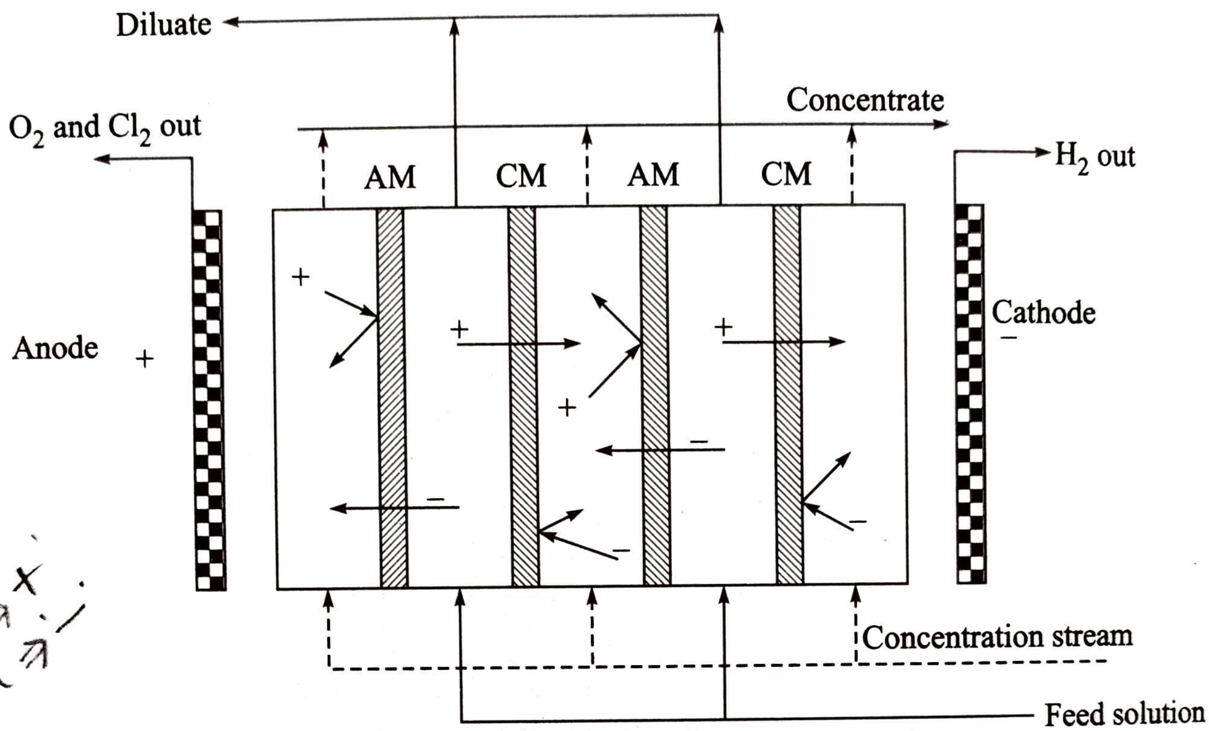
10 Ion Exchange Membrane Process: Electrodialysis

Electrodialysis, in the pure sense, is the movement of ions through ion selective membranes, under the influence of an electromotive force (voltage) applied across the membrane area. In electrodialysis (ED), developed in the early sixties by Ionics of Watertown in the USA, the ions responsible for salinity are caused to migrate through membranes under the influence of an electric charge, with positively charged cations such as sodium and calcium migrating to the cathode, and negatively charged anions such as chloride and sulphate migrating to the anode. Given its separation characteristics, electrodialysis is used today not only for the production of potable water by desalination but also in many other industrial processes. Although the principle of the process was known for more than 50 years, large scale industrial utilization did not become possible until the development of multi cell stack design and efficient ion exchange membranes.

10.1 BASIC PRINCIPLE

Electrodialysis is an electromembrane process in which ions are transported through an ion exchange membrane from one solution to another under the influence of an electrical potential gradient. The electrical charges on the ions allow them to be driven through the membranes fabricated from ion exchange polymers. Applying a voltage between two end electrodes generates the potential field required for this. During this transportation anions are able to permeate through anion-selective membranes, but are blocked by the cation-selective membranes. The opposite occurs with cations. As a result, two different solutions are produced inside the stack: one more dilute (the diluate) and the other more concentrated (the concentrate) than the feeding solution. Since the membranes used in electrodialysis have the ability to selectively transport ions having positive or negative charge and reject ions of the opposite charge, useful concentration, removal, or separation of electrolytes can be achieved by electrodialysis. Using the right combination of anion exchange and cation exchange membranes the ions of the feed solution can be separated.

The desalted stream is known as diluate, and the concentrated is known as concentrate. Electrodialysis takes place in electrodialyzer, i.e. the equipment comprising tightening boards with electrodes and a bundle consisting of ion exchange membranes and spacers. This has been schematically represented in Figure 10.1.



Cation ⇒ +
Anion ⇒ −

Figure 10.1 Schematic representation of electrodialysis process (AM: Anion exchange membrane; CM: Cation exchange membrane).

AM ⇒ Allows Anions
CM ⇒ Allows Cations

The usual reaction at the cathode is:

$$2H_2O + 2e^- \rightarrow H_2\,(g) + 2OH^-,\ E° = -0.828\ V$$

The OH^- formed must be neutralized in the cathode compartment. The cathode can be made of tantalum, niobium, or titanium all of which must be coated with platinum. In the anode the usual reaction is:

$$H_2O - 2e^- \rightarrow \frac{1}{2}O_2\,(g) + 2H^+,\ E° = -1.23\ V$$

While if Cl^- is present the reaction will be

$$2Cl^- - 2e^- \rightarrow Cl_2\,(g),\ E° = -1.360\ V$$

where the electrode potentials are the standard values at 25°C for one molar solutions of ions and partial pressures of one atmosphere for the gaseous products. Values of E° can be corrected for nonstandard conditions by the Nernst equation.

The corresponding overall cell reactions are:

$$3H_2O \rightarrow H_2\,(g) + \frac{1}{2}O_2\,(g) + 2H^+ + 2OH^-$$

or

$$2H_2O + 2Cl^- \rightarrow 2OH^- + H_2\,(g) + Cl_2\,(g),\ E° = -2.058\ V$$

The anode can be made from the same materials as the cathode or from the stainless steel. The anode and cathode compartments are separated from the stack by membranes. These compartments are vented to remove the gases formed. In a practical electrodialysis system, 200 to 400 cation and anion exchange membranes are installed in a parallel fashion to form a electrodialysis stack. Each stack contains about 100 to 200 cell pairs. Electrical energy consumption in ED units is about 1.6 – 2.6 kWh/m^3 of product water from a feed having 1500 – 2000 mg salt/litre.

To acquire a product out of one part of the solution (diluate or concentrate) only can be the goal of electrodialysis. But sometimes quality is required of both products, especially when treating waste water, e.g. diluate must comply with the regulations for releasing diluate into water, and concentrate has to be of properties useful for other treatment. Some basic information on electrodialysis are given in Table 10.1.

Table 10.1 Some basic information on electrodialysis

Driving force	Electrical potential gradient, electro osmosis
Transport mechanism	Counter ions via ion exchange membranes, coupled transport
Separation principle	Donnan exclusion mechanism
Size of retained species	Co-ions, macroions
Type of membrane	Ion exchange and bipolar, semipermeable.
Pore size	Nonporous
Membrane material	Cross-linked copolymers based on divinylbenzene (DVB), with polystyrene or polyvinylpyridine copolymers of polytetrafluoroethylene (PTFE) and polysulfonyl fluoridevinyl ether)
Module	Flat sheet
Energy consumption	Depends on feed concentration (~0.4 kWh/m^3)