Electrodialysis 1

Lecture 11

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Introduction

- First commercial equipment based on Electrodialysis (ED) technology was developed in **the1950s** to demineralize **brackish water.**
- Since then ED has advanced rapidly because of improved ion exchange membrane properties, better materials of construction and advances in technology.
- In the **1960s**, **Electrodialysis Reversal** (EDR) was introduced, **to avoid organic fouling** problems.
- Over the past twenty years EDR has earned a reputation as a membrane desalination process that works **economically** on surface water supplies, reuse water and some specific industrial applications when designed and operated properly.

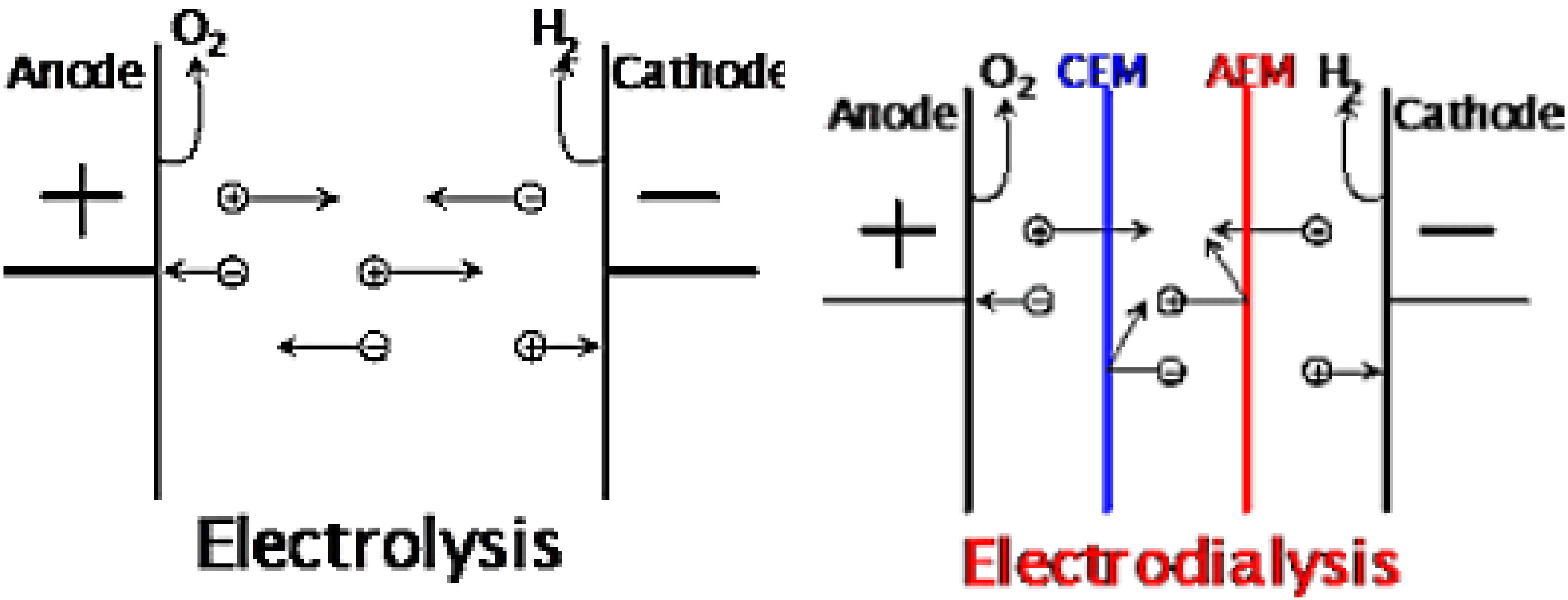
1. Applications of ED/EDR

- **Reduce inorganic salts** like radium, bromide, fluoride, iron and manganese and nitrate in drinking water.
- **Recycle municipal and industrial wastewater**.
- **Recovering reverse osmosis rejec**t.
- **Desalting wells and surface waters**.
- **Whey and soy purification**.
- **Table salt production**.
- For this kind of applications, this technology had shown **best recovery and cost effective** in front of other membrane technologies, specially **compared with Reverse Osmosis (RO).**

2. Theory

- ED is an electrochemical separation process in which ions are transferred through ion exchange membranes by means of a direct current (DC) voltage. The process uses a driving force to transfer ionic species from the source water through **cathode (negative electrode) attracts positively charged ions** and **anode (positive electrode) attracts negatively charged ions** to a concentrate wastewater stream, creating a more dilute stream.

2. Theory



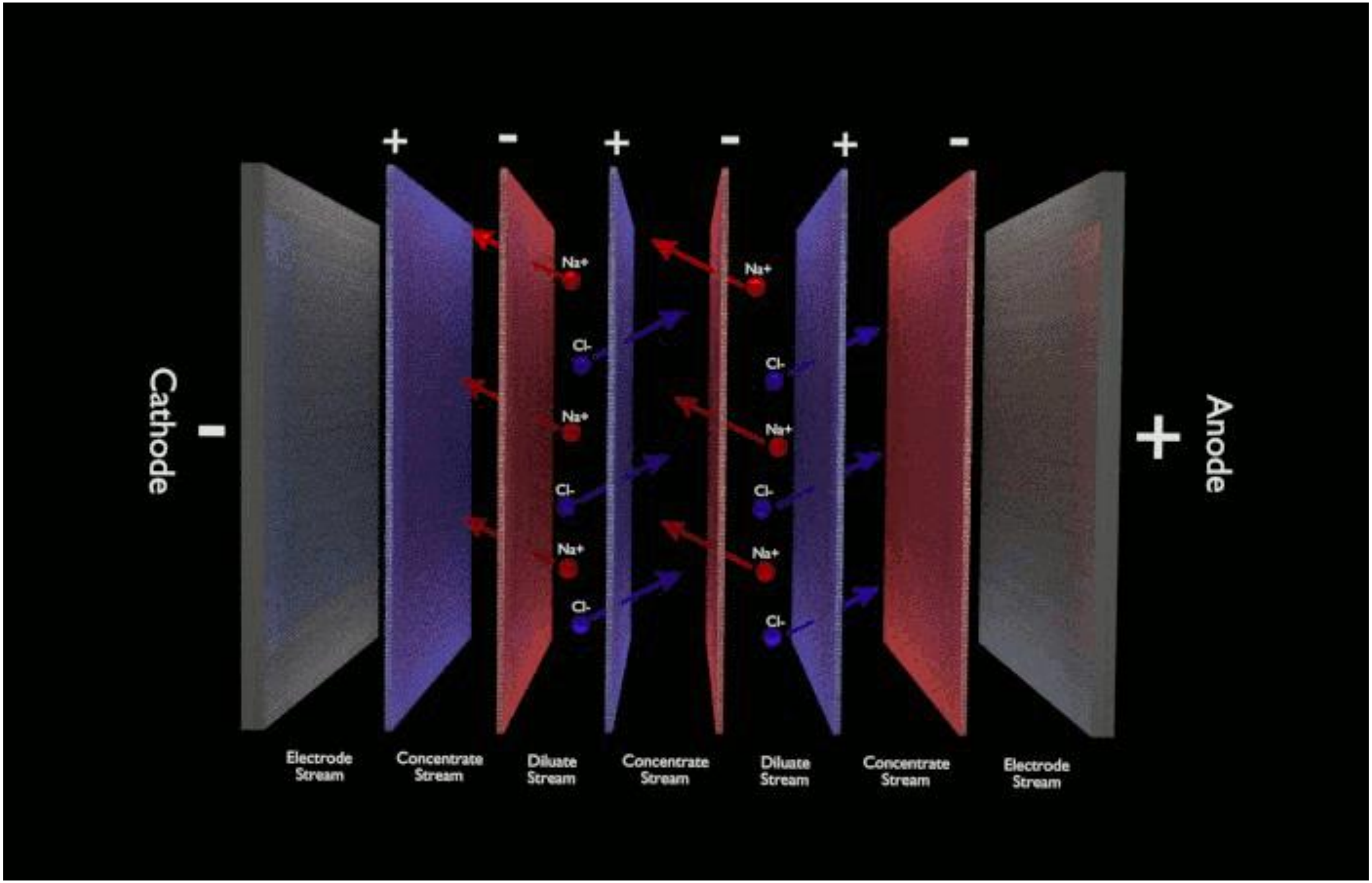
Left side demonstrates a standard electrolysis process.
Right side demonstrates the same process when ion-selective membranes are inserted.

2. Theory

- ED selectively removes dissolved solids, based on their **electrical charge**, by transferring the brackish water ions through **a semi permeable ion exchange membrane** charged with an electrical potential.
- It points out that the feed water becomes separated into the following three types of water.

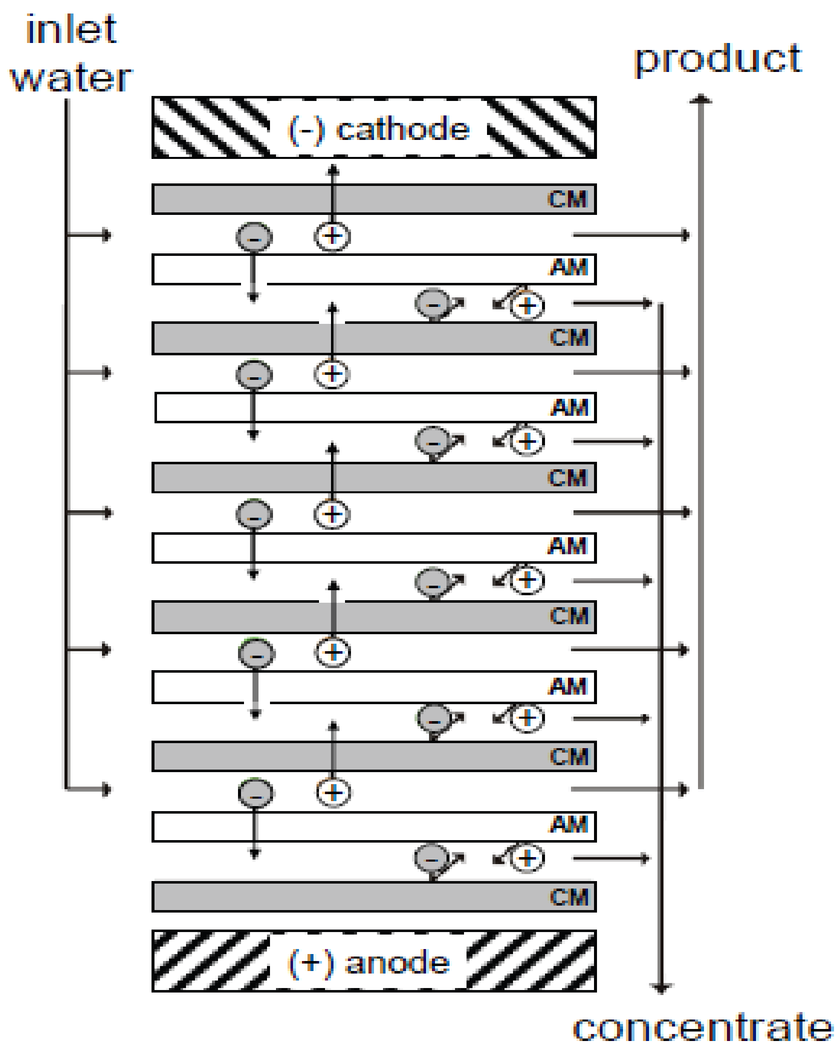
1. **Product water**, which has an acceptably low conductivity and TDS level;
2. **Brine, or concentrate**, which is the water that receives the brackish water ions; and
3. **Electrode feed water**, which is the water that passes directly over the electrodes that create the electrical potential.

2. Theory



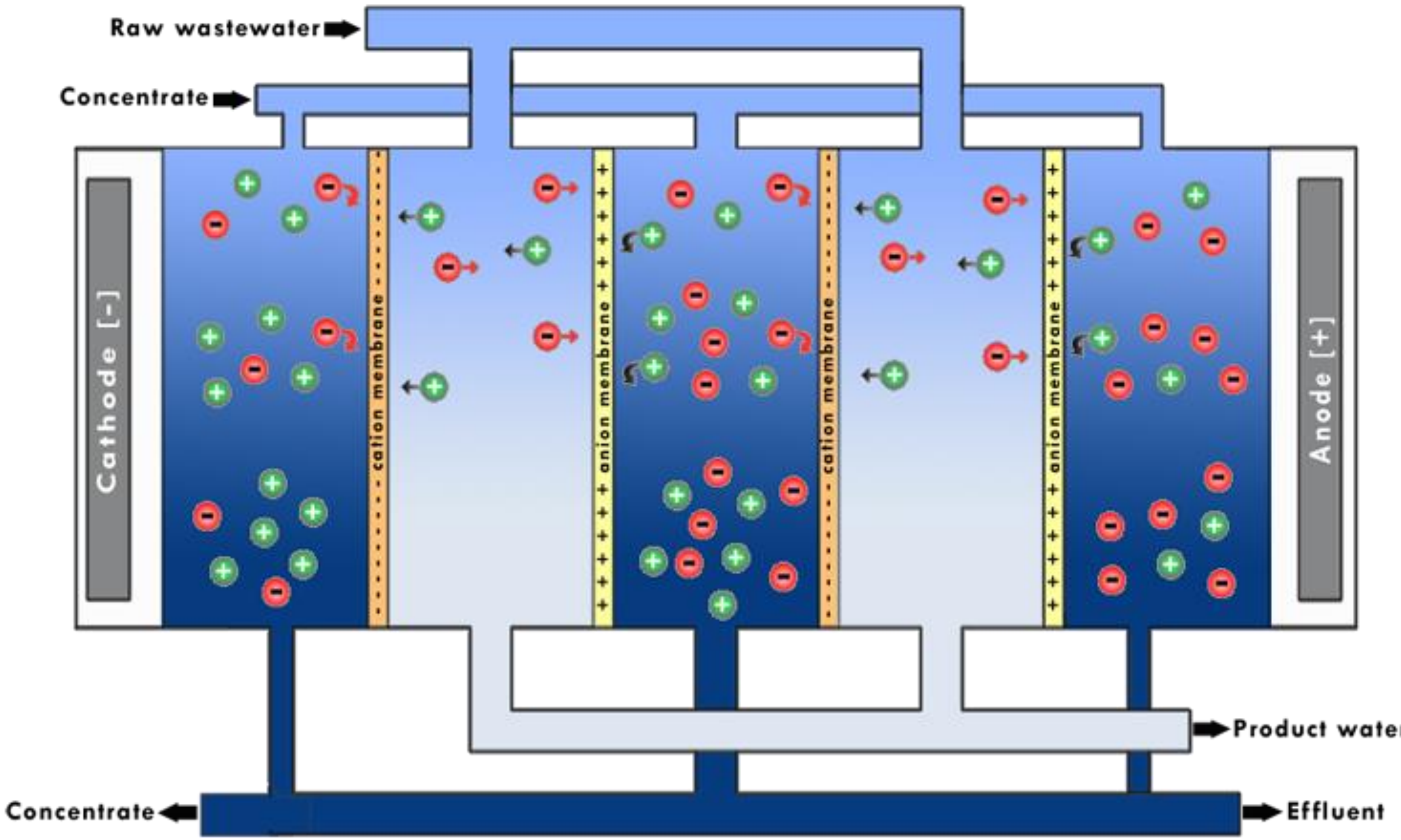
+
-
+
-
+
-
Cathode
-
Na+
Cl-
Na+
Cl-
Na+
Cl-
Na+
Cl-
Na+
Cl-
Na+
Cl-
+
Anode
Electrode Stream
Concentrate Stream
Diluate Stream
Concentrate Stream
Diluate Stream
Concentrate Stream
Electrode Stream

2. Theory



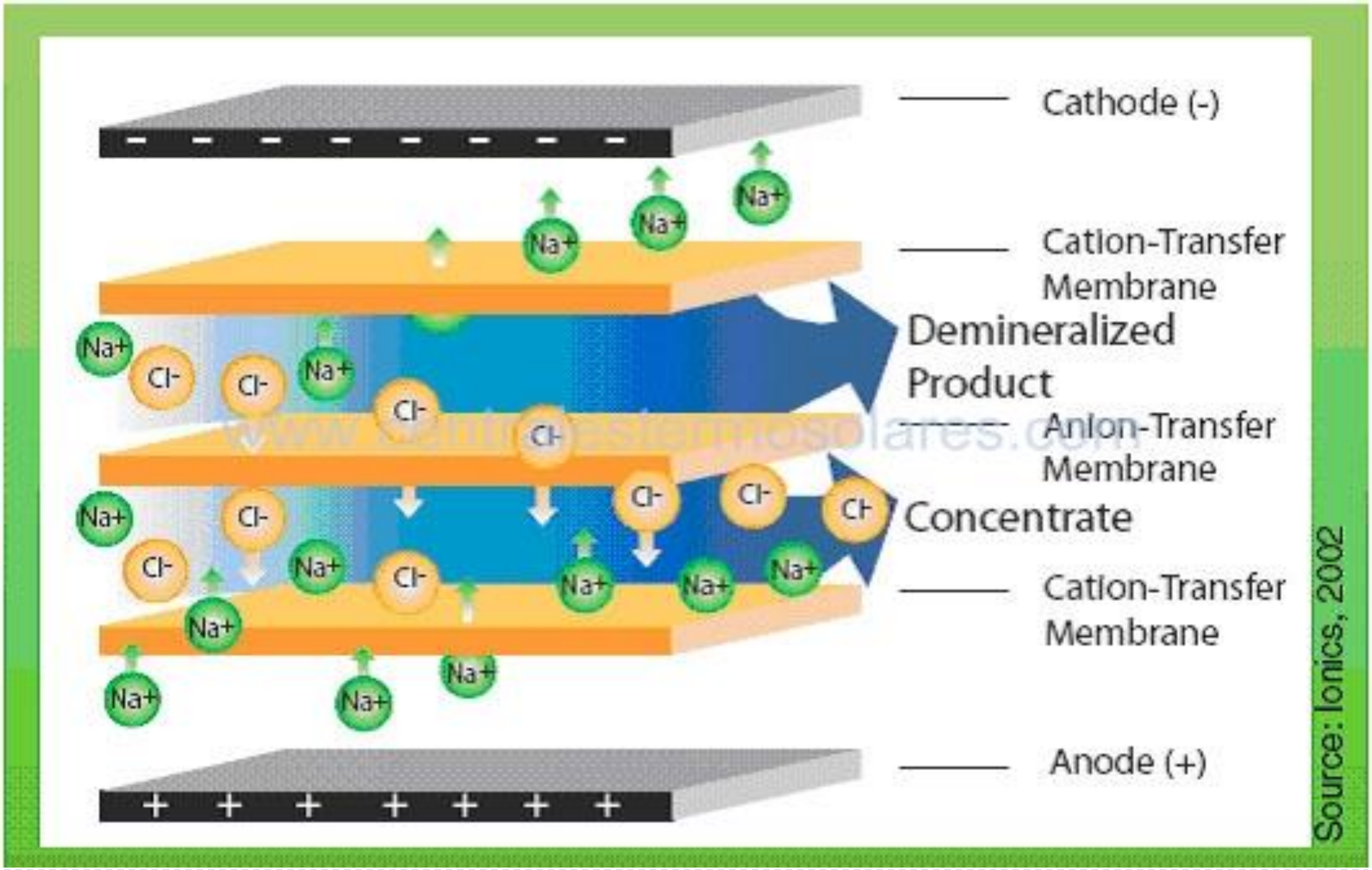
inlet water
product
(-) cathode
CM
AM
CM
AM
CM
AM
CM
AM
CM
AM
CM
(+) anode
concentrate

2. Theory



Raw wastewater
Concentrate
Cathode [-]
cation membrane
anion membrane
cation membrane
anion membrane
Anode [+]
Product water
Concentrate
Effluent

2. Theory



Cathode (-)
Cation-Transfer Membrane
Demineralized Product
Anion-Transfer Membrane
Concentrate
Cation-Transfer Membrane
Anode (+)
Na+
Cl-
Source: Ionics, 2002

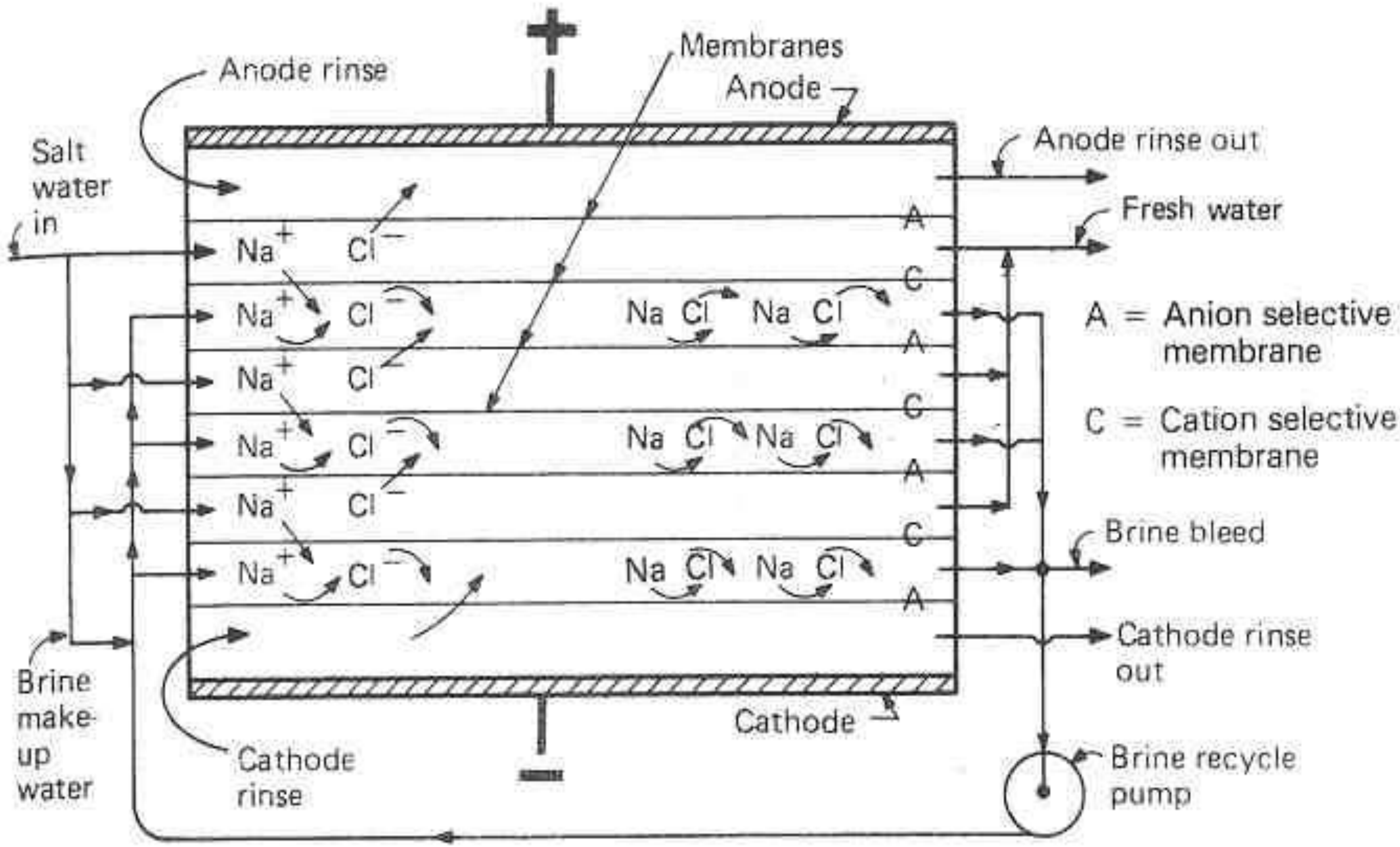
2. Theory

- EDR is a variation on the ED process, which uses **electrode polarity reversal** to automatically **clean membrane surfaces.**
- EDR works the same way as ED, except that the polarity of the DC power is **reversed two to four times per hour**.
- When the polarity is reversed, the source water **dilute** and **concentrate compartments** are also **reversed** and so are the chemical reactions at the electrodes.
- This polarity reversal helps **prevent the formation of scale** on the membranes.

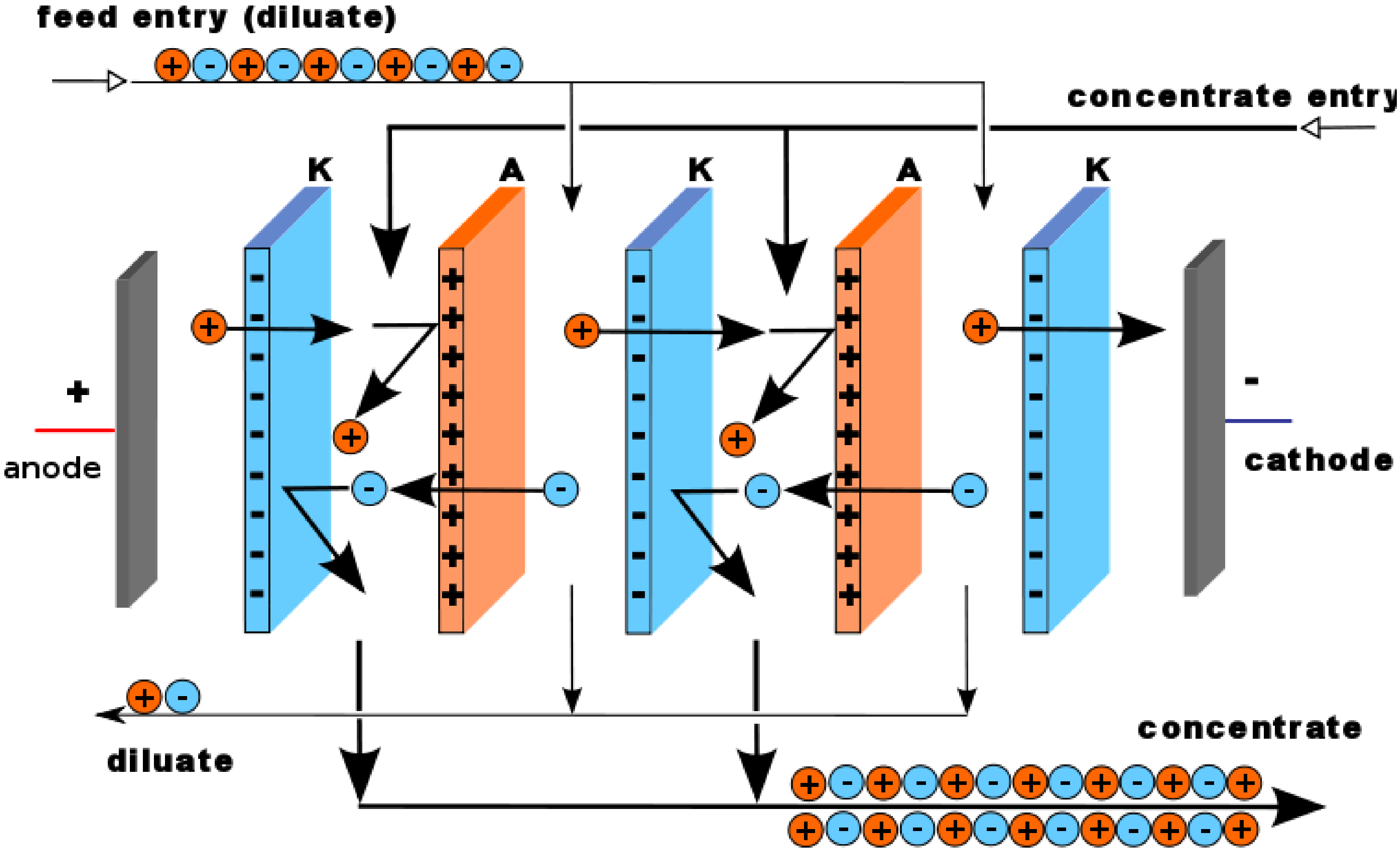
2.1 Membrane stacks

- All ED and EDR systems are designed specifically for a **particular application**.
- The amount of ions to be removed is determined by the **configuration** of the membrane **stack**.
- A membrane stack may be oriented in either a **horizontal or vertical position.**
- Each stack assembled has the two electrodes and groups of cell pairs.
- The **number of cell pairs** necessary to achieve a given product water quality is primarily determined by **source water quality,** and can design stacks with more than **600 cell pairs** for industrial applications

Horizontal stack



Vertical stack



2.1 Membrane stacks

2.1 Membrane stacks

A cell pair consists of the following:

- • Anion permeable membrane
- • Concentrate spacer
- • Cation permeable membrane
- • Dilute stream spacer

2.2 Membranes

- The **membranes** are produced in the form of **foils** composed of fine **polymer particles** with **ion exchange groups** anchored by polymer matrix.
- Membranes are **reinforced** with **synthetic fiber** which improves the **mechanical properties** of the membrane

2.2 Membranes

- The two types of ion exchange membranes used in electrodialysis are:
- **<u>Cation transfer membranes</u>** which are electrically conductive membranes that allow only **<u>positively charged ions</u>** to pass through.
- Commercial cation membranes generally consists of cross linked **<u>polystyrene</u>** that has been **<u>sulfonated</u>** to produce $-SO_3H$ groups attached to the polymer, in water this group ionizes producing a mobile counter ion (H^+) and a fixed charge ($-SO_3$).

2.2 Membranes

- **Anion transfer membranes**, which are electrically conductive membranes that allow only **negatively charged ions** to pass through.
- Usually, the membrane matrix has fixed positive charges from **quaternary ammonium groups** (NR_3^+OH) which repel positive ions.

2.2 Membranes

Both types of membranes shows common properties:

- Low electrical resistance,
- Insoluble in aqueous solutions,
- Semi-rigid for ease of handling during stack assembly,
- Resistant to change in pH from 1 to 10,
- Operate temperatures in excess of 46 °C,
- Long life,
- Resistant to fouling

2.2 Membranes

- The membranes are permselective (or ion selective) that refers to their ability to discriminate between different ions to allow passage or permeation through the membrane.
- In these sense membranes can be tailored to inhibit the passage of divalent anions or cations, such as sulfates, calcium, and magnesium.
- For example, some membranes show good permeation or high transport numbers for mono-valent anions, such as Cl or NO_3, but have low transport numbers and show very low permeation rates for divalent or trivalent ions, such as SO_4^2, PO_4^3, or similar anions.

2.2 Membranes

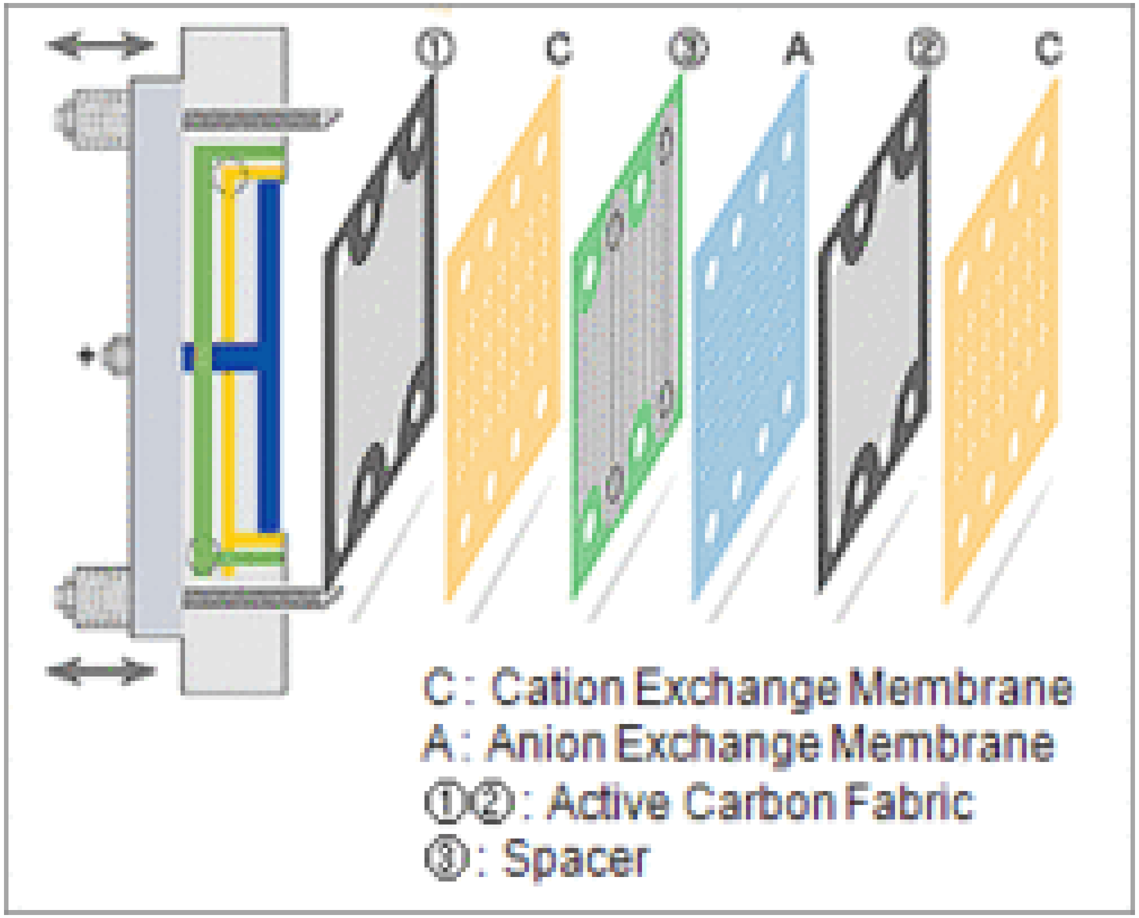
- **Membrane** is 0.1 to 0.6 mm thick and is either **homogeneous or heterogeneous**, according to the connection way of charge groups to the matrix or their chemical structure.

- In the case of **homogeneous** membranes, charged groups are **chemically bonded** and for **heterogeneous** they are **physically mixed** with the membrane matrix.

2.3 Spacers

- The spaces between the membranes represent the flow paths of the demineralized and concentrated streams formed by **plastic separators** which are called **demineralized and concentrate** water flow **spacers** respectively.
- These spacers are made of **polypropylene** or **low density polyethylene** and are alternately positioned between membranes in the stack to create independent flow paths, so that **all the demineralized streams are manifolded together** and **all the concentrate streams are manifolded together too**.

2.3 Spacers


①
C
③
A
②
C
C : Cation Exchange Membrane
A : Anion Exchange Membrane
①② : Active Carbon Fabric
③ : Spacer

2.3 Spacers

- **Demineralizing spacers** **allow water** to flow across membrane surfaces where ions are removed, whereas **concentrating spacers** prevent the concentrate stream from contaminating the demineralized stream.
- There is a spacer design with a **"tortuous path**" in which the spacer is folded back upon it self and the liquid **flow path is much longer** than the linear dimensions.
- Another kind of spacers is a **"sheet flow"** that consists of an open frame with a **plastic screen** separating the membranes.

2.3 Spacers

- In general the **increase of turbulence** promotes **mixing of the water**, **use of the membrane area**, and the **transfer of ions**.
- **Turbulence** resulting from spacers also **breaks up particles** on the membrane surface and attracts ions to the membrane surface.
- Flow **velocity** ranges from 18 to 35 cm/s.
- A velocity **less than 18 cm/s** promotes **polarization**.

2.4 Electrodes

- A metal electrode at each end of the membrane stack conducts DC into the stack.
- Electrode compartments consist of an electrode, an electrode water-flow spacer.
- The electrode **spacer is thicker** than a normal spacer, which increases water velocity to prevent scaling.
- This spacer also prevents the electrode waste from entering the main flow paths of the stack.

2.4 Electrodes

- Because of the corrosive nature of the anode compartments, **electrodes are usually made of titanium and plated with platinum.**
- Its life span is dependent on the ionic composition of the **source water** and the **amperage** (the strength of an electric current in amperes) applied to the electrode.
- **Large amounts of chlorides in the source water and high amperages reduce electrode life**.

Questions

- **Answer with Yes or No and corrects the wrong ones:**

1. First commercial equipment based on Electrodialysis (ED) technology was developed in the1980s.
2. ED has best recovery and cost effective compared with Reverse Osmosis (RO).
3. Product water stream in ED has an acceptably high conductivity and TDS level.
4. EDR works the same way as ED, except that the polarity of the DC power is reversed four to eight times per hour.
5. ED stacks with more than 600 cell pairs for municipal applications.

Questions

- **<u>Complete the following statements:</u>**

1. The basic ED unit consists of several ----------- pairs bound together with electrodes on the outside and is referred to as a membrane stack.
2. Depending on the design of the system, chemicals may be added to the streams in the stack to reduce the potential for --------------.
3. Cation transfer membranes which are electrically conductive membranes that allow only --------- charged ions to pass through.
4. In the case of homogeneous membranes, charged groups are------------ bonded to the membranes.

Questions

5. There is a spacer design with a--------- path in which the spacer is folded back upon it self and the liquid flow path is much longer than the linear dimensions.
6. In ED stack a velocity less than 18 cm/s_promotes ------.
7. The electrode spacer is ------ than a normal spacer in thickness.
8. In ED electrodes are usually made of --------- and plated with -------.
9. Large amounts of -------- in the source water and high -------------- reduce electrode life.