PROCESS INTENSIFICATION: Water Electrolysis in a Centrifugal Acceleration Field

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Outlines

- Introduction
- Rig design
- Experimental results
- Discussions & conclusions
Introduction: Background

- Green energy tends to fluctuate. However, consumers need a stable power supply;
- One solution to this problem is to store pressurised hydrogen from an electrolytic cell then recover power via a fuel cell;
- The efficiency of the conversion needs to be improved
Introduction: Background

Bubble blocking around electrodes in 1-g field and Micro-g field (Matsushima et al 2003)
Elevated acceleration fields increase the buoyancy force \((\Delta \rho \cdot g)\) for gas-liquid systems;

This raises bubble terminal velocities, interfacial shear stress and flooding rates;

When applied to water electrolysis, high \(g\) eliminates inter-electrode gas bubbles even at high current densities;

Close electrode spacing and high-area electrodes may be exploited without incurring gas blinding problems;
Introduction: Objectives

• The present study was aimed at establishing the **feasibility and performance** of a rotary water electrolyser;

• Of the particular interest was the possibility of very thin cells and high area electrodes so as to give **high volumetric performance at high energy efficiency**;

• Ultimately a bipolar rotary cell stack is envisaged which will operate effectively with **intermittent power** sources.
• **General**
  - In order to provide a comparison with conventional technology, a static cell was operated under similar conditions to those used for the rotary cell.

• **Variables covered**
  - Current density: 0-20 kA/m²;
  - Rotation acceleration: 1-65 g;
  - Electrolyte concentration: 10%-40% w/w KOH/water;
  - Temperature: Ambient - 80°C;
  - Sundry electrode structures based on nickel and stainless steel
Rig Design: static rig (Cell)

Ni Mesh: Actual area/project area = 2.2; thickness = 0.5 mm
DC transmission: an unsuccessful case

- The envisaged cell stack (D~0.5 m) requires ~2000 Amps.
- Conventional slip rings are bulky and generate significant frictional and resistive losses.
- A low-melting alloy (Cerebend) bath at first performed well but quickly developed a mousse-like consistency.

Molten Metal Baths using Cerebend:
Bi- 50%,
Pb-26.7%
Sn-13.3%
Cd-10%
in w/w.
Rig Design: Rotary rig

- Driving Motor
- Electrolyser Cell
- Telemetry Pickup
- Electrolyte Pump
- Data Logger
- Current Supply

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Rig Design: Schematic of the Cell

- Shaft (Left)
- Shaft (Right)
- Gaskets
- Membrane
- Anode (Nickel Mesh)
- Cathode (Nickel Mesh)
- Electrolyte Sucker tube
- Electrolyte Feeder tube
- Current Feeder (In)
- Current Feeder (Out)
- Metering Wire
Rig Design: Electrode and diaphragm
Static rig results: Effect of inter-electrode space

Extra space for gas removal reduces cell voltage
Electrode: 1 layer Ni mesh; 30% KOH, 80 C.

Time trace of cell voltage in 1-g rig: Current density 10kA/m²

More difficult gas removal gives higher cell voltage level and more violent voltage fluctuations

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Static rig results: Electrode material

Potential v.s. Current Density for Different Materials, 30% KOH w/w, 75°C, 1mm Spacer in each side of the diaphragm

1 Layer of Ni Mesh, Inc  
1 Layer of Ni Mesh, Dec  
1 Layer Cat. Ni, Inc  
1 Layer Cat. Ni, Dec  
SS plate, Inc  
SS plate, Dec

Increase of actual area of electrodes helped to reduce the cell voltage, catalyst coating has little effect
Static rig results: Electrode structure

Extra mesh layers reduces cell voltage especially at high current density

Potential v.s. Current Density, Nickel Mesh, 30% KOH w/w, 75°C
1mm spacer in each side of the diaphragm

1 Layer of Ni Mesh, Inc
1 Layer of Ni Mesh, Dec
2 Layers, Inc
2 Layers, Dec
3 Layers, Inc
3 Layers, Dec
Static rig results: Alkaline concentration

Potential v.s. Current Density, 3 Layers of Nickel Mesh, 75C, Diaph Spaced

Optimum electrolyte concentration is around 30%
Summary

• As expected easier gas removal reduces cell voltage;
• Extra nickel electrode area tends to reduce cell voltage;
• Optimum electrolyte concentration is around 30%
Rotary rig results: Stainless steel foam

30% w/w KOH, 70°C, 0.5 mm spacer each side of diaphragm;
Electrode: 2 layers of stainless steel foam

Higee benefit achieved up to ~10 g

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Rotary rig results:
Multi-layer nickel mesh

Commercial pressurised electrolyser @ 4000 A/m² e.g. H₂ IGen 300/1/25

Electrode: 3 layers of Ni mesh

Higee benefit achieved up to ~10 g
Rotary rig results: Electrolyte concentration and temperature

Ambient temperature $T_{\text{bulk}}=81\,\text{C}$

Optimum electrolyte concentration was around 30%

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Rotary rig results: Electrolyte temperature

Current Density 13.5 kA/m\(^2\), 30% w/w KOH, 1 mm Spacer each side of diaphragm, 3 layers of Ni Mesh;

Cell Voltage, V

Ambient T

T=81 C

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Rotary rig results: Spacer geometry

Current Density 4.5 kA/m², 30% w/w KOH, Ambient T, with spacer each side of diaphragm, 3 layers of Ni Mesh

Cell Voltage, V

Rotation a/g

Spacer 1
Spacer 2
Spacer 3

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Multi-layer beneficial?  
Nickel mesh-Yes;  Stainless steel foam-No
Rotary rig results: Traces of cell voltage

**CD=13.5 kA/m²**

Current density=13.5 kA/m², KOH 30% w/w, 71°C, 0.5 mm spacer in each side of the diaphragm; 3 layers of Ni mesh

- **Acceleration=3.2 g**

Rotation acceleration=3.2 g, KOH 30% w/w, 71°C, 0.5 mm spacer in each side of the diaphragm; 3 layers of Ni mesh

Similarity exists between the trace with **high CD, High g** and the trace with **low CD, low g**

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Comparisons of Energy efficiency

<table>
<thead>
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<th>Energy Required System kWh/kg</th>
<th>HHV of Hydrogen (equivalent to 142 MJ/kg) kWh/kg</th>
<th>System Efficiency %</th>
<th>Production Pressure psig</th>
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<tr>
<td>Stuart: IMET 1000</td>
<td>53.4</td>
<td>39</td>
<td>73</td>
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<td>Teledyne: EC-750</td>
<td>62.3</td>
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<td>60-115</td>
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<td>Proton: HOGEN 380</td>
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<td>Norsk Hydro: Atmospheric Type No.5040 (5150 Amp DC)</td>
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<td>73</td>
<td>435 up to 10,000</td>
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<td>Avalence: Hydrofiller 175</td>
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<td><strong>This study</strong></td>
<td><strong>53.2</strong></td>
<td><strong>39</strong></td>
<td><strong>73</strong></td>
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</tbody>
</table>

- This study: pure nickel/stainless steel; atmospheric pressure
Conclusions

• The data telemetry system and current connector worked well;
• At normal cell operating conditions (30% KOH, ~75 C) most of the cell voltage benefits were achieved at low rotational speed (>10g);
• At 70 C Nickel mesh electrodes were more effective than stainless steel foam. Multiple layers also reduced cell voltage;
• The rotary cell voltage was about 0.25-0.5 V less than the equivalent static cell under similar operating conditions, depending on the current density;
• The cell voltages achieved without an effective electrode coating were comparable with the best industrial values using fully developed pressurised cells.
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