Feasibility of alkaline water electrolysis with cation-selective membrane

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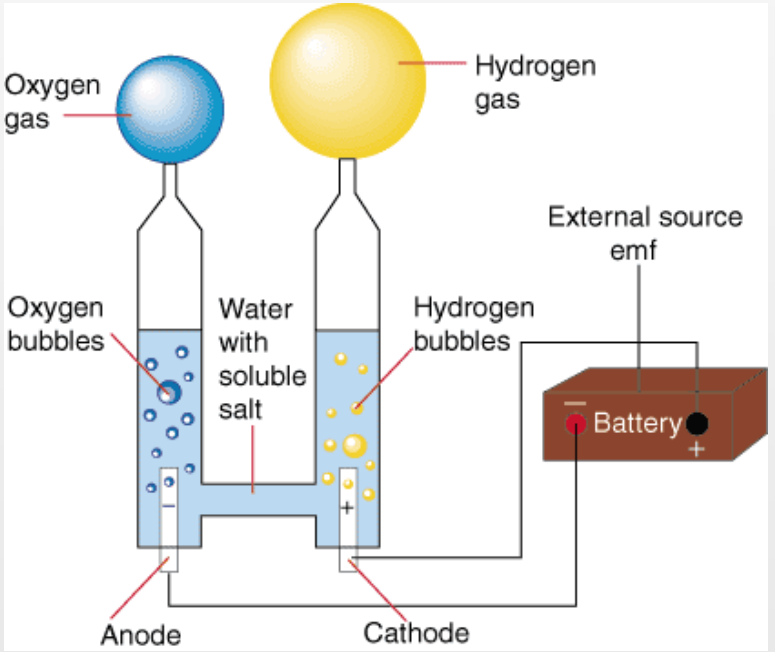
Water electrolysis process

- Direct method of producing hydrogen
- Inexhaustible storage material: WATER
- Highest hydrogen quality
- Zero emmision → clean process

- High operating costs
  → high cost of hydrogen
  → little extended process (cca 5 %)

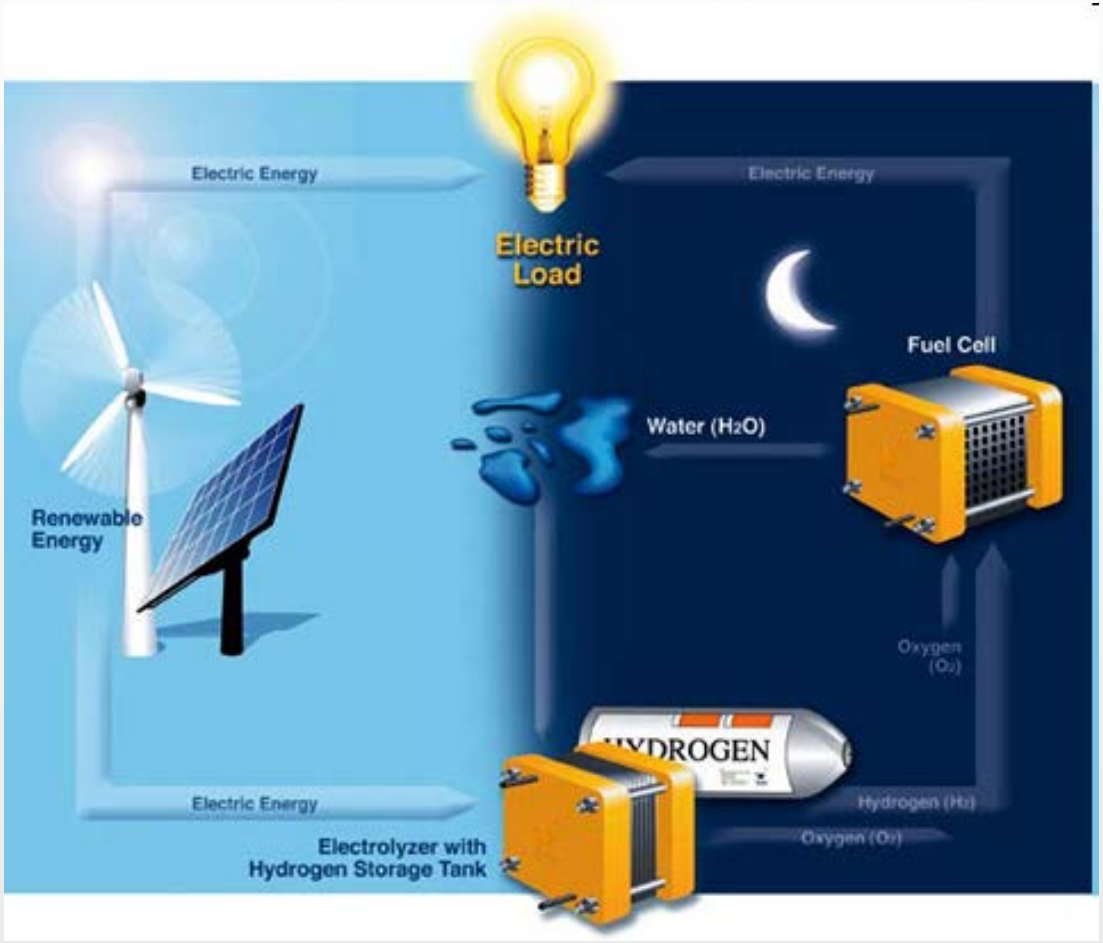
- Water electrolysis
  - Alkaline
  - PEM (Acidic)
  - High-temperature
  - Electrolysis of brine (hydrogen as byproduct)



Schema of water electrolysis [1]

[1] www.instructables.com/id/Separate-Hydrogen-and-Oxygen-from-Water-Through-El

Water electrolysis in energy storage



h-tec

unavoidable step in hydrogen production from alternative sources

process flexibility - required

Industrial alkaline water electrolysis

- **Electrolyte:** 25 – 35 % (wt.) KOH
- **Temperature:** 70 – 90 °C
- **Anode:** Nickel
- **Cathode:** Nickel, Steel
- **Separating partition:** Diaphragm
  - asbestos, ceramic, polymer, composite
- **Operating prassure:** 1 – 30 Bar

NEL hydrogen electrolyzer [1]

- **Advantage:** Low investment cost, simple construction – well matured process
- **Disadvantage:** Higher power consumption (U = 1.8 – 2.1 V), larger dimensions (compared to PEM electrolysis), asbestos diaphragm (thickness, electrochemistry properties)

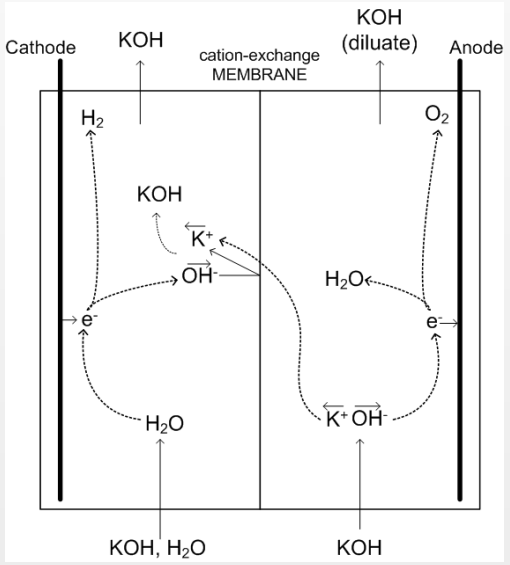
[1] http://www.nel-hydrogen.com

Alkaline water electrolysis with Nafion®

Replacement of asbestos diaphragm by Nafion® membrane

- Compared to industry electrolysis
  - Reduced inter-electrode distance
  - Reduced device dimensions
  - High membrane cost
- Compared to PEM electrolysis
  - Low cost catalysts
  - Lower mobility of K^+ / Na^+ ions (vs H^+)

  ⟹ higher cell voltage, lower efficiency

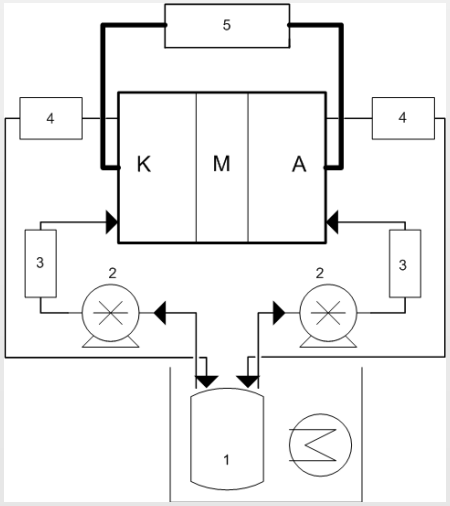


- Additional benefits
  - Allows to provide additional process to hydrogen production – e.g.: **caustic concentration from diluted solutions**
  - Possibility to raise temperature (> 150 °C) ⟹ reduction of the cell voltage

Experimental

Electrolyzer

- Membrane: Nafion® N 117 (20 cm^2)
- Anode: Ni plate, Ni expanded mesh
- Cathode: Ni (Fe) plate, Ni (Fe) expanded mesh
- Cell arrangement: space between electrodes and membrane
  - spacer (1 mm)
  - expanded metal (zero-gap)



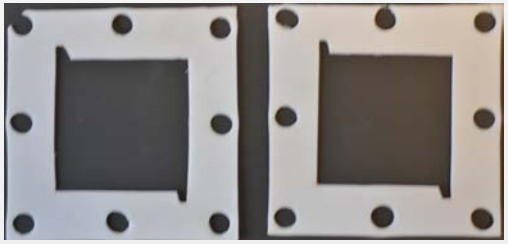
Experimental conditions

- Electrolytes
  - KOH vs. NaOH
  - different concentrations (5 to 25 % wt.)
  - different temperatures (25, 50 and 73 °C)
  - volume: 0.5 dm^3
- Current density (125 to 500 mA/cm^2)
- Mode of operation
  - Load curves – linear voltametry

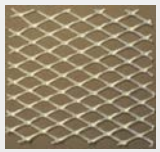
Electrolyzer construction

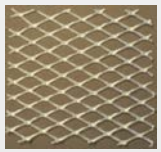
Ni smooth plates electrodes

Teflon frames

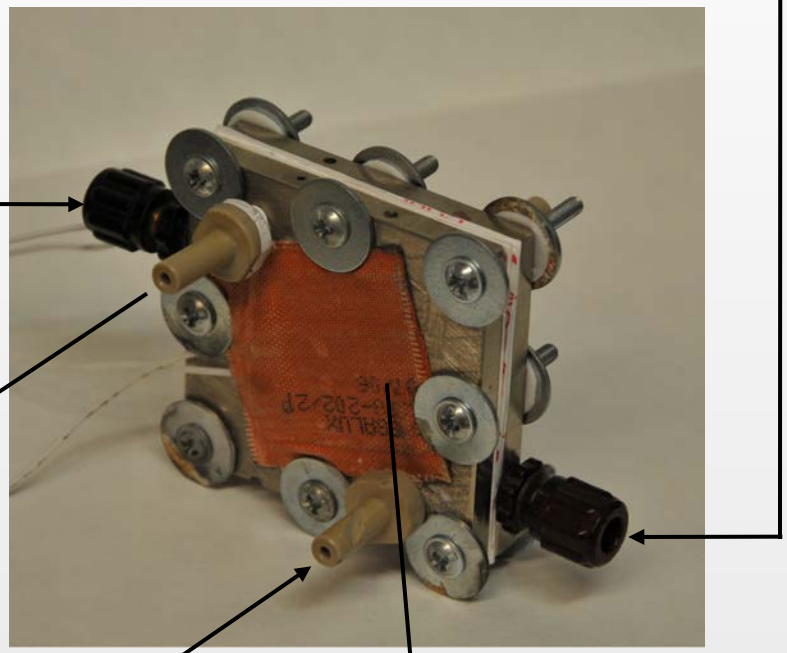


Spacers used

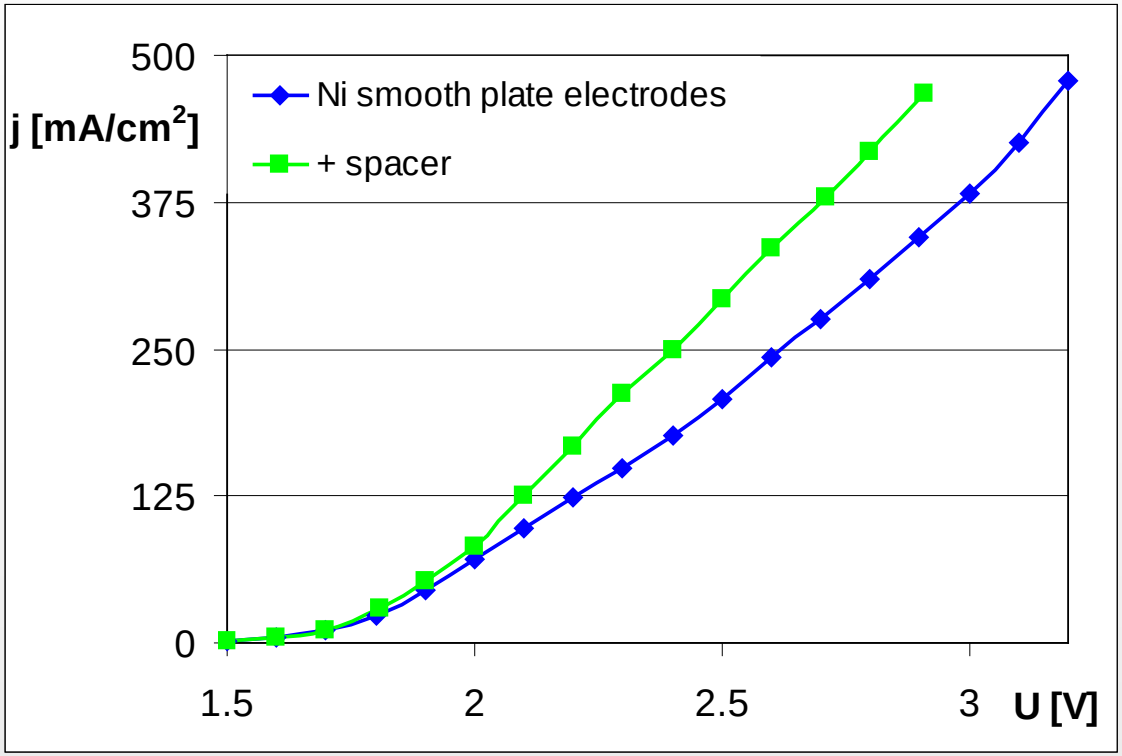




Nafion® membrane



Influence of spacer



Electrolysis of 15 % KOH, 73 °C, 120 ml/min electrolyte flow.

Prevent sticking the membrane to the electrodes + better electrolytes distribution

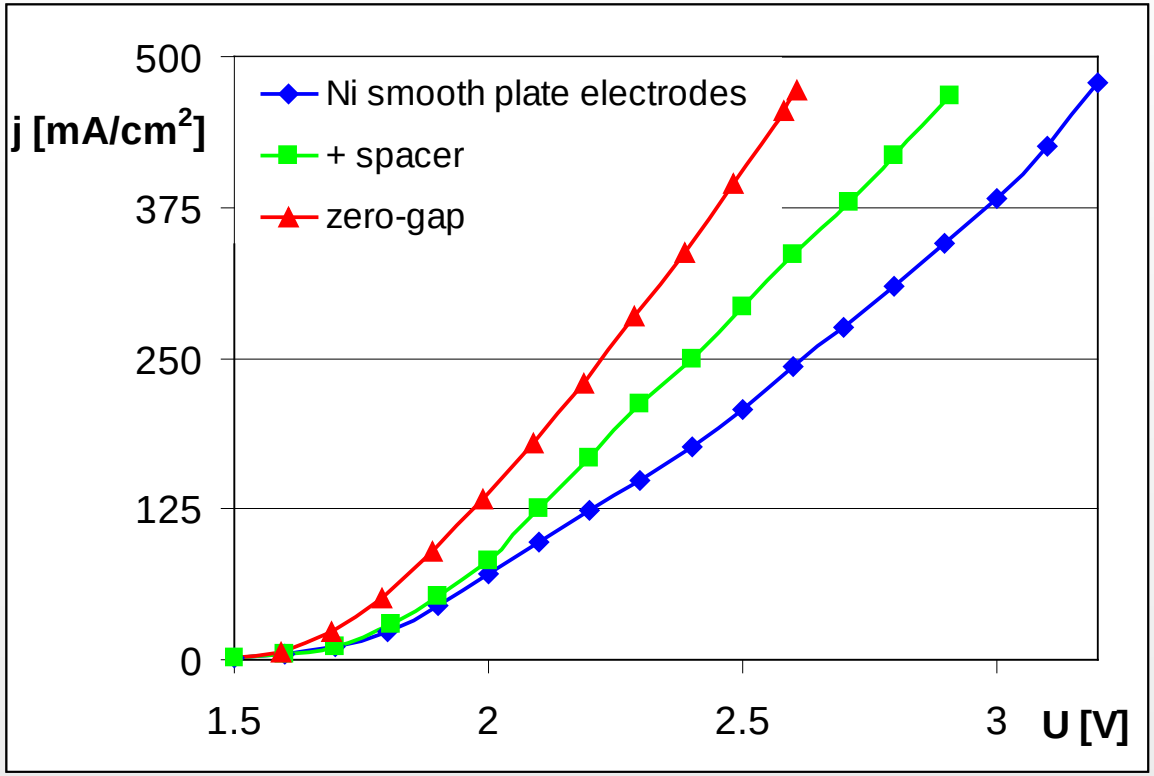
Expanded metal - Zero-gap arrangement

Ni plate with flow channels

Ni expanded mesh

Zero-gap electrode

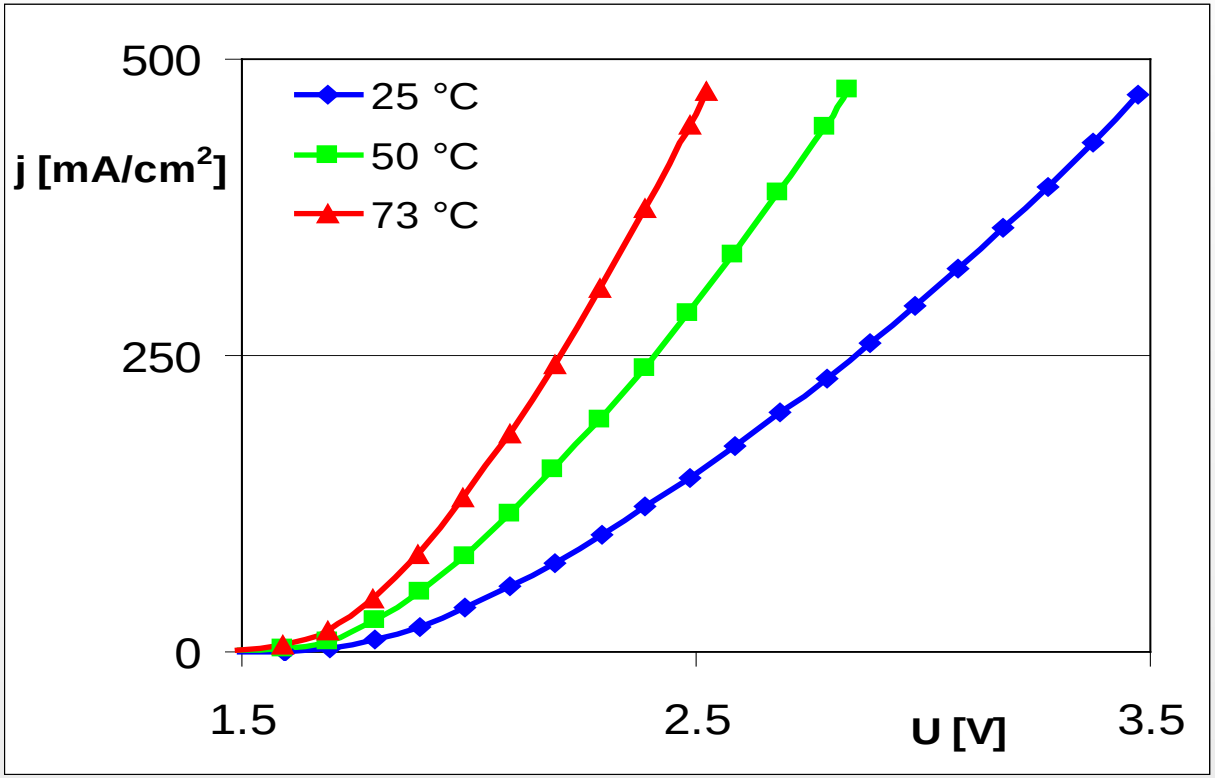
Zero-gap arrangement



Electrolysis of 15 % KOH, 73 °C, 120 ml/min electrolyte flow.

Zero-gap = minimal inter-electrode distance + improved construction = better electrolyte distribution and bubbles dissipation ⇒ Improvement about 35 % (measured at 2.2 V)

Influence of operating temperature

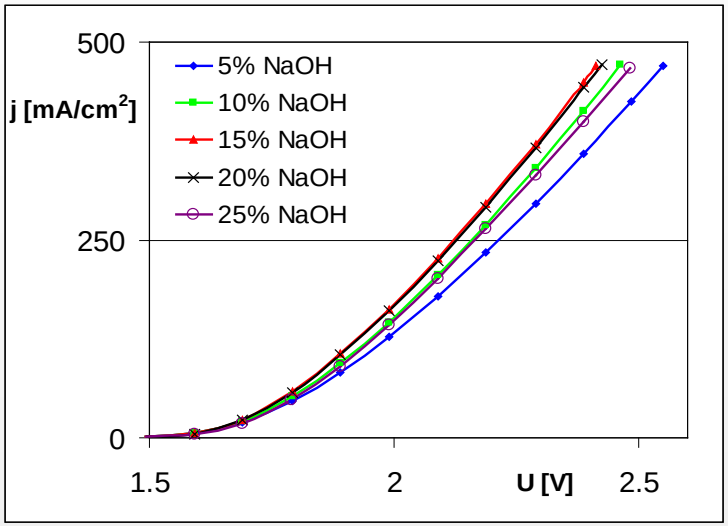


Electrolysis of 10 % NaOH, different temperature, 120 mL/min.

- Energy parameters strongly influenced by temperature
  - space for another improvement

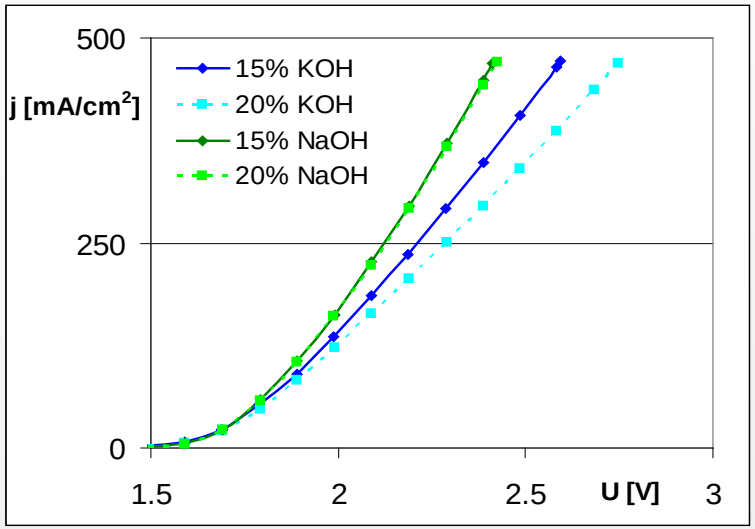
Influence of operating parameters

Concentration

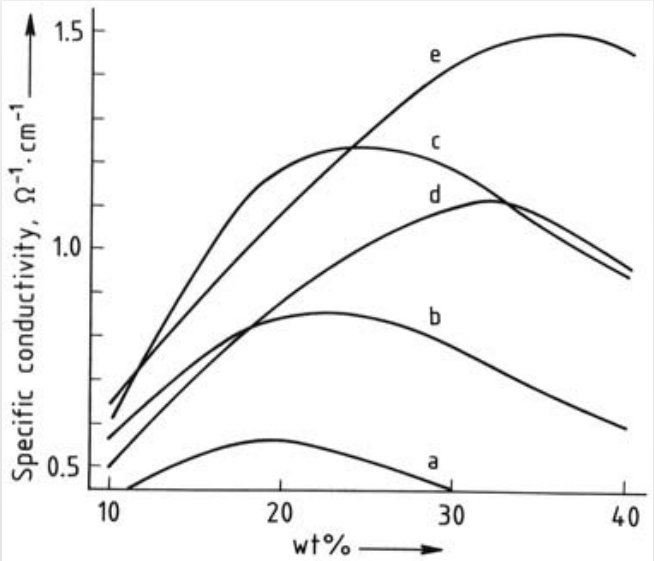


Electrolysis of NaOH, 73 °C, 120 mL/min.

KOH vs. NaOH



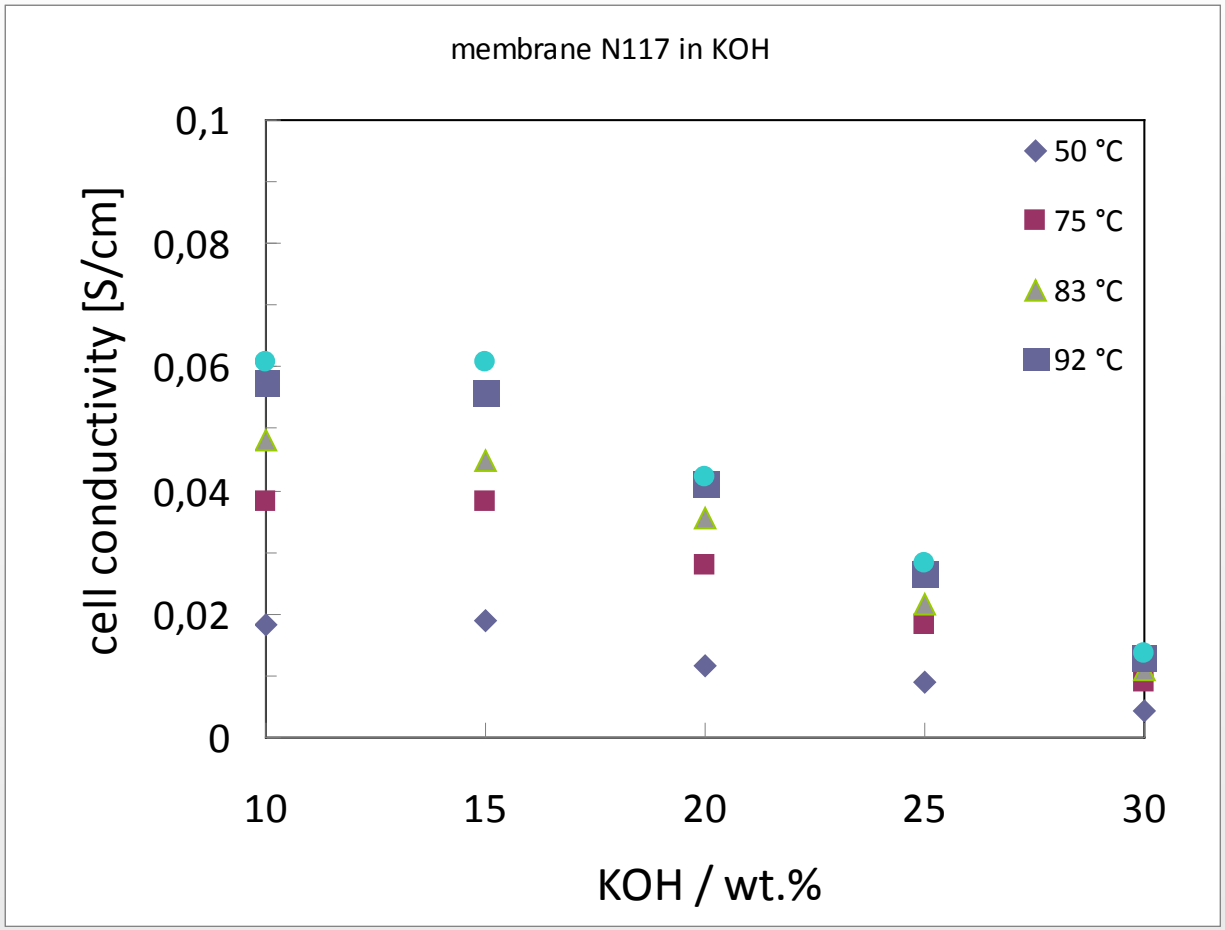
Electrolysis of KOH vs. NaOH, 73 °C, 120 mL/min.



- NaOH better than KOH
- 15 – 20 % (wt.) NaOH best results

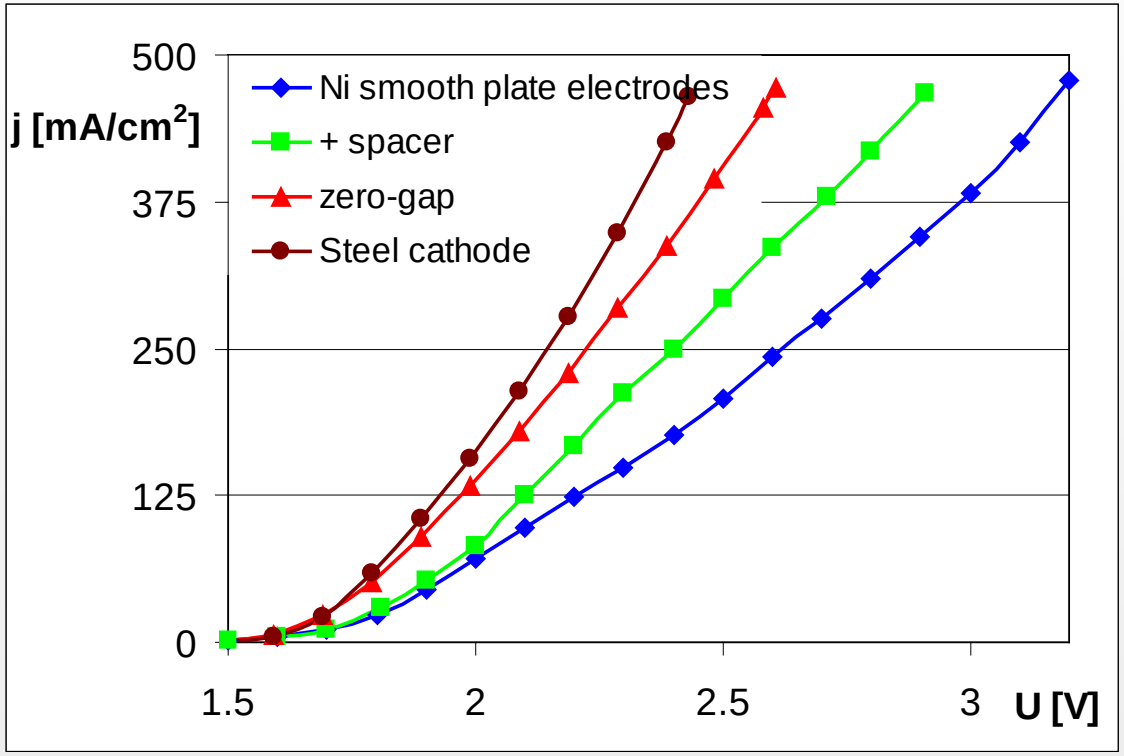
Ullmann encyclopedia:
a-NaOH(40 °C), b-NaOH(60 °C),
c-NaOH(80 °C), d-KOH(60 °C),
e-KOH(80 °C)

Cell conductivity



- decrease of conductivity due to membrane conductivity loss (hydration)
- similar behavior for NaOH

Steel cathode

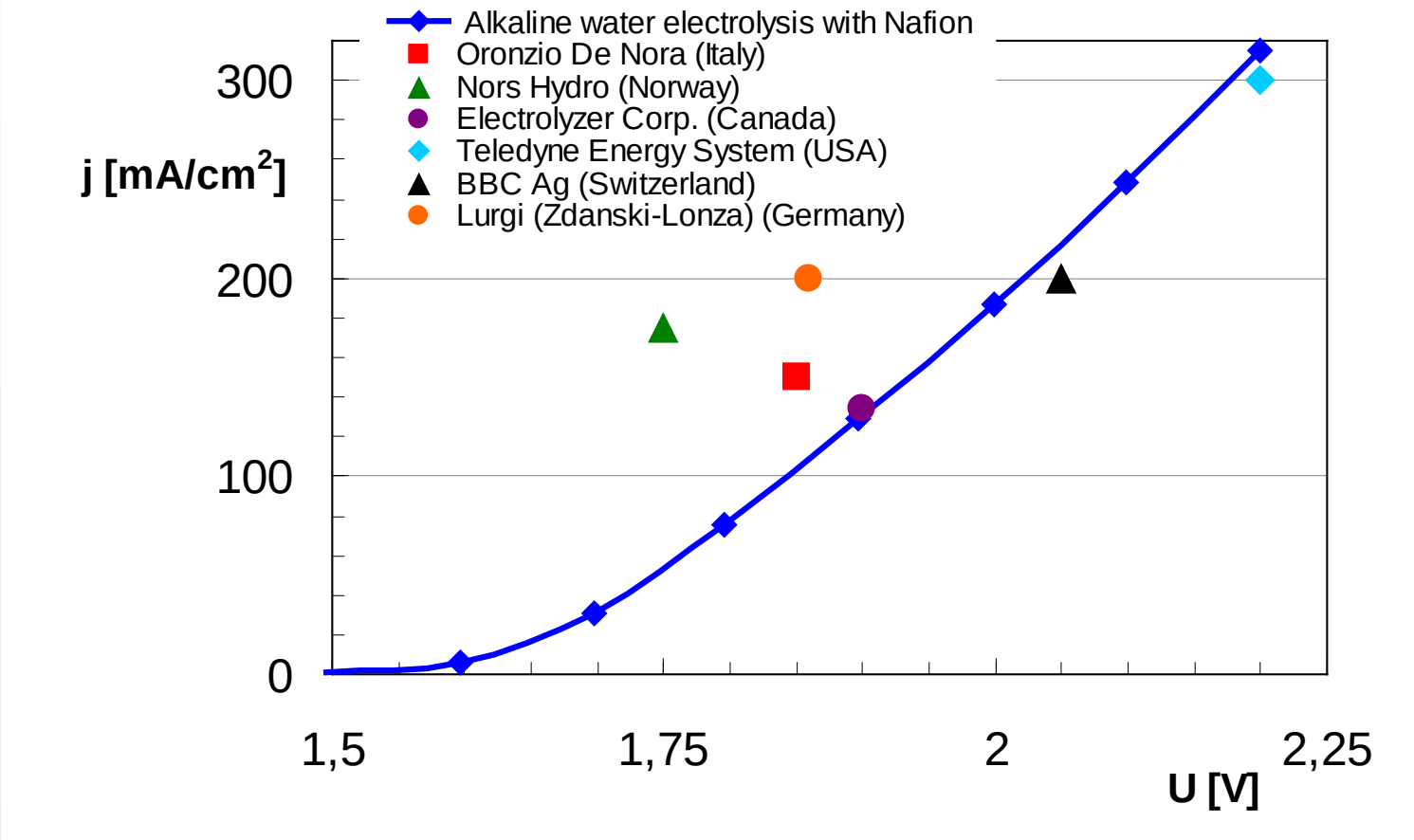


Electrolysis of 15 % KOH, 73 °C, 120 ml/min electrolyte flow.

Steel has lower hydrogen overvoltage than nickel ➡

➡ Improvement about 25 % (measured at 2.2 V)

Comparison with Industry



Results comparable with industry alkaline water electrolyzers

- Space for another improvement (temperature, catalyst)

Conclusions

- Alkaline water electrolysis with Nafion® membrane is feasible.
- Zero-gap arrangement – best results from tested construction type.
- Results comparable with industrial alkaline water electrolysis.
- Low electrolyte concentration - more flexible operation
- Optimal operating parameters:
  - hydroxide concentration: 15 – 20 % (wt.)
  - NaOH better than KOH

- Next possibility for another improvement in the future:
  - higher temperature (120 – 130 °C)
  - using catalyst
  - cell design (thinner membrane)

Thank you for attention