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.

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§ 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:

$$\boxed{p = cRT}$$

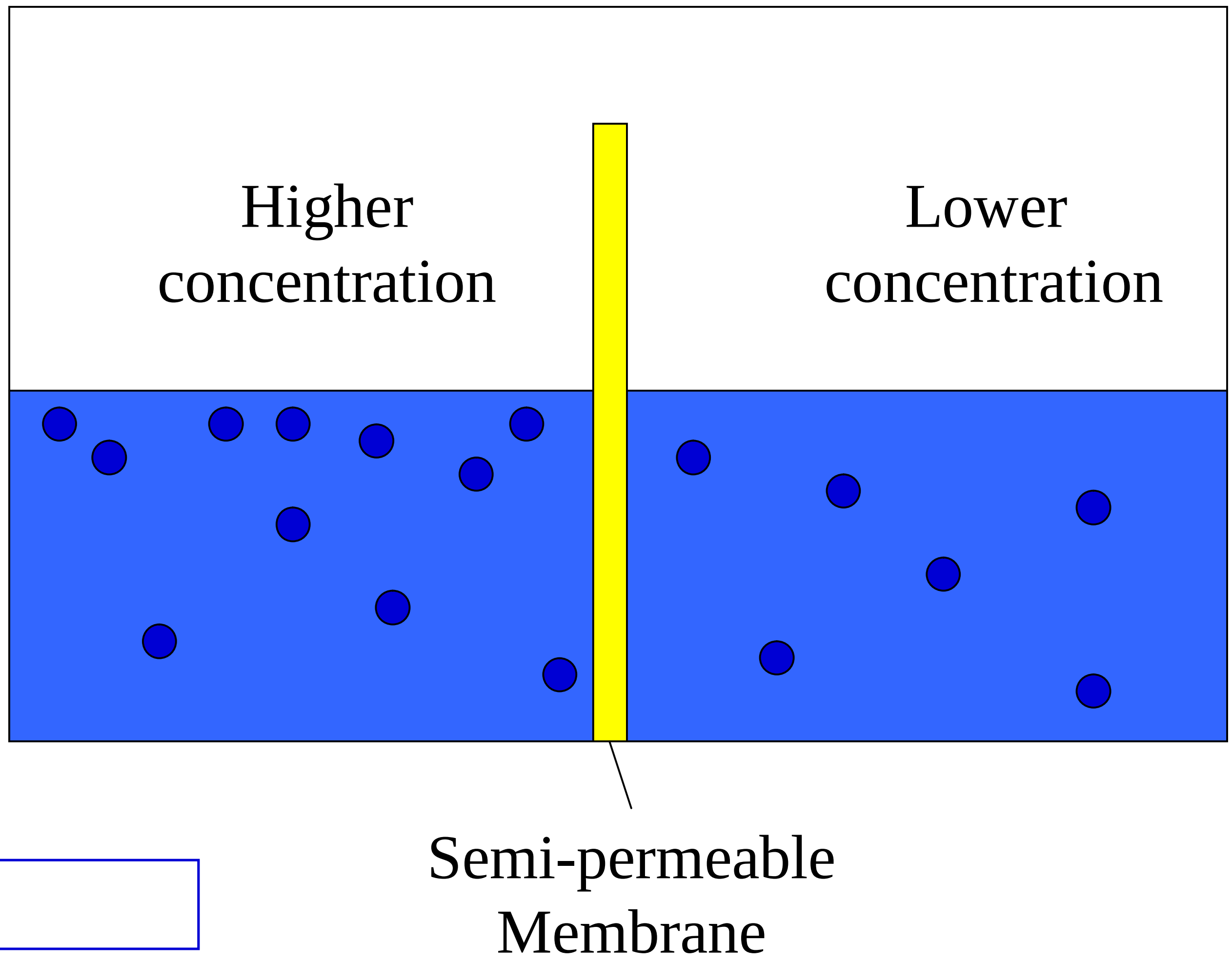
Where, c = summation of the molar concentration of the dissolved ions

R = Universal gas constant

T = Temperature in degrees Kelvin.

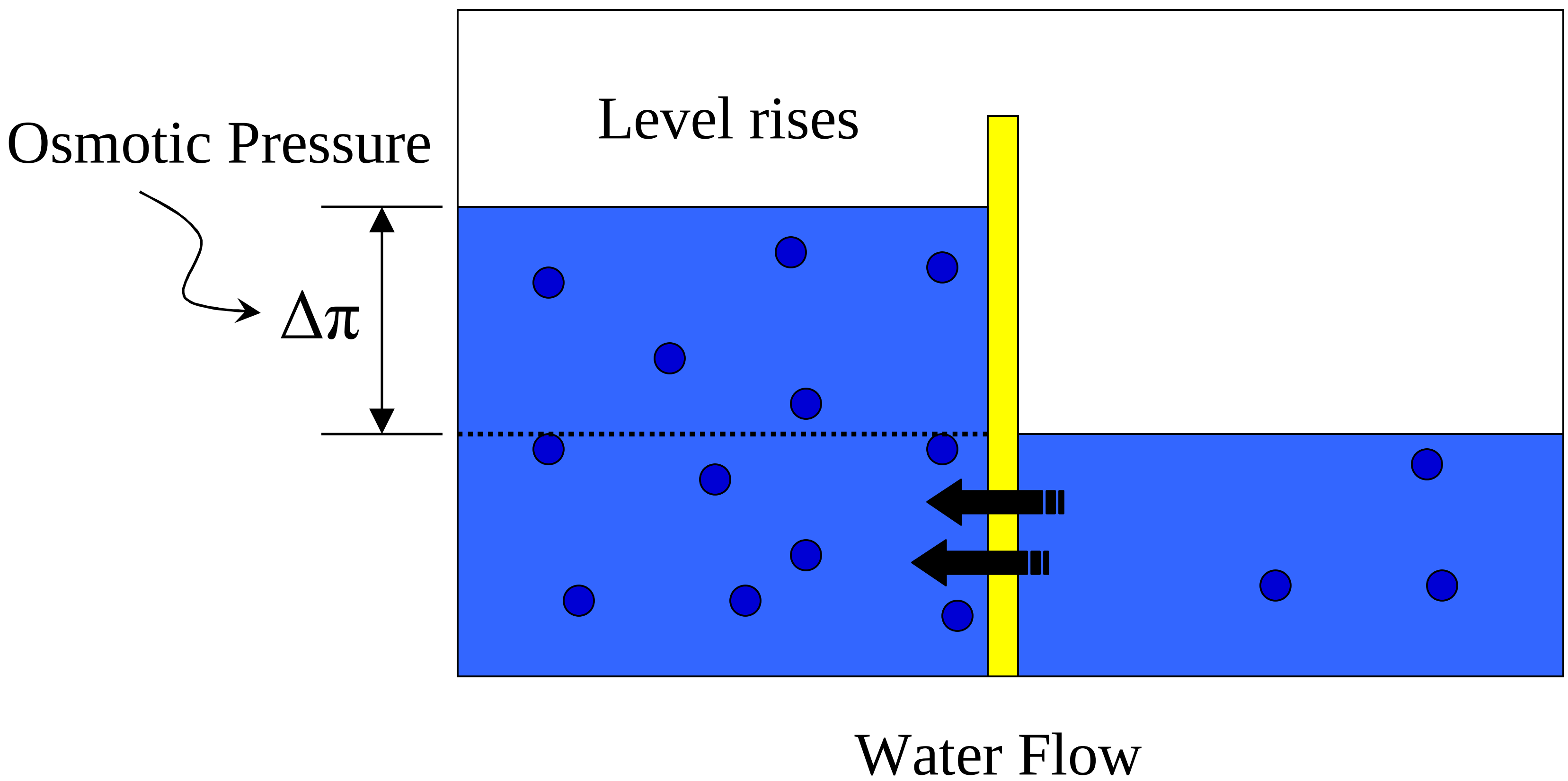
Figures 5.1 and 5.2 describe this phenomena.

Osmosis



Higher concentration
Lower concentration
Semi-permeable Membrane

Osmosis



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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

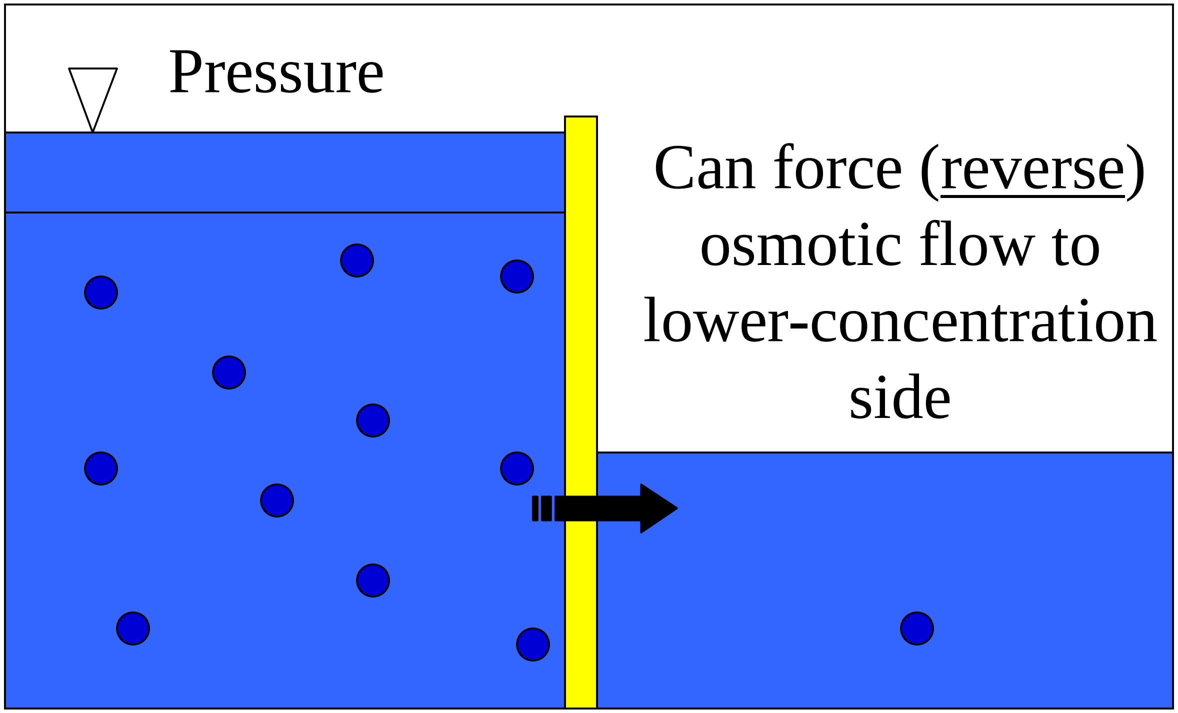


Fig. 5.3

Semi-permeable
Membrane

Reverse Osmosis Applied

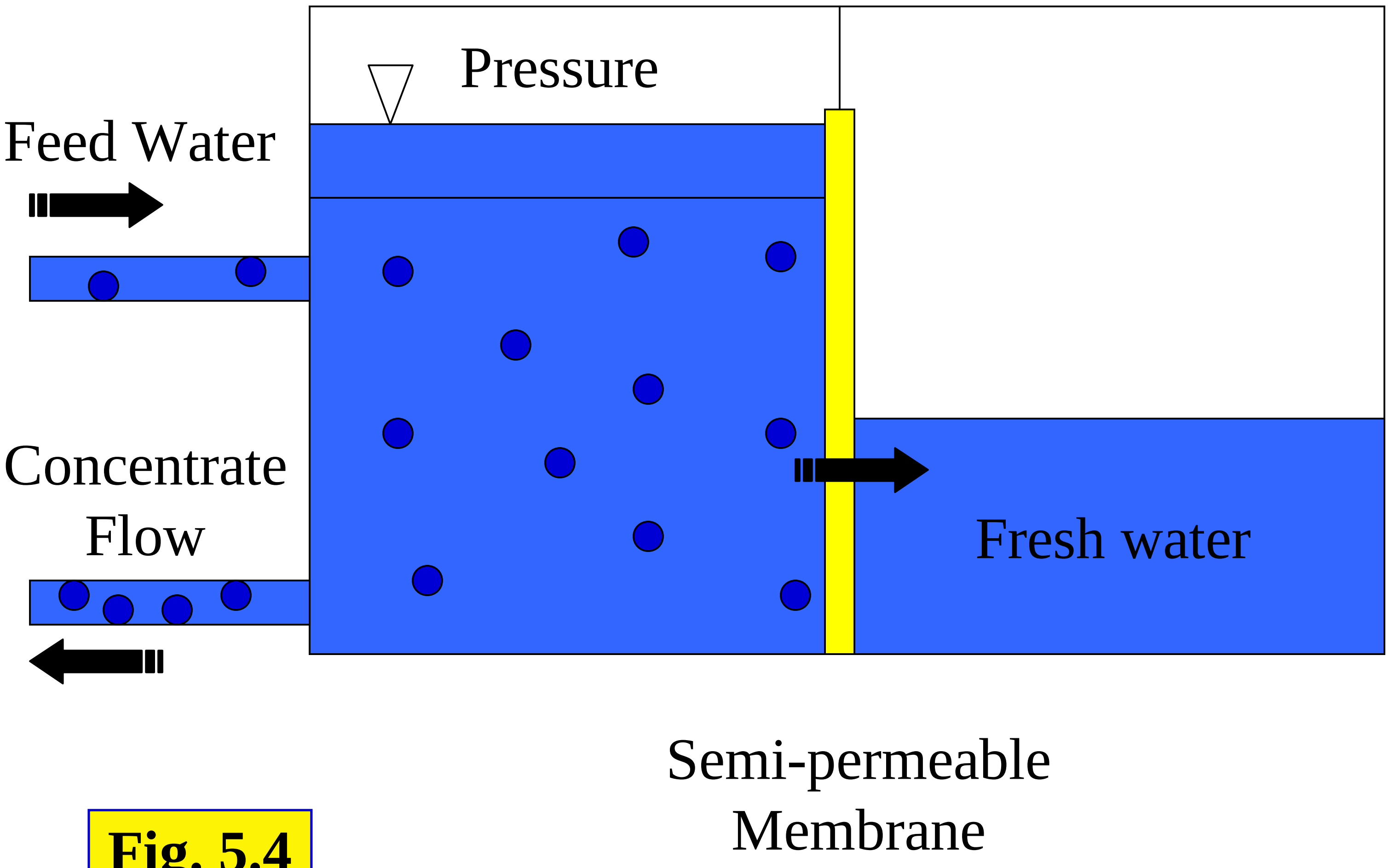
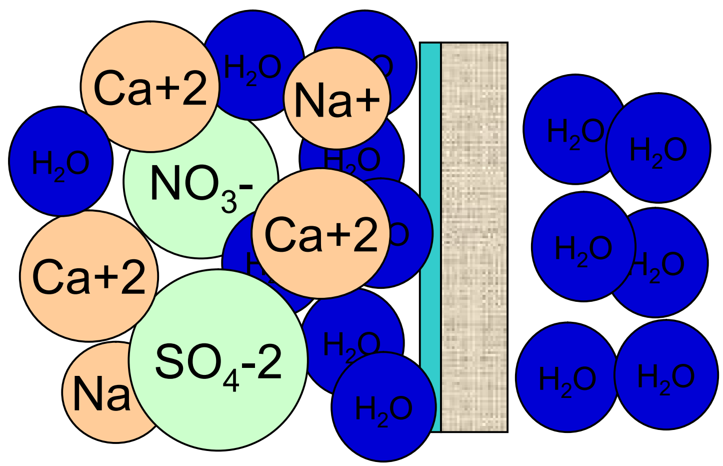


Fig. 5.4

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.

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)

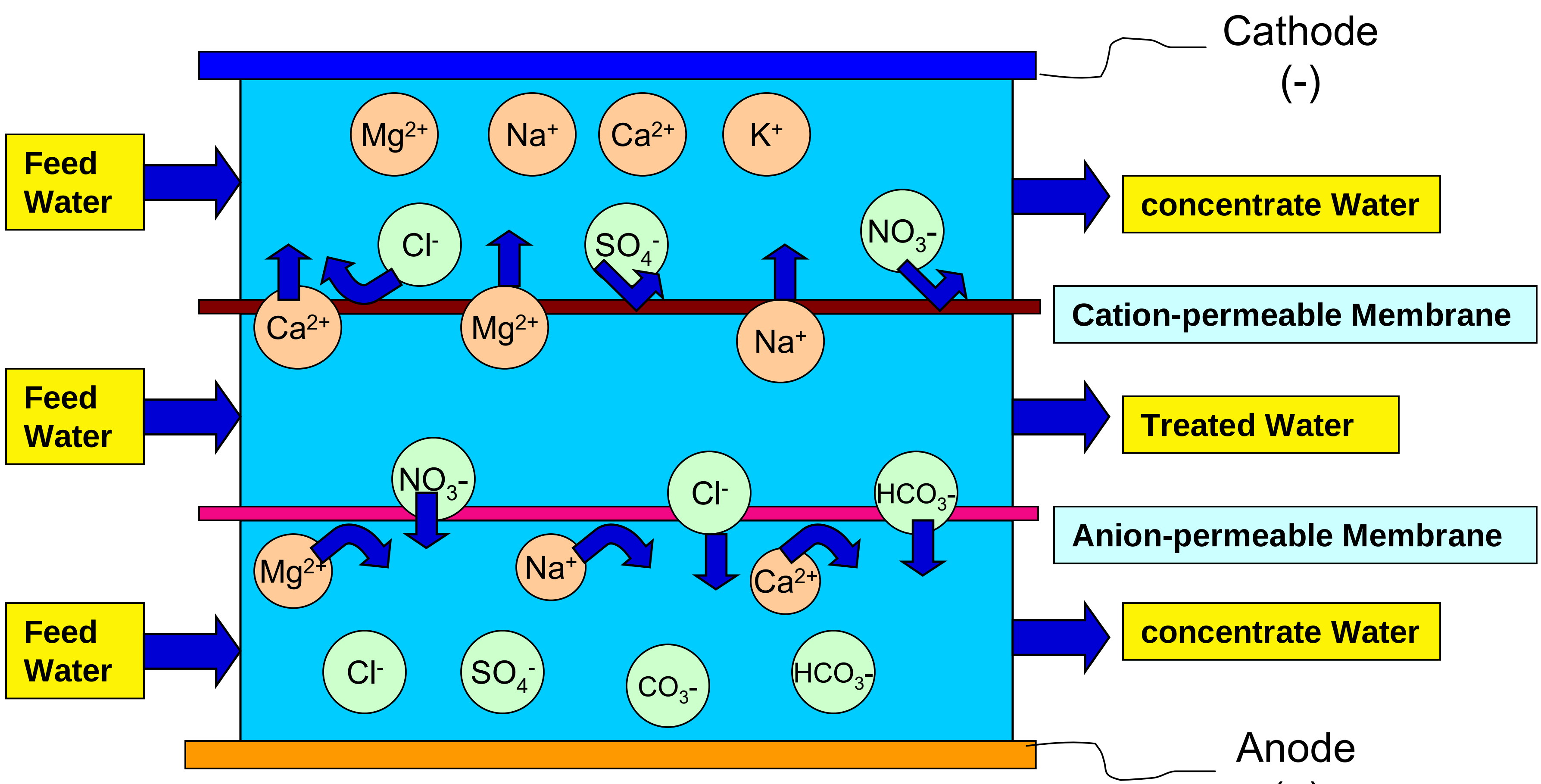


Fig. 5.6 Schematic of Electrodialysis process

Electrodialysis treatment (ED)

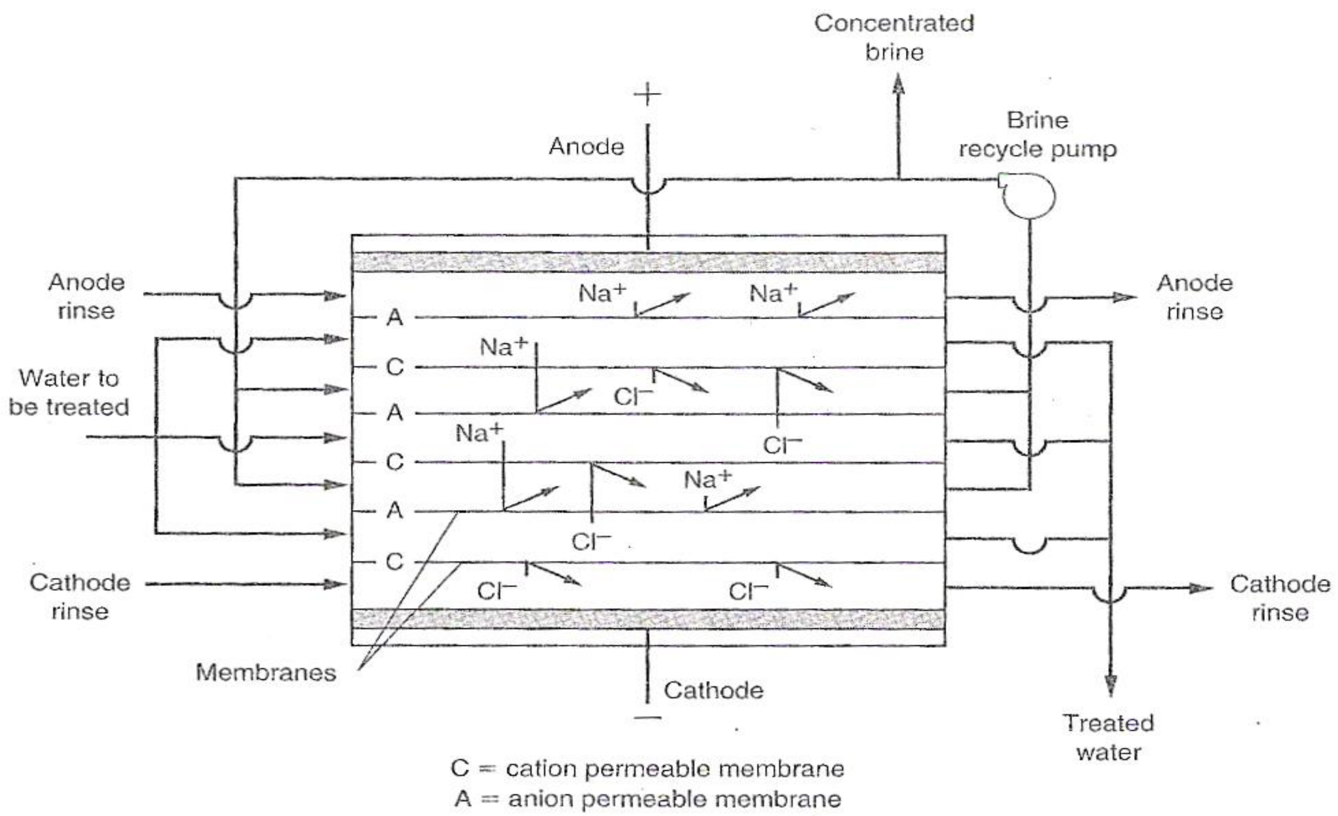


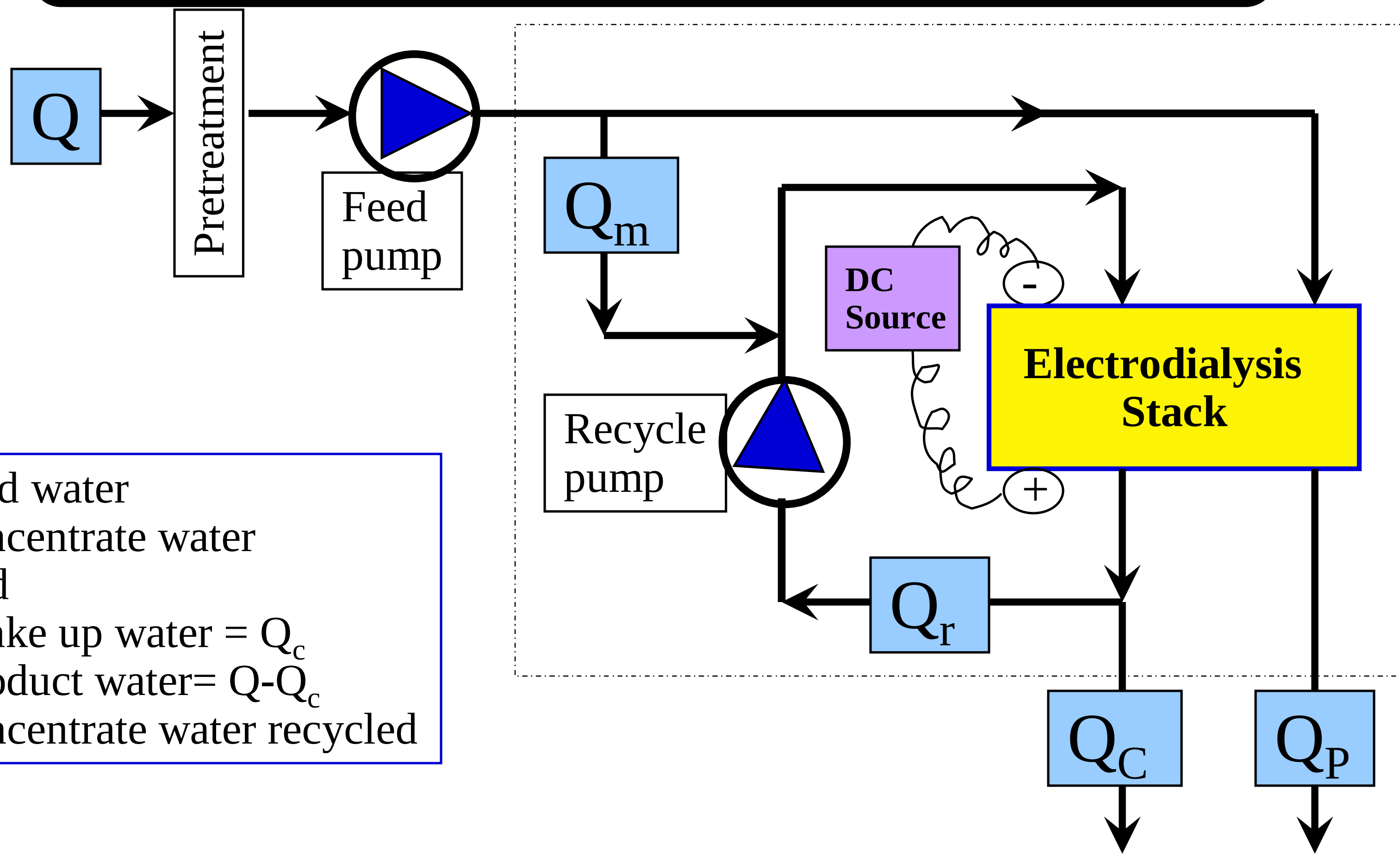
Fig. 5.7 **Schematic diagram of Electrodialysis process with three cells**

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**

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.