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)

Water electrolysis in energy storage

unavoidable step in hydrogen production from alternative sources

process flexibility - required

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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 pressure:** 1 – 30 Bar
- **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)

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 cm²)
- 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 dm³
- Current density (125 to 500 mA/cm²)
- Mode of operation
  - Load curves – linear voltametry
Electrolyzer construction

- Ni smooth plates electrodes
- Teflon frames
- Spacers used
- Nafion® membrane

Diagram with labeled parts:
- Current feeders
- Electrolyte inlet
- Electrolyte outlet
- Heating
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

Zero-gap electrode

Ni expanded mesh
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

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

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

- 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

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