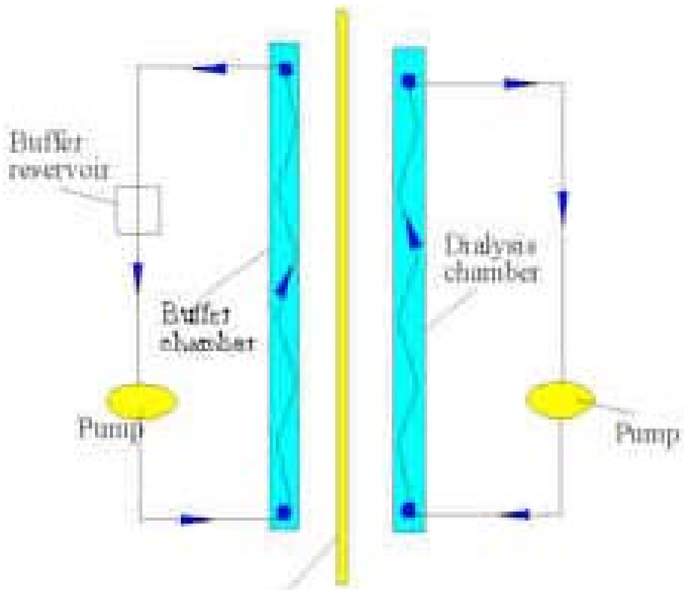
- Dialysis

  - Applied since the 70's.
  - Low industrial interest.
  - Ions & species of low MW (~<100 Da).
  - Ionic Membranes (just like ED).
  - Driving Force: concentration gradient.
  - Slow and low selective.

- Dialysis

- Artificial kidney.

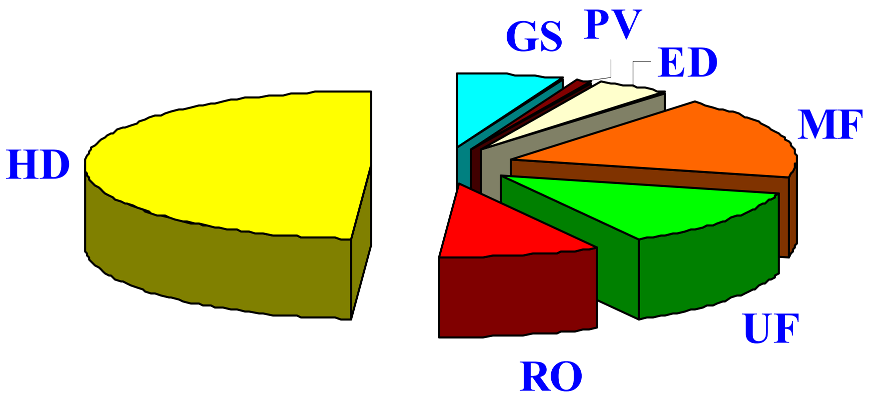


- NaOH recovery in textile effluents, alcohol removal from beer, salts removal (pharmaceutical industry).

Membrane Technology

- Dialysis

Looks not very important...?.



Membrane and module markets

- Electrodialysis (ED)

- First applications back at 30's.

- Ion Separations.

- Ionic Membranes (non porous).

- Driving Force: gradient in electrical potential.

- Potential: 1-2 V.

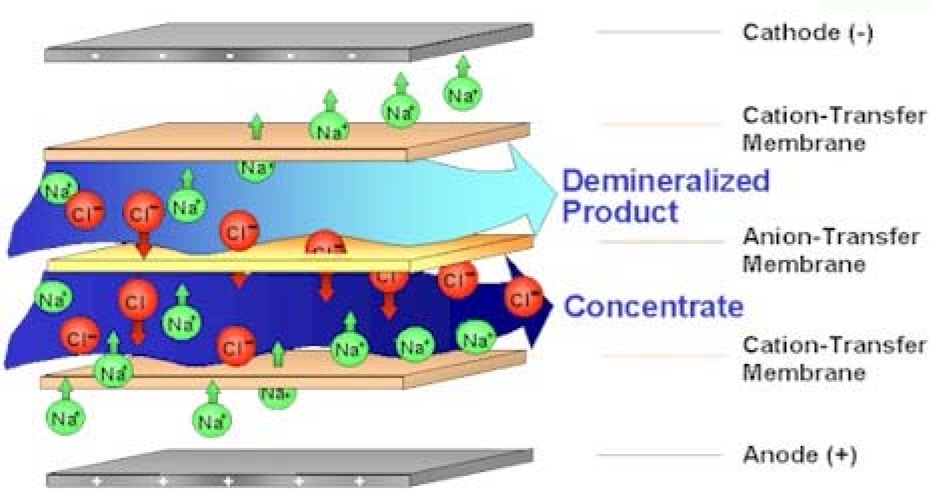
- Flat configuration.

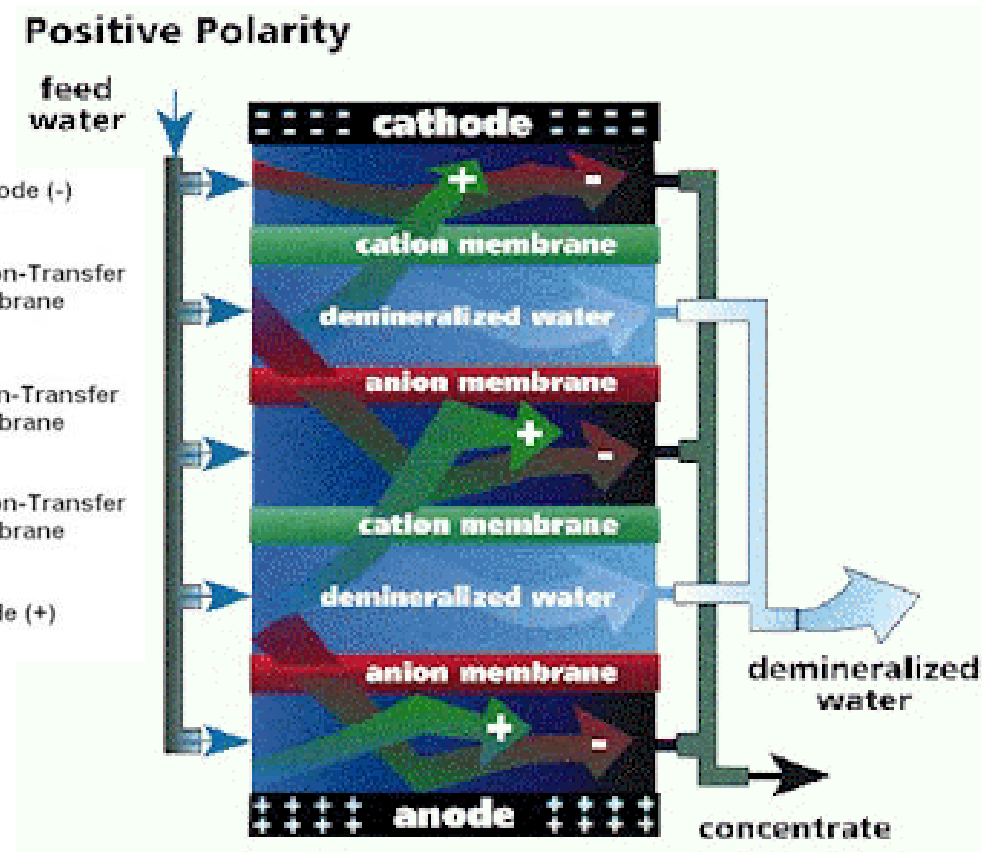
- Hundreds of anionic and cationic membranes placed alternatively.

- Orthogonal electrical field.

Membrane Technology

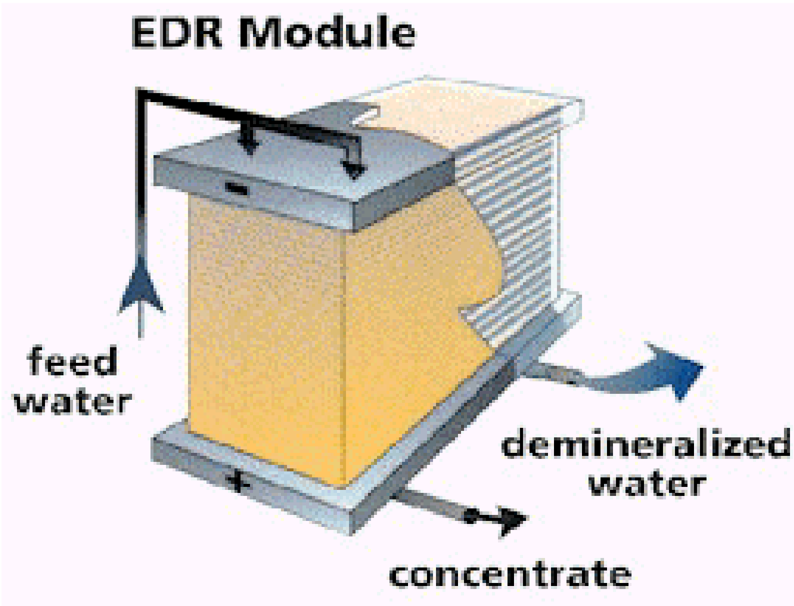
- Electrodialysis (ED)





Membrane Technology

- Electrodialysis (ED)



- Electrodialysis (ED)

- Ionic Membranes (non porous).

- Based on polystyrene or polypropylene with sulfonic and quaternary amine groups.

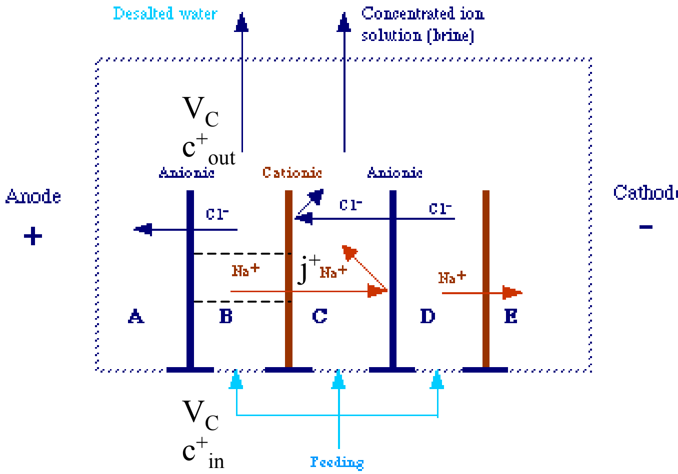
- Thickness: 0.15-0.6 mm.

- ED with reverse polarization (EDR).
- ED at high temperature (60ºC).
- ED with electrolysis.

Membrane Technology

• Electrodialysis (ED)

- Required membrane area



- Mass balance (in equivalents)

$$j^+ \cdot dA^+_m + V_C \cdot z \cdot dc^+ = 0$$

- Charge flow

$$\frac{j^+ \cdot F}{\eta} = i = \frac{dI}{dA_m}$$

i: electric current density (A/m^2)

A_m: membrane surface (m^2)

combining

$$A_T = N \cdot A_m = \frac{N \cdot V_C \cdot \left(c^+_{in} - c^+_{out}\right) \cdot z \cdot F}{\eta \cdot i} = \frac{V \cdot \left(c^+_{in} - c^+_{out}\right) \cdot z \cdot F}{\eta \cdot i}$$

η: global electrical efficiency (~0.5 commercial equipment) j: cation flow (eq/m^2 s)

F: Faraday constant (96500 C/eq) N: number cells in the equipment z: cation charge (eq/mol)

- Electrodialysis (ED)

- Then the required energy, E (J), is

$$E = N \cdot U_C \cdot I \cdot t = N \cdot I^2 \cdot R_C \cdot t$$

U_C: potential gradient in a cell (V)

R_C: total resistance in a cell (Ω)

as

$$I = i \cdot A_m = \frac{V_C \cdot \left(c_{in}^{+} - c_{out}^{+}\right) \cdot z \cdot F}{\eta}$$

then

$$E = N \cdot \left(\frac{V_C \cdot \Delta c \cdot z \cdot F}{\eta} \right)^2 \cdot R_C \cdot t$$

ó $$P = N \cdot \left(\frac{V_C \cdot \Delta c \cdot z \cdot F}{\eta} \right)^2 \cdot R_C$$

P: required Power (J/s)

- Electrodialysis (ED)

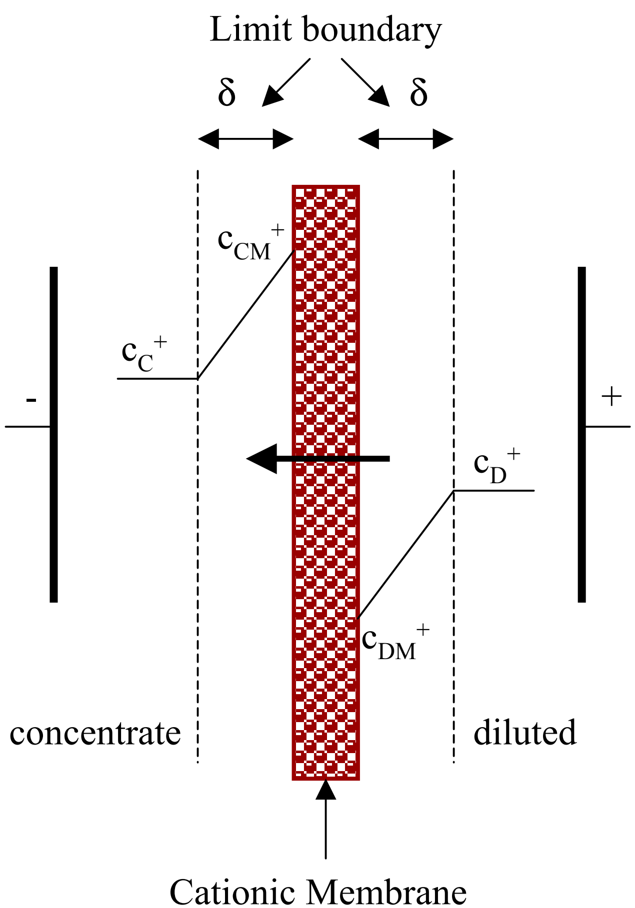
Where, the required specific energy, (J/m^3), is

$$\hat{E} = \frac{E}{N \cdot V_C \cdot t} = V_C \cdot \left(\frac{\Delta c \cdot z \cdot F}{\eta} \right)^2 \cdot R_C$$

La cell resistance can be estimated from a model based on series of resistances where the resistances to transport are considered through two membranes and the compartments concentrate and diluted.

• Electrodialysis (ED)

- How to determine operational *i*?



• Cation Transport

$$\frac{i}{F}\cdot t_M^+ = D\cdot\frac{z\cdot\left(c_D^+ - c_{DM}^+\right)}{\delta} + \frac{i}{F}\cdot t^+$$

$$i = \frac{D\cdot F\cdot z\cdot\left(c_D^+ - c_{DM}^+\right)}{\delta\cdot\left(t_M^+ - t^+\right)}$$

If $c_{DM}^{+} = 0$

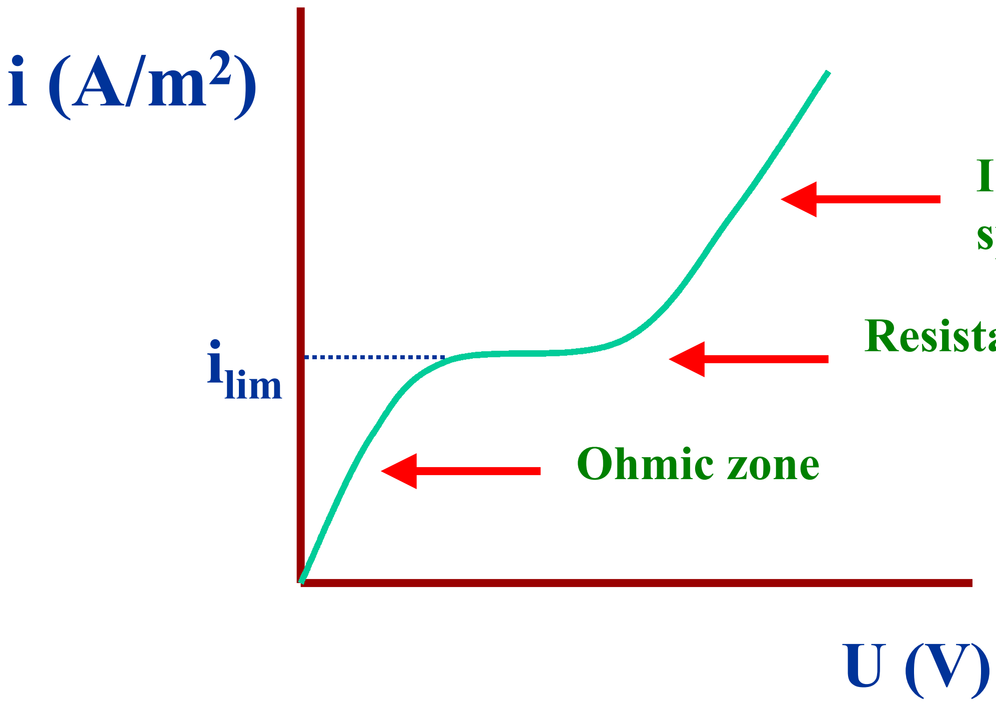
$$i_{lim} = \frac{D\cdot F\cdot z\cdot c_D^+}{\delta\cdot\left(t_M^+ - t^+\right)}$$

Usually: $i = 0.8\cdot i_{lim}$

t: transport number
D: diffusion coefficient

• Electrodialysis (ED)

- Intensity Evolution versus applied potential



- Electrodialysis (ED)

- Fields of application:
  Water desalination.

- Competing to RO.

- Economically more interesting at very high or very salt concentrations.

- Other fields of application:
  Food Industry.
  Treatment of heavy metal polluted water.

- Electrodialysis (ED)

- Examples:

√ Production of drinking water from salty water.

√ Water softening.

√ Nitrate removal.

√ Lactose demineralization.

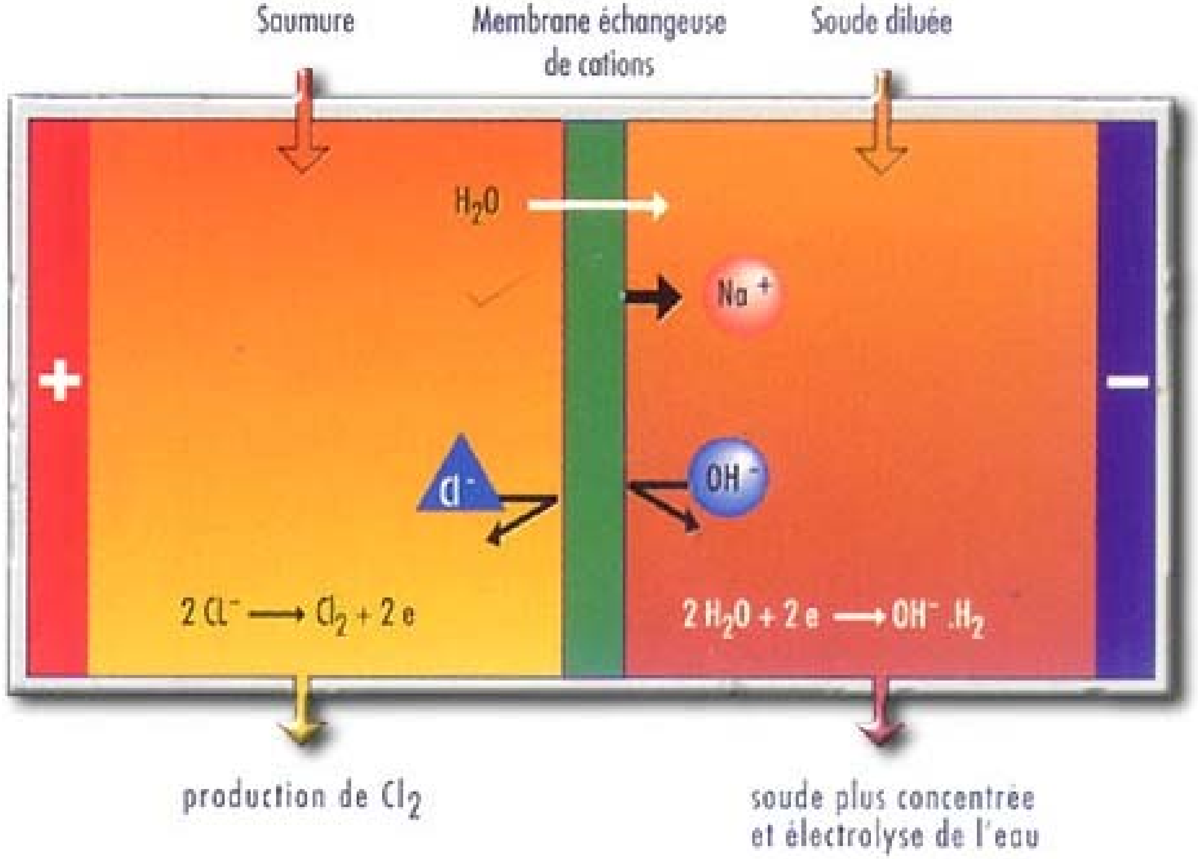
√ Acid removal in fruit juice.

√ Tartrate removal from wines.

√ Heavy metal recovery.

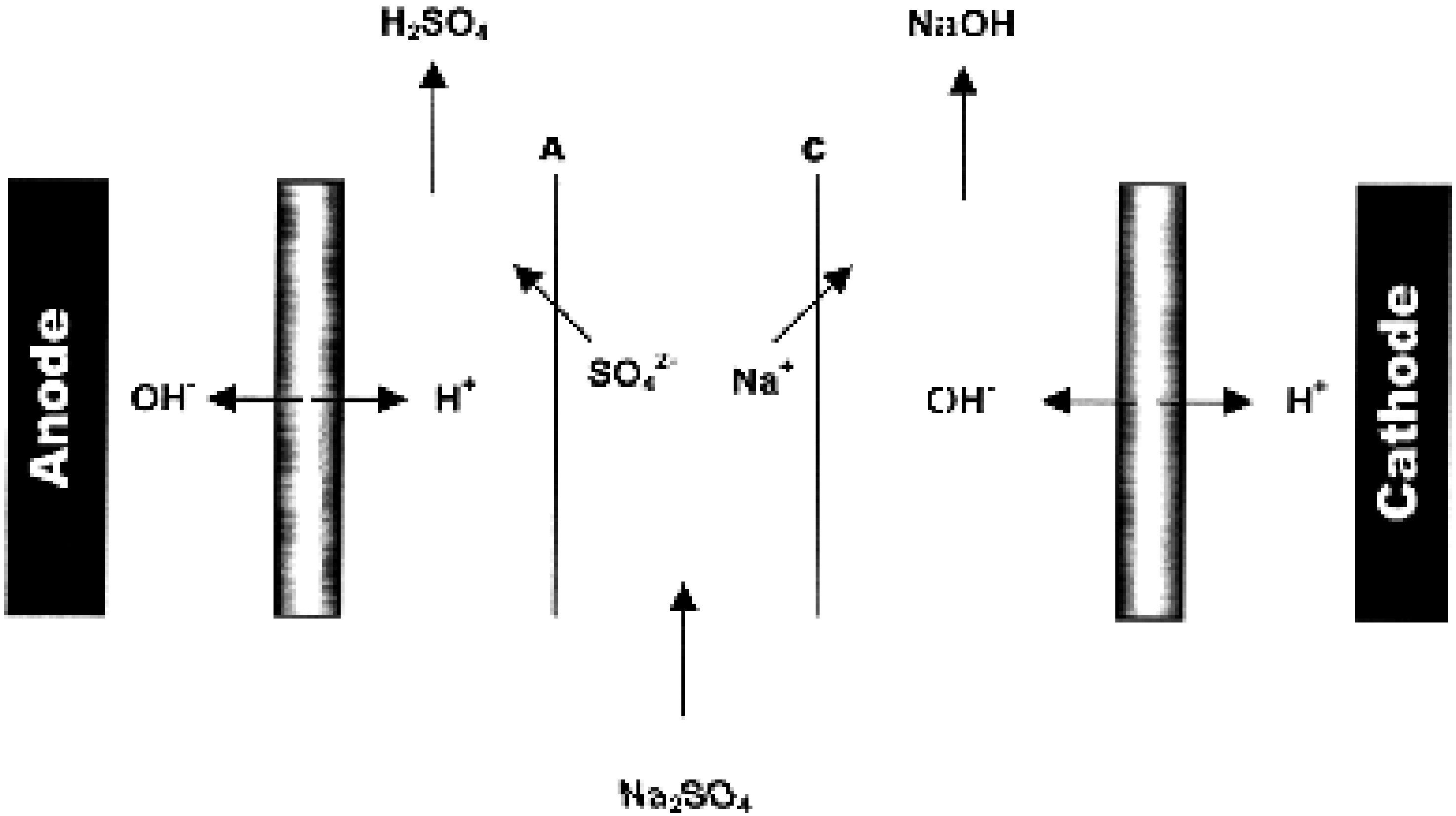
√ Production of chlorine and sodium hydroxide.

- Electrodialysis (ED)



electrolytic Cell for the production of chlorine and sodium hydroxide with cationic membrane.

- Electrodialysis (ED)



Electrolytic cell for the production of sulfuric acid and sodium hydroxide with bipolar membrane.