of any solution can be approximated by the following equation:

$$\boxed{p = cRT}$$

Where, c = summation of the molar concentration of the dissolved ions

R = Universal gas constant

T = Temperature in degrees Kelvin.

Figures 5.1 and 5.2 describe this phenomena.

Osmosis

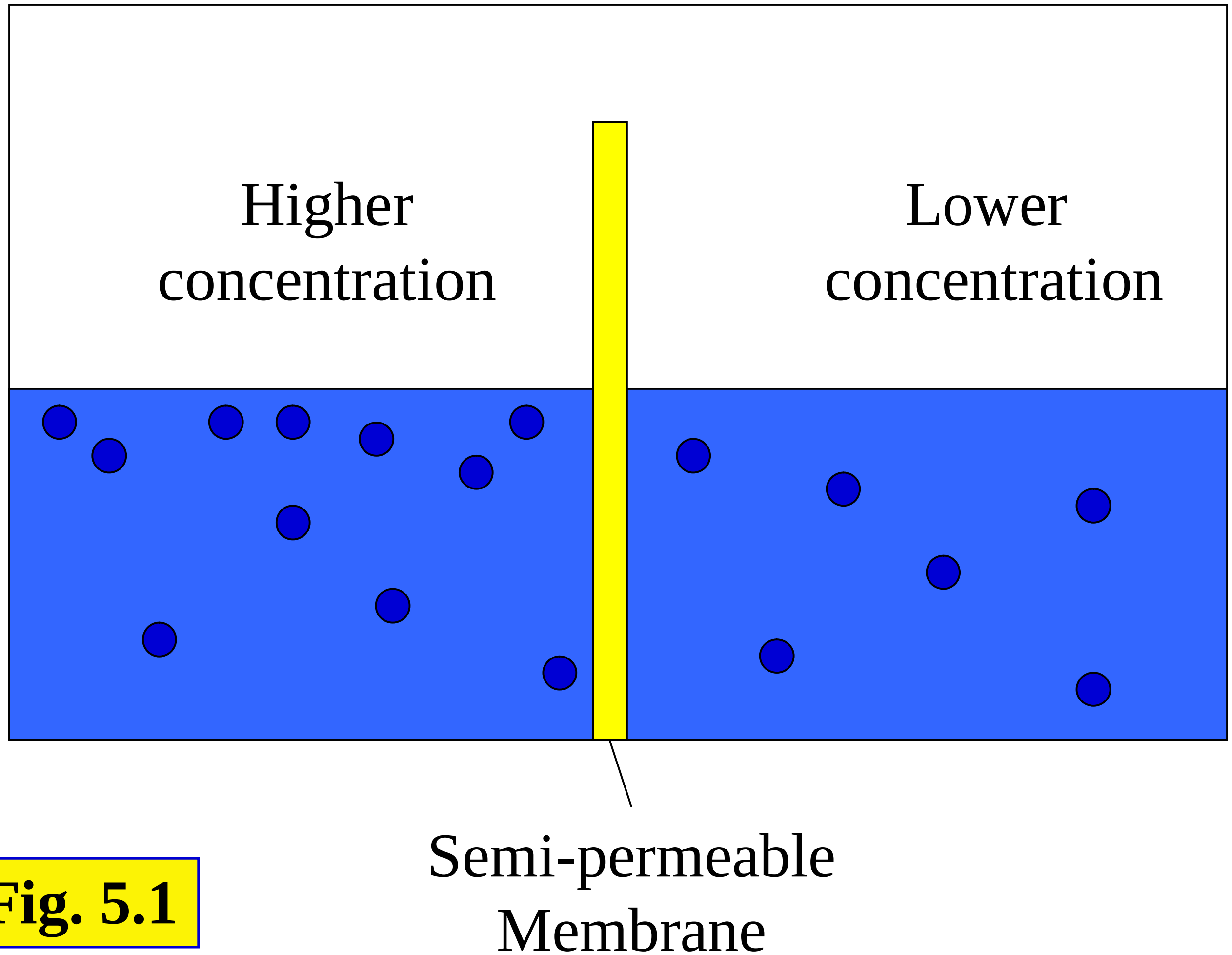


Fig. 5.1

Osmosis

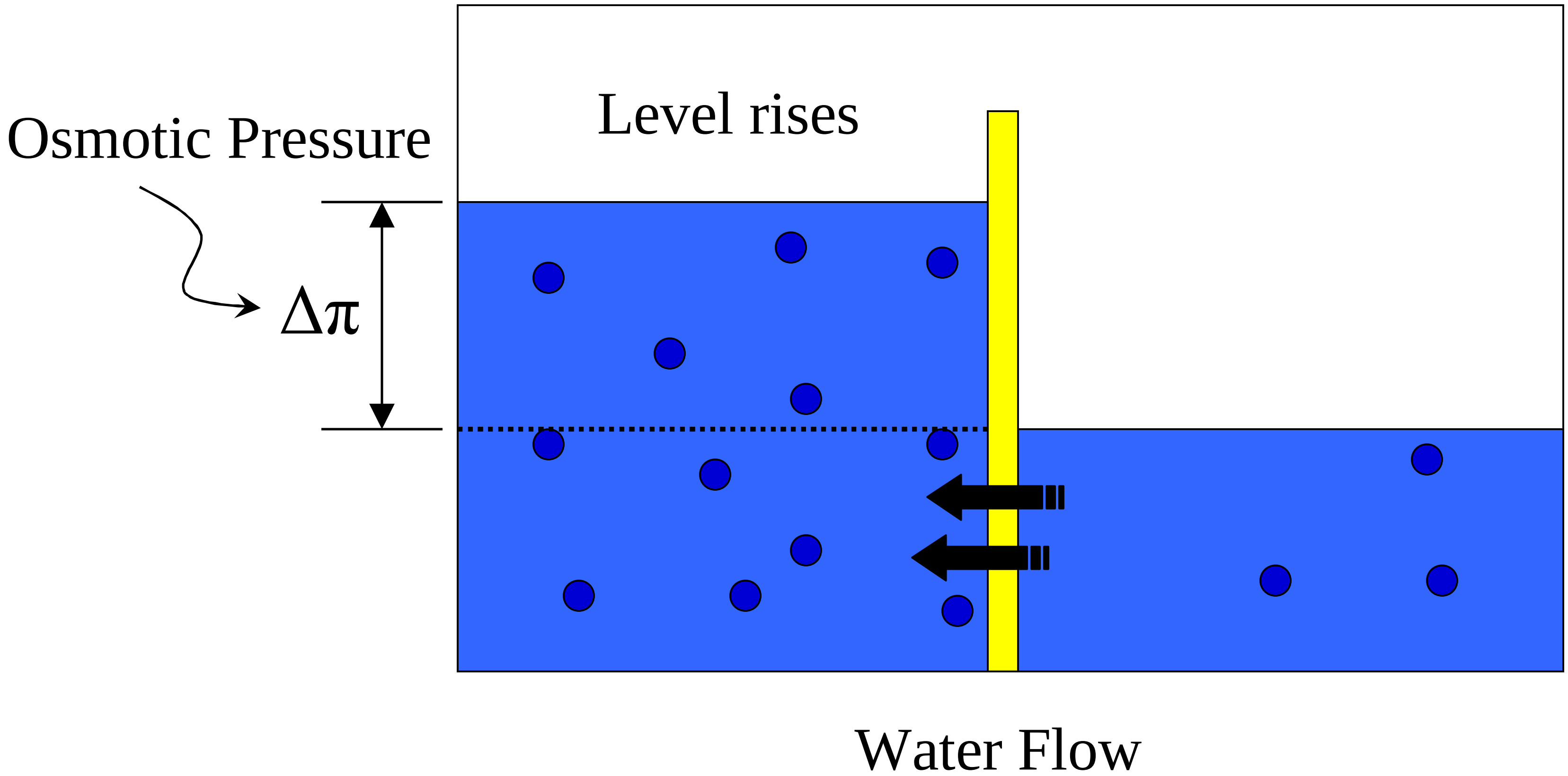


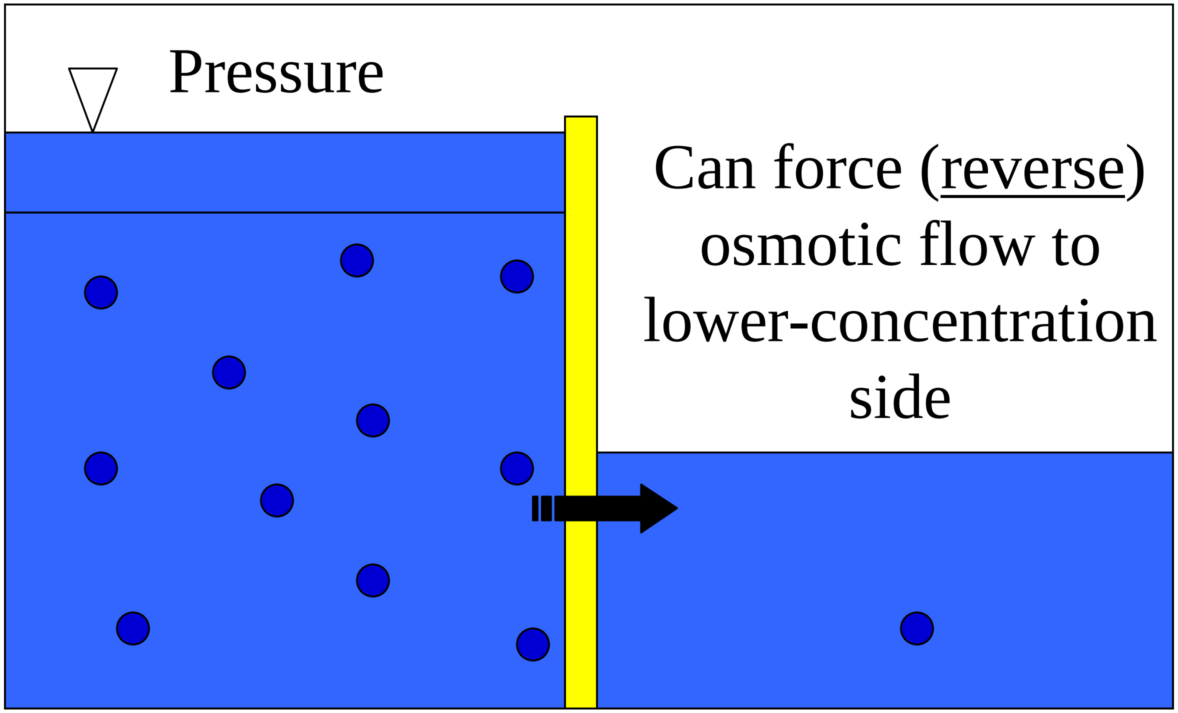
Fig. 5.2

Reverse Osmosis Treatment (RO)

B. Reverse Osmosis (RO):

- Reverse Osmosis is the forced passage of a solvent (e.g. water) through a membrane against the natural osmotic pressure to accomplish separation of the solvent from a solution of dissolved solids.
- If a pressure equal to the Osmotic pressure ($\Delta\pi$) is applied to the side of higher salt content, the water flow from lower to higher salt concentration will stop. If an additional pressure is exerted the water flow will be reversed and to the direction from high to low salt concentration producing fresh water.
- The membrane allow the passage of the solvent while blocking the passage of salt ions. The salt ions or the dissolved matter are called Solutes. However, some salts move with water since each membrane has a rejection efficiency that is less than 100%.
- Figures 5.3 and 5.4 illustrate the RO process .

Reverse Osmosis



Semi-permeable Membrane

Fig. 5.3

Reverse Osmosis Applied

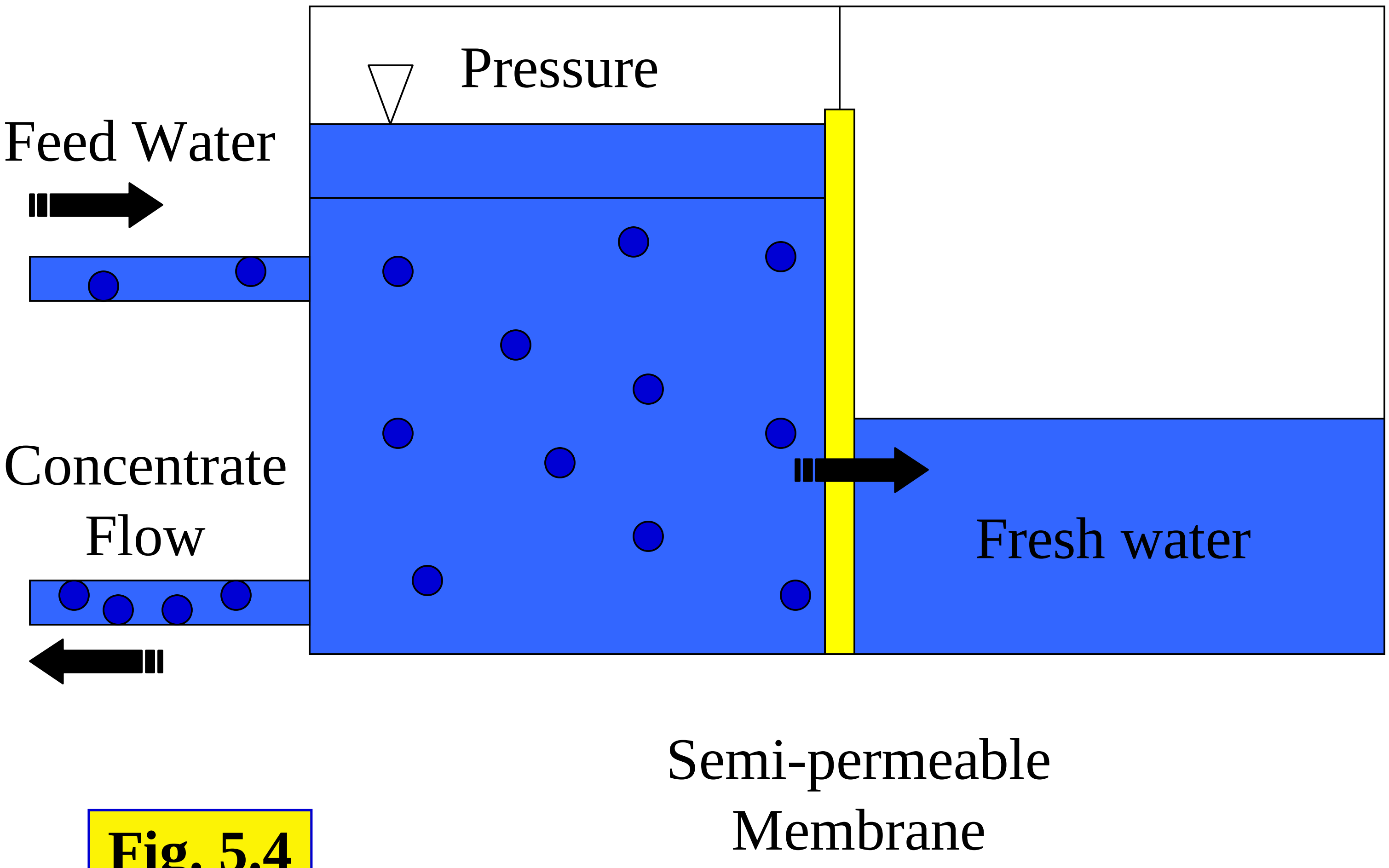
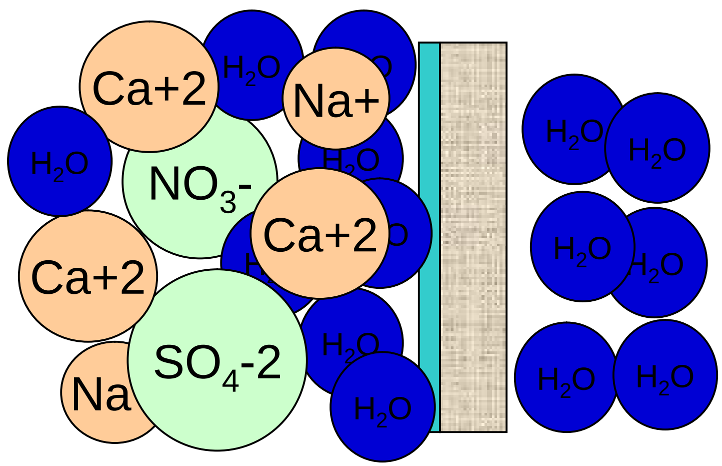


Fig. 5.4

Reverse Osmosis Treatment (RO)



Dissolved Solids Removal (>96% Sodium Rejection)

Reverse Osmosis (RO) Membrane

Fig 5.5

Example 5.1

The molar concentration of the major ions in a brackish groundwater supply are as follows: Na^+, 0.02; Mg^{2+}, 0.015; Ca^{2+}, 0.01; K^+, 0.001; Cl^-, 0.025; HCO_3^-, 0.001; NO_3^-, 0.02; and SO_4^{2-}, 0.012.

(*a*) What would be the approximate osmotic pressure difference across a semipermeable membrane that had brackish water on one side and mineral-free water on the other, assuming the temperature is 25°C?

The molar concentration of particles in the brackish water is

$$c = 0.02 + 0.015 + 0.01 + 0.001 + 0.025 + 0.001 + 0.002 + 0.012$$
$$= 0.086 \text{ M}$$

From Eq. (3.24)

$$\pi = cRT = \frac{0.086 \text{ mol}}{\text{liter}} \times \frac{0.08206 \text{ L}-\text{atm}}{\text{K}-\text{mol}} \times (273 + 25) \text{ K}$$
$$= 2.10 \text{ atm or } 30.3 \text{ pounds per square inch (psi)}$$

(*b*) If in part (*a*), a yield of 75 percent fresh water were desired, what minimum pressure would be required to balance the osmotic pressure difference that will develop?

For a 75 percent yield, the salts originally present in four volumes of brackish water would be concentrated in one volume of brackish water left behind the membrane after three volumes of fresh water have passed through the membrane. Thus, the molar concentration of salt in the brackish water would be four times that of the original brackish water or 0.344 M. Then,

$$\pi = 0.344 \times 0.08206 \times 298 = 8.41 \text{ atm or } 124 \text{ psi}$$

At this point the pressure required to push the fresh water through the membrane would be in excess of 124 psi.

Reverse Osmosis Treatment (RO)

2. Mathematical model

- Many mathematical models have been developed to describe the membrane systems including RO.
- These models describe the solvent (e.g. water) flux and the solute flux (i.e. dissolved salts) through membrane.
- Figure 5.5 is a definition sketch of the membrane system.
- The following pages give the most common model used to describe the membrane treatment system.

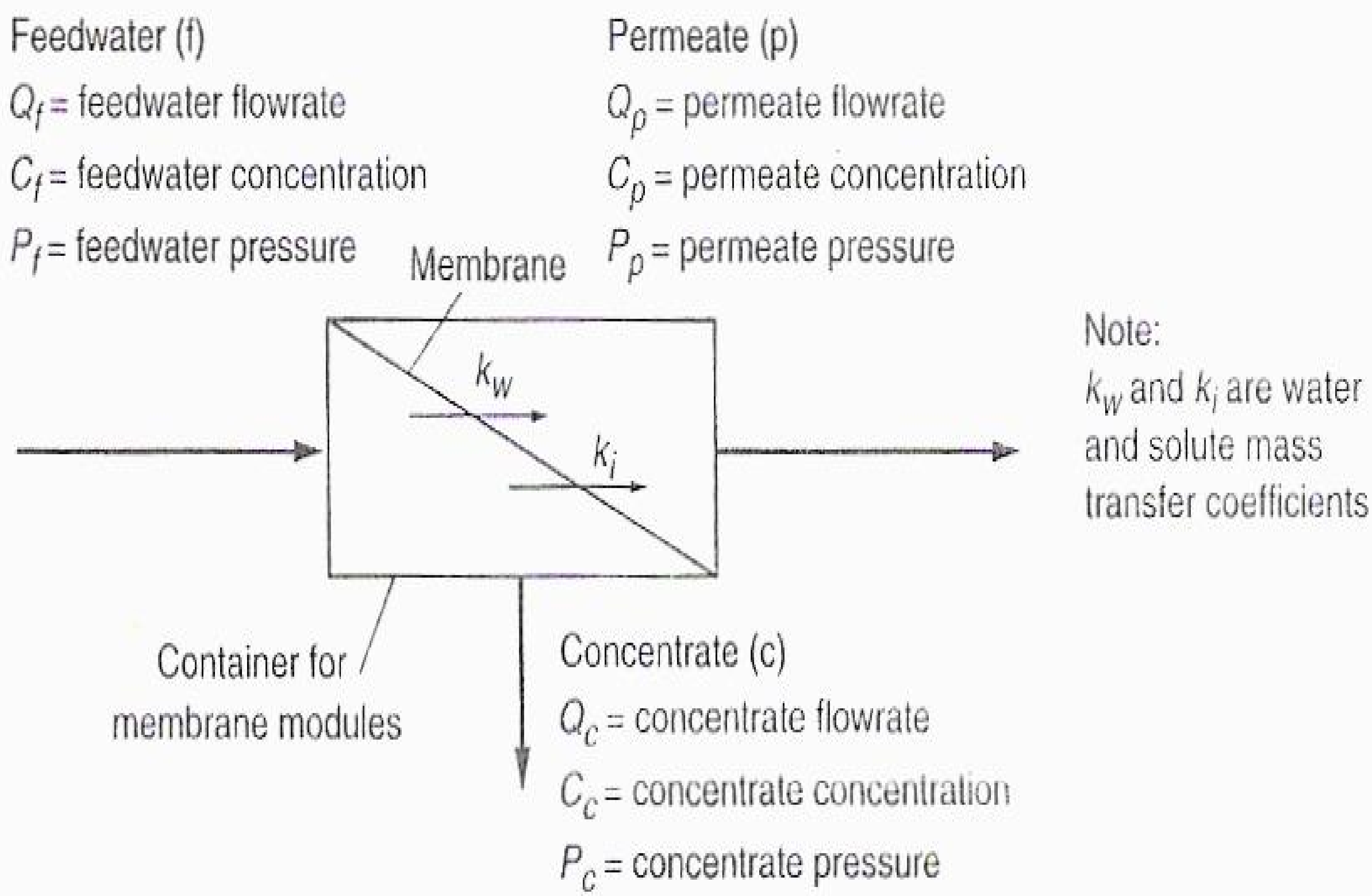


Fig. 5.5 **Definition sketch for a membrane process such as RO**

Reverse Osmosis Treatment (RO)

Water flux through the membrane as a function of pressure gradient:

$$F_w = k_w(\Delta P_a - \Delta\pi) \quad \ldots\ldots\ldots\ldots\ldots(5.1)$$

$$F_w = \frac{Q_p}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.2)$$

$$\Delta P_a = \left[\frac{P_f + P_c}{2}\right] - P_p \quad \ldots\ldots\ldots\ldots(5.3)$$

where F_w = water flux rate, $kg/m^2.s$

k_w = water mass transfer cofficient involving temperature, membrane charcteristics, and solute characteristics, s/m

ΔP_a = averge imposed pressure grdient, kPa

$\Delta\pi$ = osmatic pressure gradient, kPa

Q_p = permeate stream flow, kg/s

A = membrane area, m^2

P_f = feed water pressure, kPa

P_p = permeate pressure, kPa

P_c = concentrate pressure, kPa

Reverse Osmosis Treatment (RO)

Solute flux through the membrane :

$$F_i = k_i \, \Delta C_i \text{.......... ....}(5.4)$$

$$F_i = \frac{Q_p C_p}{A} \text{ ....}(5.5)$$

$$\Delta C_i = \left[\frac{C_f + C_c}{2}\right] - C_p \text{ ....}(5.6)$$

$$r = \frac{Q_p}{Q_f} X \ 100 \text{ ....}(5.7)$$

$$R = \left[\frac{C_f - C_p}{C_f}\right] X \ 100 \text{ ....}(5.8)$$

where $F_i = \textit{flux of solute species } (i)$, $\text{kg/m}^2.\text{s}$

$k_i = \textit{solute mass transfer cofficient}$, m/s

$\Delta C_i = \textit{solute concentration grdient}$, kg/m^3

$C_f = \textit{solute concentrtion in feed stream}$, kg/m^3

$C_c = \textit{solute concentrtion in concentrate stream}$, kg/m^3

$C_p = \textit{solute concentrtion in permeate stream}$, kg/m^3

$r = \textit{water}$ recovery $\textit{rate}$, %

$R = \textit{Solute rejection rate}$, %

Reverse Osmosis Treatment (RO)

3. Rejection efficiency of RO treatment

- Table 5.1 shows the rejection efficiency of two different RO membranes for various dissolved salts, organic matter and microorganisms.
- It is noticed that RO has a very high efficiency of inorganic chemicals.
- However, it also has a very high efficiency in removing dissolved organic matter as shown in the table 90-99%, but it is preferred to remove these materials using other methods such as carbon adsorption. This is due to the fouling nature of organic matter.
- RO is capable of removing more than 99% of microorganisms.

Table 5.1

RO Contaminant Rejection efficiency

Inorganics	CTA Rejection	TFC Rejection	inorganic	CTA Rejection	TFC Rejection
Sodium	85-90%	90-95%	Fluoride	85-90%	90-95
Calcium	90-95%	93-98%	Phosphate	90-95%	93-98%
Magnesium	90-95%	93-98%	Chromate	85-90%	90-95%
Potassium	85-90%	90-95%	Cyanide	85-90%	90-95%
Iron	90-95%	93-98%	Sulfate	90-95	93-98%
Manganese	90-95%	93-98%	Boron	30-40%	55-60%
Aluminum	90-95%	93-98%	Arsenic+3	60-70%	70-80%
Copper	90-95%	93-98%	Arsenic+5	85-90%	93-98%
Nickel	90-95%	93-98%	Selenium	90-95%	93-98%
Zinc	90-95%	93-98%	Radioactivity	90-95%	93-98%
Strontium	90-95%	93-98%	**Biological&Particles**		
Cadmium	90-95%	93-98%	Bacteria	>99%	>99%
Silver	90-95%	93-98%	Protozoa	>99%	>99%
Mercury	90-95%	93-98%	Amoebic Cysts	>99%	>99%
Barium	90-95%	93-98%	Giardia	>99%	>99%
Chromium	90-95%	93-98%	Asbestos	>99%	>99%
Lead	90-95%	93-98%	Sediment/Turbidity	>99%	>99%
Chloride	85-95%	90-95%	**Organics**		
Bicarbonate	85-90%	90-95%	Organics MW>300	>90%	>99%
Nitrate	40-50%	85-90%	Organics MW<300	0-90%	0-99%

CTA- Cellulose Membrane , TFC- Thin Film Composite, All rejections nominal for 60 psi net pressure and at 77ºF

Reverse Osmosis Treatment (RO)

Example 5.2

Determination of Membrane Area Required for Demineralization A brackish water having a TDS concentration of 3000 g/m^3 is to be desalinized using a thin-film composite membrane having a flux rate coefficient k_w of 1.5×10^{-6} s/m and a mass transfer rate coefficient k_i of 1.8×10^{-6} m/s. The product water is to have a TDS of no more than 200 g/m^3. The flowrate is to be 0.010 m^3/s. The net operating pressure $(\Delta P_a - \Delta\Pi)$ will be 2500 kPa. Assume the recovery rate will be 90 percent. Estimate the rejection rate and the concentration of the concentrate stream.

Solution

1. The problem involves determination of the membrane area required to produce 0.010 m^3/s of water and the TDS concentration of the permeate. If the permeate TDS concentration is well below 200 g/m^3, blending of feed and permeate will reduce the required membrane area.
2. Estimate membrane area using Eq. (11–43).

$$F_w = k_w(\Delta P_a - \Delta\Pi)$$

$$= (1.5 \times 10^{-6}\ \text{s/m})(2500\ \text{kg/m}^2) = 3.75 \times 10^{-3}\ \text{kg/m}^2\cdot\text{s}$$

$$Q_p = F_w \times A$$

$$A = \frac{(0.010\ \text{m}^3/\text{s})(10^3\ \text{kg/m}^3)}{(3.75 \times 10^{-3}\ \text{kg/m}^2\cdot\text{s})} = 2667\ \text{m}^2$$

Reverse Osmosis Treatment (RO)

Example:5.2..cont'd

3. Estimate permeate TDS concentration using Eq. (11–44).

$$F_i = k_i \Delta C_i = \frac{Q_p C_p}{A}$$

$$Q_p C_p = k_i\left(\left[\frac{C_f + C_c}{2}\right] - C_p\right)A$$

Assume $C_c \approx C_f$ and solve for C_p

$$C_p = \frac{k_i A C_f}{Q_p + k_i A}$$

Assume $Q_p = r\, Q_f$

$$C_p = \frac{(1.8 \times 10^{-6}\ \mathrm{m/s})(2667\ \mathrm{m^2})(3.0\ \mathrm{kg/m^3})}{(0.01)(0.9) + (1.8 \times 10^{-6}\ \mathrm{m/s})(2667\ \mathrm{m^3})} = 0.152\ \mathrm{kg/m^3}$$

The permeate solute concentration is lower than necessary. It may be possible to reduce the area by blending.

4. Estimate the rejection rate using Eq. (11–40)

$$R, \% = \frac{C_f - C_p}{C_f} \times 100$$

$$R = \frac{(3.0\ \mathrm{kg/m^3} - 0.152\ \mathrm{kg/m^3})}{(3.0\ \mathrm{kg/m^3})} \times 100 = 95\%$$

5. Estimate the concentrate stream TDS using Eq. (11–42)

$$C_c = \frac{Q_f C_f - Q_p C_p}{Q_c}$$

$$C_c = \frac{(0.1\ \mathrm{L})(3.0\ \mathrm{kg/m^3}) - (0.9\ \mathrm{L})(0.152\ \mathrm{kg/m^3})}{0.1\ \mathrm{L}} = 31.4\ \mathrm{kg/m^3}$$

Reverse Osmosis Treatment (RO)

Example 5.3

Estimate Quantity and Quality of Waste Streams from a Reverse Osmosis Facility Estimate quantity and quality of the waste stream, and the total quantity of water that must be processed, from a reverse osmosis facility that is to produce 4000 m^3/d of water to be used for industrial cooling operations. Assume that both the recovery and rejection rates are equal to 90 percent and that the concentration of the feed stream is 400 g/m^3.

Solution

1. Determine the flowrate of the concentrated waste stream and the total amount of water that must be processed.
   a. Combining Eqs. (11–41) and (11–39) results in the following expression for the concentrate stream flowrate:

$$Q_c = \frac{Q_p(1-r)}{r}$$

   b. Determine the concentrate stream flowrate.

$$Q_c = \frac{(4000\ \mathrm{m^3/d})(1-0.9)}{0.9} = 444\ \mathrm{m^3/d}$$

   c. Determine the total amount of water that must be processed to produce 4000 m^3/d of RO water. Using Eq. (11–41), the required amount of water is

$$Q_f = Q_p + Q_c = 4000\ \mathrm{m^3/d} + 444\ \mathrm{m^3/d} = 4444\ \mathrm{m^3/d}$$

Reverse Osmosis Treatment (RO)

Example 5.3.. Cont'd

2. Determine the concentration of the permeate stream. The permeate concentration is obtained by writing Eq. (11–40) as follows:

$$C_p = C_f(1 - R) = 400 \text{ g/m}^3 (1 - 0.9) = 40 \text{ g/m}^3$$

3. Determine the concentration of the concentrated waste stream. The required value is obtained by solving Eq. (11–42):

$$C_c = \frac{Q_f C_f - Q_p C_p}{Q_c}$$

$$C_c = \frac{(4444 \text{ m}^3/\text{d})(400 \text{ g/m}^3) - (4000 \text{ m}^3/\text{d})(40 \text{ g/m}^3)}{(444 \text{ m}^3/\text{d})}$$

$$C_c = 3643 \text{ g/m}^3$$

Reverse Osmosis Treatment (RO)

4. Checking the need for pretreatment:

- As mentioned in the previous lecture, a very high quality feed water is required for efficient operation of RO.
- RO membrane may be fouled by many ways, such as colloidal mater, bacterial activity, iron and manganese, chlorine, scale for chemical precipitation such as calcium carbonate.
- Many parameters have been used to assess the need for pretreatment of feed water before the RO units. The most common indexes are the silt density index (SDI), and the modified fouling index (MFI).
- Fouling indexes are determined from simple membrane tests. The samples are passed through a 0.45μm Millipore filter at a gage pressure of 210 kPa . The time needed for the test varies between 15min-2hr depending on the fouling nature of the water. The same equipment is used for the two indexes.
- The equation of the SDI :

Reverse Osmosis Treatment (RO)

$$\mathrm{SDI} = \frac{100\left[1 - \dfrac{t_i}{t_f}\right]}{t}$$

whre t_i = time to collect initial sample of 500 ml

t_f = time to collect final sample of 500 ml

t = total time for running the test

§ Approximate values for fouling indexes:

Membrane	Fouling index SDI	Fouling index MFI, s/L^2
RO hollow fiber	0-2	0-2
RO spiral wound	0-3	0-2

§ The equation of the MFI :

$$\frac{1}{Q} = a + \mathrm{MFI}\ X\ V$$

where Q = averageflow, L/s

a = constan

MFI = modifiedfoulingindex, s/L^2

V = volume of water filterd in the test

§ see example 5.4

Reverse Osmosis Treatment (RO)

Example 5.4

Silt Density Index for Reverse Osmosis Determine the silt density index for a proposed feedwater from the following test data. If a spiral-wound RO membrane is to be used, will pretreatment be required?

Test run time = 30 min

Initial 500 mL = 2 min

Final 500 mL = 10 min

Solution

1. Calculate the SDI using Eq. (11–45).

$$SDI = \frac{100[1 - (t_i/t_f)]}{t}$$

$$SDI = \frac{100[1 - (2/10)]}{30} = 2.67$$

2. Compare the SDI to the acceptable criteria.

Comment Calculated SDI value of 2.67 is less than 3 (see Table 11–19); therefore, no further pretreatment would be needed normally. As a practical matter, because the SDI value is close to 3.0 it may be prudent to consider some form of pretreatment to prolong the filtration cycle.

Electrodialysis treatment (ED)

1. Principles of Electrodialysis:

- Electrodialysis is a membrane treatment method in which the driving force is electromotive force. This is the main difference between this technology and other technologies such as RO,MF,UF, and NF in which hydrostatic pressure is the driving force.
- In electrodialysis ionic components of a solution are separated through the use of a semipermeable ion-selective membranes.
- Figure 5.6 illustrates the configuration of a one cell stack electrodialysis unit.
- The cell has two membranes one is cation permeable and the other is anion permeable. The cell is placed inside the stack in addition to two electrodes are on is Anode(+) and one is Cathode (-).
- The water is introduced to the cell and to the Anode and Cathode compartments.
- When a Direct Current (DC) power supply is connected to the electrodes, a direct current passes through water between the electrodes.
- Positively charged ions (cations) migrate towards the Cathode, and negatively charged ions (anions) migrate towards the Anode.

Electrodialysis treatment (ED)

- The cations can pass through the cation-permeable membranes but they are rejected by the anion-permeable membrane.
- In a similar manner, the anions can pass through the anion-permeable membranes but they are rejected by the cation-permeable membrane.
- As a result the water in the **treatment cell** is cleared from most of the ions, and the resulting product is called the treated water stream. The removed ions are concentrated in the adjacent compartments or concentrate cells and the resulting product is called the concentrate or brine stream.

For stacks with more than on treatment cell as in Figure 5.7, alternate cells or compartments are formed. Each treatment cell is surrounded by adjacent concentrate cell. In Figure 5.7 we have 3 treatment cells and 4 concentrate cells. So the number of concentrate cell is always one cell more than the treatment cells. The number of membranes used in one electrodialysis stack is twice as the number of cells. Half of the membranes is anion-permeable and the other half is cation-permeable.

- Treatment cells in one stack is connected in parallel to meet the flow requirements. Electrodialysis stacks maybe connected in series to increase the treatment efficiency.

Electrodialysis treatment (ED)

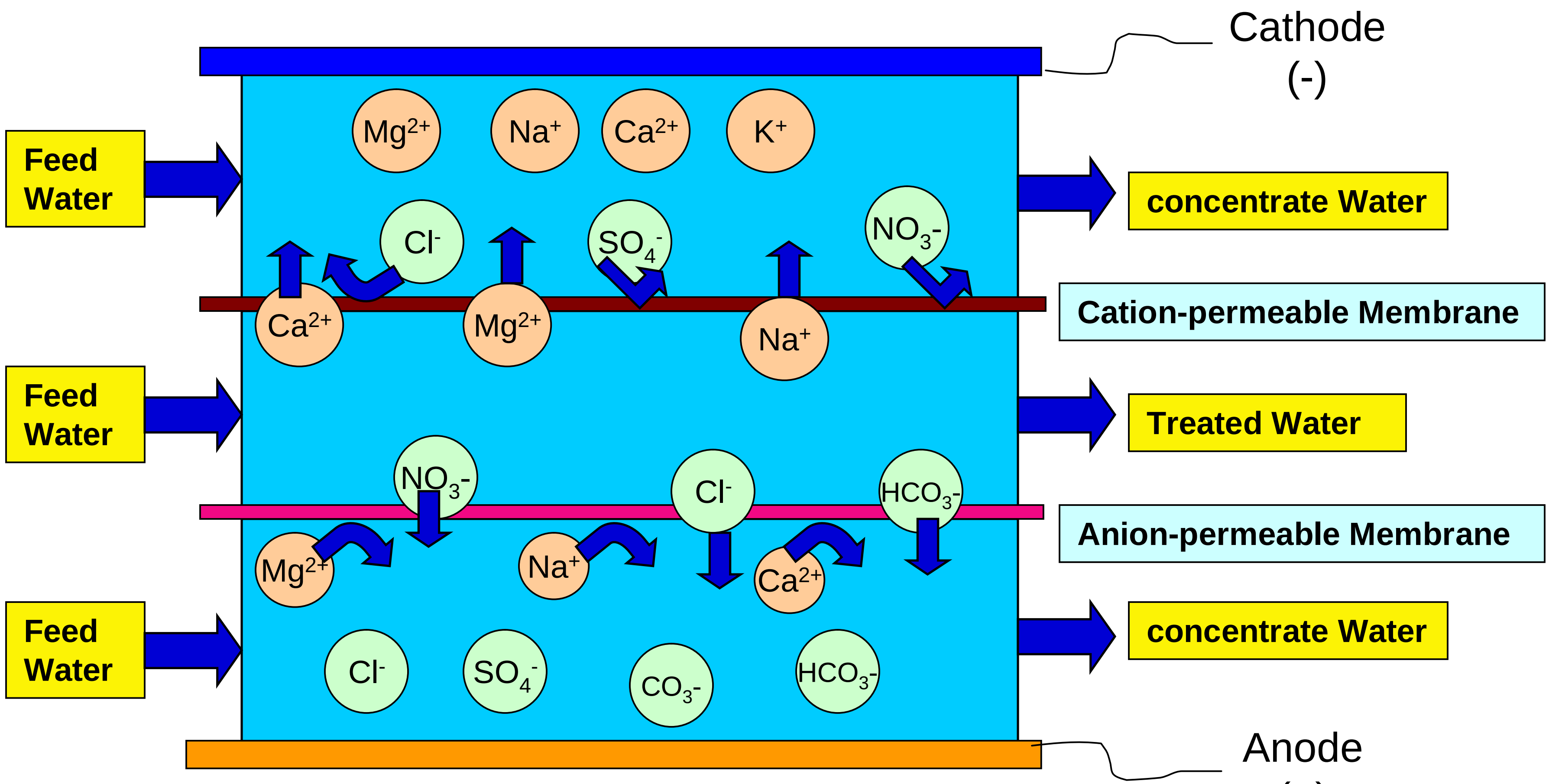


Fig. 5.6 Schematic of Electrodialysis process

Electrodialysis treatment (ED)

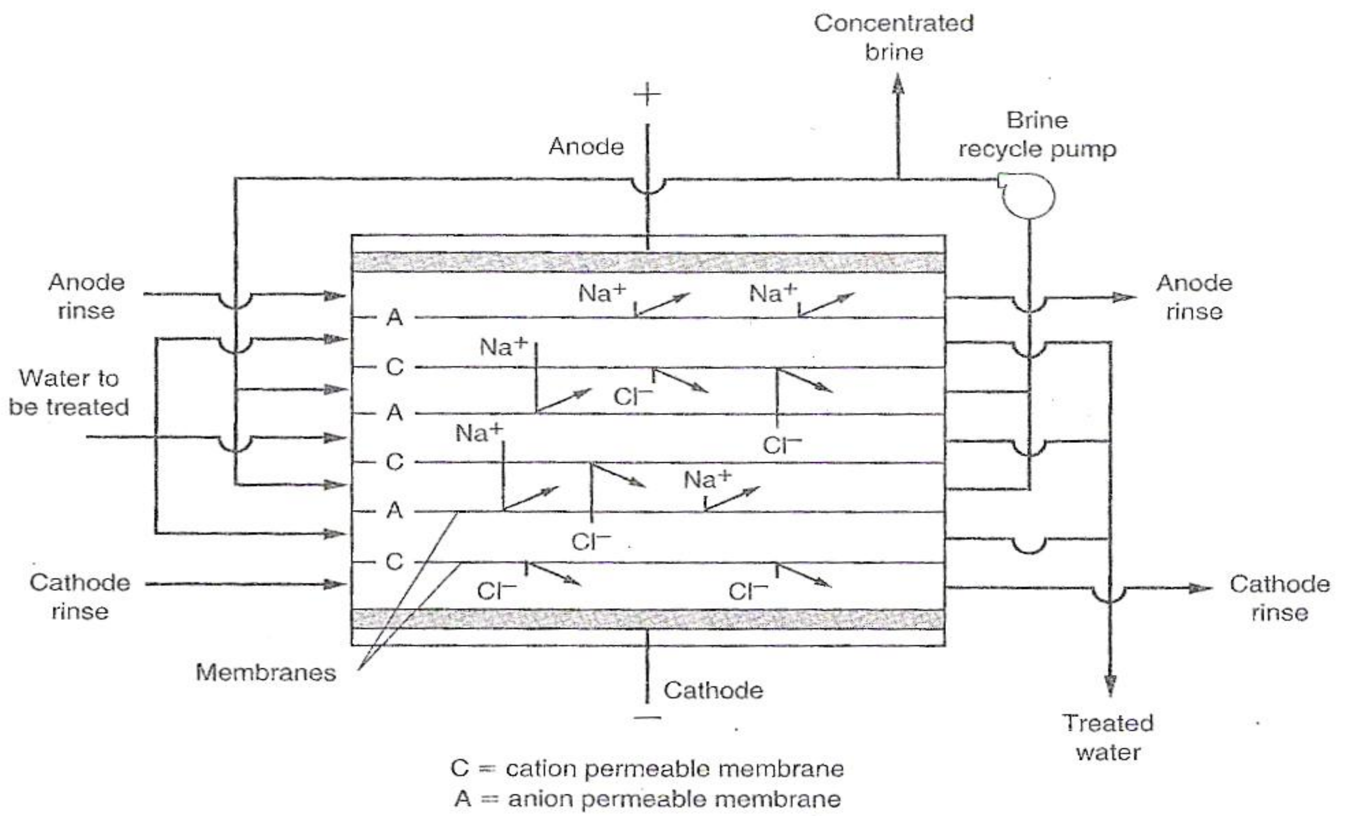


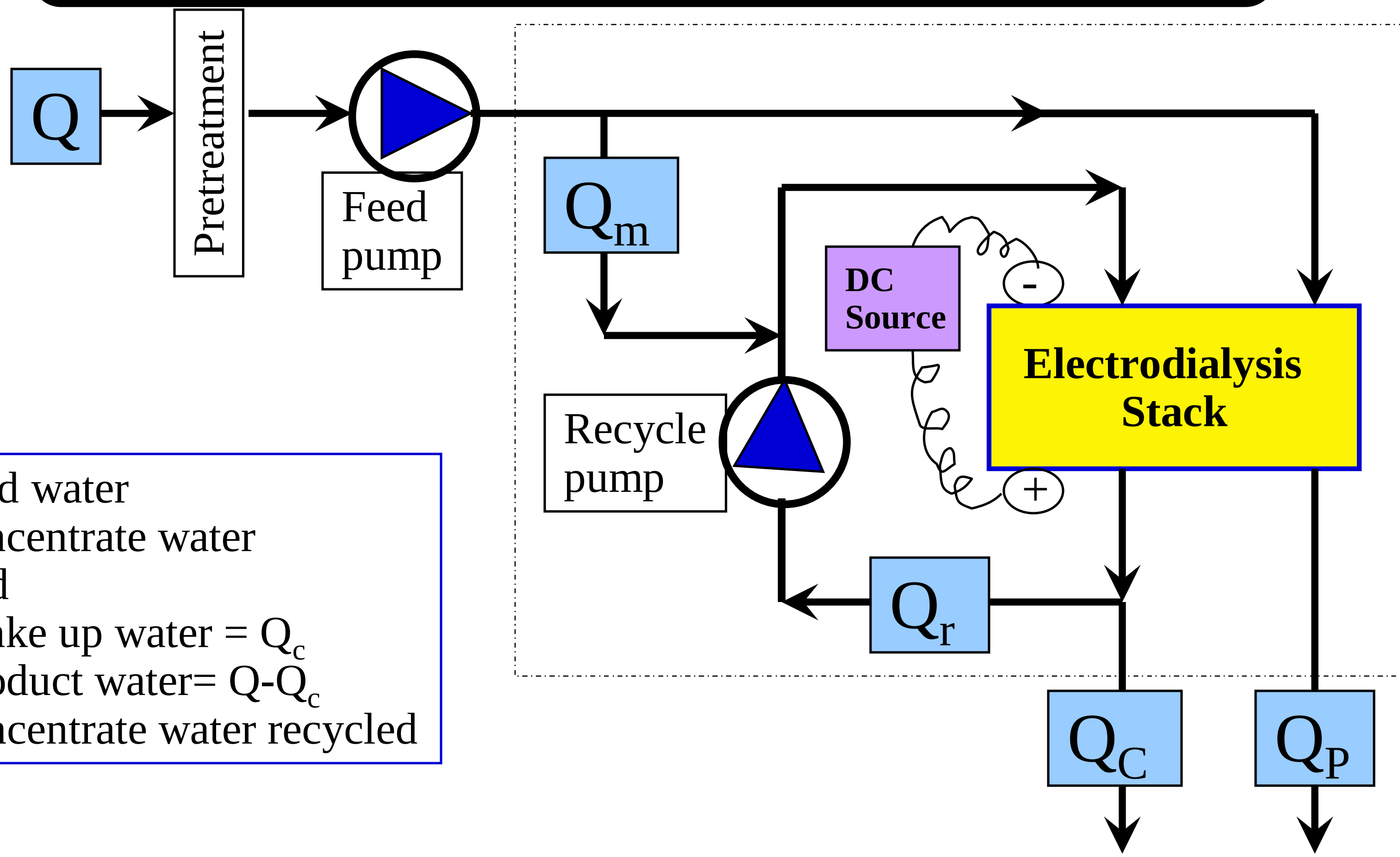
Fig. 5.7 **Schematic diagram of Electrodialysis process with three cells**

Electrodialysis treatment (ED)

2. Electrodialysis system layout:

- Figure 5.8 shows a typical layout of electrodialysis water treatment system.
- As shown in the figure, the raw water may need a pretreatment before pumping it to the ED system.
- The ED stack is connected to a DC power supply system.
- The disposed concentrate water stream Q_c is in the range of 10-20%, which leaves a treated water stream Q_p of 80-90% of the feed flow (Q). Some of the concentrate steam is internally recycled (Q_r) to the concentrate cells so that the system can work . Part of the raw feed flow (Q_m) is added to the recycled concentrate stream (Q_r) to makeup for the disposed Q_c. The remaining part of the feed flow ($Q – Q_m$) inters to the treatment cells only.
- The salts removal efficiency for one pass in one stalk is in the range of 40-60% according to the contact time in each treatment cell which is in the range of 10-20 seconds.
- To increase the efficiency ED stacks are connected in series.
- Typical ED stacks has from 100 to 250 treatment cells (200-500 membranes).

Electrodialysis treatment (ED)



Q = feed water
Q_c = concentrate water disposed
Q_m = make up water = Q_c
Q_p = product water= $Q-Q_c$
Q_r = concentrate water recycled

Fig. 5.8 **Typical flow diagram for Electrodialysis treatment process**

3. Current requirements and design equations of ED:

§The electric current required in ED stack is calculated using the faraday's laws of electrolysis. One faraday (F) of electricity (96,500 Ampere. second or coulombs) will cause 1 g-eq of charged substance from one electrode to another. The number of g-eq removed per unit time from an electrolytic treatment cell is given by equation 5.9:

$$G = QNh \quad ....(5.9)$$

$G = grame\ quivalents\ removed\ from\ water\ per\ unit\ time\ , eq/s$

$Q = Solution\ flow\ rate, L/s$

$N = normality\ of\ the\ solution, eq/L$

$h = electrolyte\ removal\ as\ a\ fraction$

Electrodialysis treatment (ED)

§ The electric current required in ED stack for an (n) number of treatment cells is thus given by equation 5.10:

$$I = \frac{FQNh}{nE_c} \quad ....(5.10)$$

$\mathrm{I = current, amp}$

$\mathrm{F = Farady's\ constant}$

$\mathrm{= 96{,}485\ \ amp.s/(grame\ \ quivalent) = 96{,}485\ \ A.s/eq}$

$\mathrm{n = number\ of\ \ treatment\ cells\ in\ stack}$

$\mathrm{E_c\ = current\ efficiency\ expressed\ as\ fraction}$

Electrodialysis treatment (ED)

§ The power and voltage required in ED stack can be calculated from given by equation 5.11:

$$P = E\left(I\right) = R\left(I\right)^2 \ldots\ldots\ldots\ldots\ldots\ldots (5.11)$$

P = power, watt

E = voltage, V

I = current, amp

R = resistance of the membrane to electric current, ohm $\left(\Omega\right)$

Electrodialysis treatment (ED)

§ An important parameter in the design of the ED system is $R_{CD/N}$ which is the ratio between the electric current density (CD) and the normality (N) of the water solution under treatment. This parameter is given in equation 5.12:

$$R_{CD/N} = \frac{CD}{N} \quad \ldots\ldots\ldots\ldots\ldots(5.12)$$

R_{CDN} = ratio of current density to normality of feed solution

CD = current density, amp/cm^2

N = normality of the feed solution, eq/L

§ Table 5.2 gives typical values of many of the parameters needed in equations 5.9 to 5.12.

§ Example 5.5 illustrates the design procedure for ED system.

Electrodialysis treatment (ED)

Table 5.2

Parameter	Unit	Range
Detention time in stack	Seconds	10–20
CD/N ratio	mA/cm^2	500–800
Membrane resistance, Ω	ohms	4–8
Salt-removal efficiency	%	40–60
Current efficiency	%	85–95
Concentrate stream flow	% of feed	10–20

Electrodialysis treatment (ED)

Example: 5.4

Area and Power Requirements for Electrodialysis Determine the area and power required to demineralize 4000 m^3/d of treated wastewater to be used for industrial cooling water using an electrodialysis unit comprised of 240 cells. Assume the following data apply:

1. TDS concentration = 2500 mg/L
2. Cation and anion concentration = 0.010 g-eq/L
3. Efficiency of salt removal = 50 percent
4. The current efficiency = 90 percent
5. The CD/N ratio = 500 mA/cm^2
6. Resistance = 5.0 Ω

Solution:

1. Calculate the current using Eq. (11–48).

$$I = \frac{FQN\eta}{nE_c}$$

$$Q = (4000\ m^3/d)(10^3\ L/m^3)/(86{,}400\ s/d) = 46.3\ L/s$$

$$I = \frac{(96{,}485\ A\cdot s/g\ eq)(46.3\ L/s)(0.010\ g\ eq/L)(0.50)}{240 \times 0.90}$$

$$I = 103.4\ A$$

Electrodialysis treatment (ED)

Example: 5.4 ..cont'd

2. Determine the power required using Eq. (11–49).

$$P = R(I)^2$$

$$P = (5.0\ \Omega)(103.4\ \text{A})^2 = 53{,}477\ \text{W} = 53.5\ \text{kW}$$

3. Determine the required surface area.
   a. Determine the current density:

$$CD = (500)\ (\text{normality}) = 500\ \text{mA/cm}^2 \times 0.010 = 50\ \text{mA/cm}^2$$

   b. The required area is

$$\text{Area} = \frac{(103.4\ \text{A})(10^3\ \text{mA/A})}{(50\ \text{mA/cm}^2)} = 2068\ \text{cm}^2$$

   c. Determine area of membrane assuming a square configuration will be used.

$$\text{Area per membrane} = \sqrt{2068\ \text{cm}^2} \approx 45\ \text{cm}^2$$

4. If the detention time is 10 s, what is the volume and the width of one cell?

$$\boxed{V = \frac{Q*q}{n} = \frac{(43.3\ L/s)*10\ s}{240} = 1.804\ L}$$ **and** $$\boxed{Width\ of\ the\ cell = \frac{V}{A} = \frac{1.804\ L}{2068\ cm^2} * \frac{1000\ cm^3}{1L} = 0.87\ cm}$$

Electrodialysis treatment (ED)

Example: 5.5

For an ED stack Calculate the following: 1) salts concentration in the product water, 2) the salts concentration in the disposed concentrate water, 3) recycled concentrate water and recycle ratio <u>given the following data</u>:

Q_f = 4000 m^3/d (feed flow), C_f = 5000 mg/L
Q_c = 20 % of Q_f (disposed concentrate stream flow)
η = 60 % salt removal percent .
Treatment cells = 240 (i.e concentrate cells = 241)

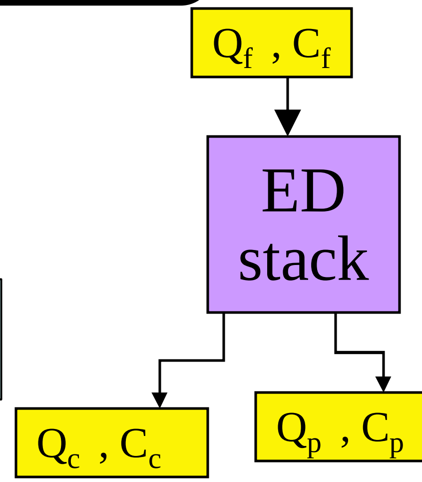
From mass balance application on the ED stack equations 5.13 and 5.14 are derived:

$$C_c = \frac{Q_f * C_f - Q_p * C_p}{Q_c} \quad \text{......................} 5.13$$

$$C_p = \frac{Q_f * C_f \left[1 - h\right]}{Q_p} \quad \text{.........................} 5.14$$

Electrodialysis treatment (ED)

Example: 5.5



Solution:

Q_c = 0.20*4000 = 800 m^3/d
Q_p = 4000-800 = 3200 m^3/d

1- $$C_p = \frac{Q_f * C_f \left[1-h\right]}{Q_p} \rightarrow C_p = \frac{4000 * 5000 \left[1-0.6\right]}{3200} = 2500\ mg/L$$

2- $$C_c = \frac{Q_f * C_f - Q_p * C_p}{Q_c} \rightarrow C_c = \frac{4000 * 5000 - 3200 * 2500}{800} = 15000\ mg/L$$

3- The flow in the concentrate cell should be equal to the flow in the treatment cell. The flow per treatment cell is:

$$Q_{cell} = \frac{Q_f - Qm}{n} = \frac{4000-800}{240} = 13.33\ m^3/d = 0.154\ L/s$$

Electrodialysis treatment (ED)

Example: 5.5

The concentrate flow for the 241 concentrate cells is:

$$Q_{concentarte\ cells} = Q_{cell} * 241 = 13.33 * 241 = 3213.33\ m^3/d$$

From figure 5.8 Q $_{\textbf{concentrate cells}}$ is:

$$Q_{concentarte\ cells} = Q_r + Q_m$$

$$then,$$

$$Q_r = Q_{concentarte\ cells} - Q_m$$

$$Q_r = 3213.33 - 800 = 2413.33\ m^3/d$$

$$\mathrm{Re}\,cycle\ ratio = \frac{Q_r}{Q_f} = \frac{2413.33}{4000} = 0.603$$

Electrodialysis treatment (ED)

4. Applications of ED units:

- ED removes IONS from water , it does NOT remove bacteria (Crypto, Giardia), viruses, uncharged molecules, suspended solids etc.
- ED is particularly adapted for deionization of brackish waters of 5000 mg/L dissolved solids (TDS) or less to produce a product water with TDS of about 500 mg/L.
- Electrodialysis is not well suited to the deionization of sea water because of the very high energy consumption , since from equation 5.10 the electrical energy required is directly proportional to the amount of salts removed.
- Since RO desalts at a comparable cost and gives other pollutants removals, it has a greater potential in water treatment than ED.
- Electrodialysis can be less expensive for low TDS waters or when a 50% removal is adequate.