PROCESS INTENSIFICATION: Water Electrolysis in a Centrifugal Acceleration Field

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L Lao, C Ramshaw and H Yeung
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Outlines

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

Introduction: Background

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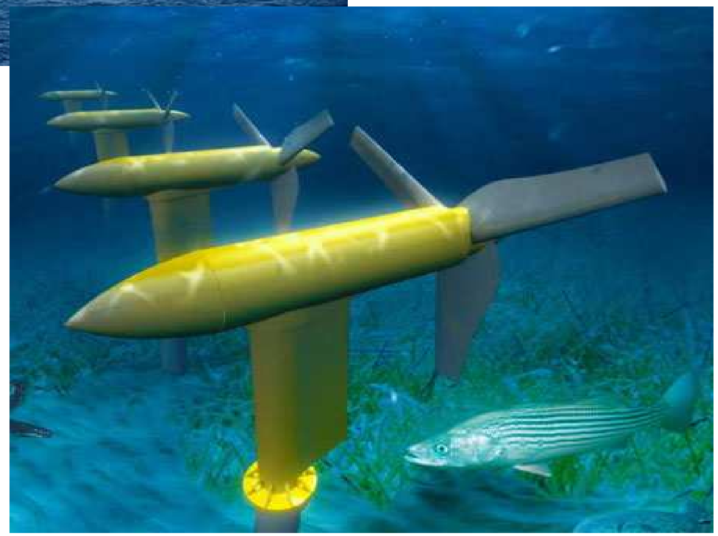
- Green energy tends to fluctuate. However consumers need a stable power supply;
- One solution to this problem is to store pressurised hydrogen from an electrolytic cell then recover power via a fuel cell;
- The efficiency of the conversion needs to be improved

Wind turbine



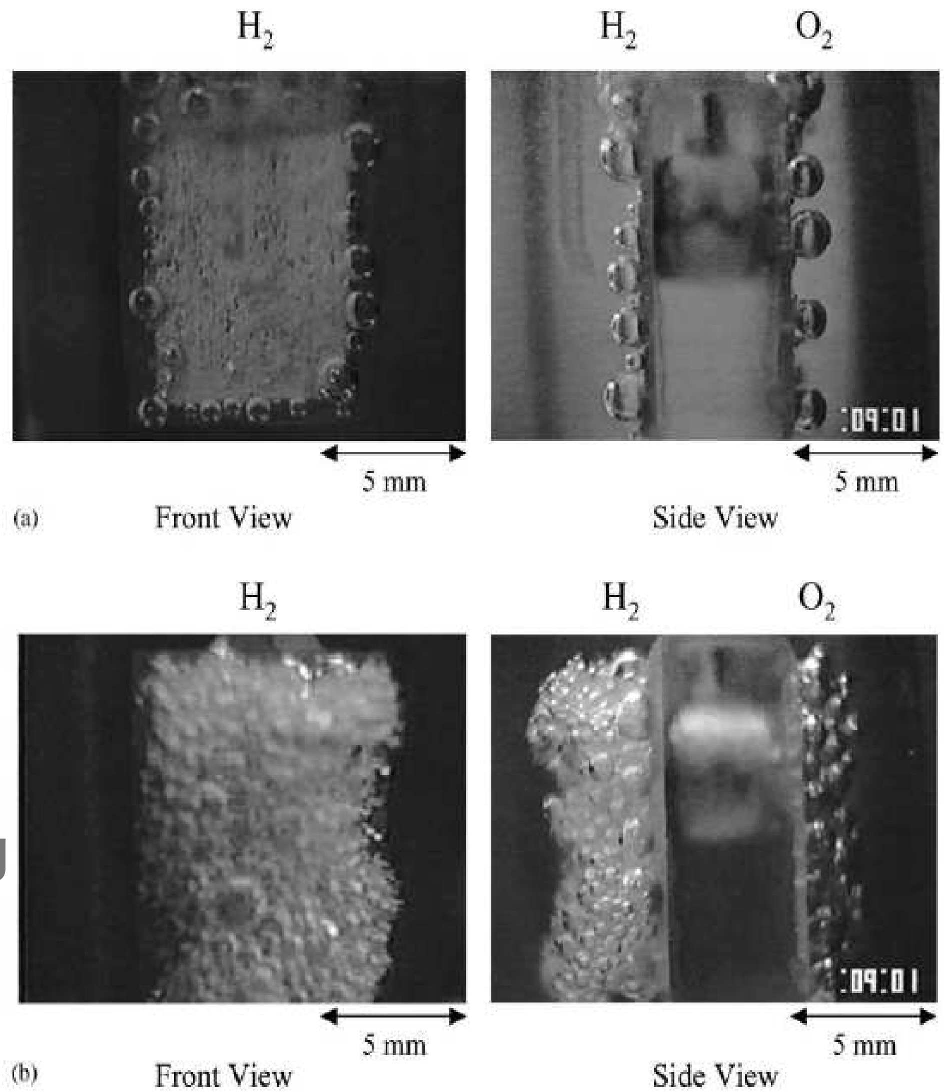
Tidal power

Introduction: Background

Bubble blocking Around electrodes in 1-g field and Micro-g field (Matsushima et al 2003)

1-g

Micro-g



Introduction: Background

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- Elevated acceleration fields increase the buoyancy force (***Δρ*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

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- 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.

Introduction: Project Scope

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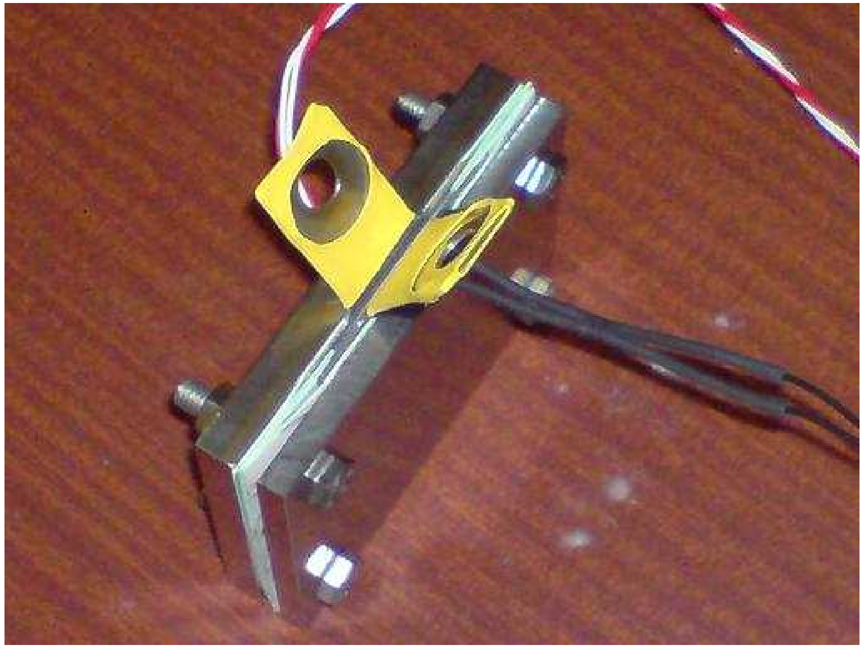
- **General**
  - In order to provide a comparison with conventional technology, a static cell was operated under similar conditions to those used for the rotary cell.
- **Variables covered**
  - Current density 0-20 kA/m2;
  - Rotation acceleration: 1-65 g;
  - Electrolyte concentration: 10%-40% w/w 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

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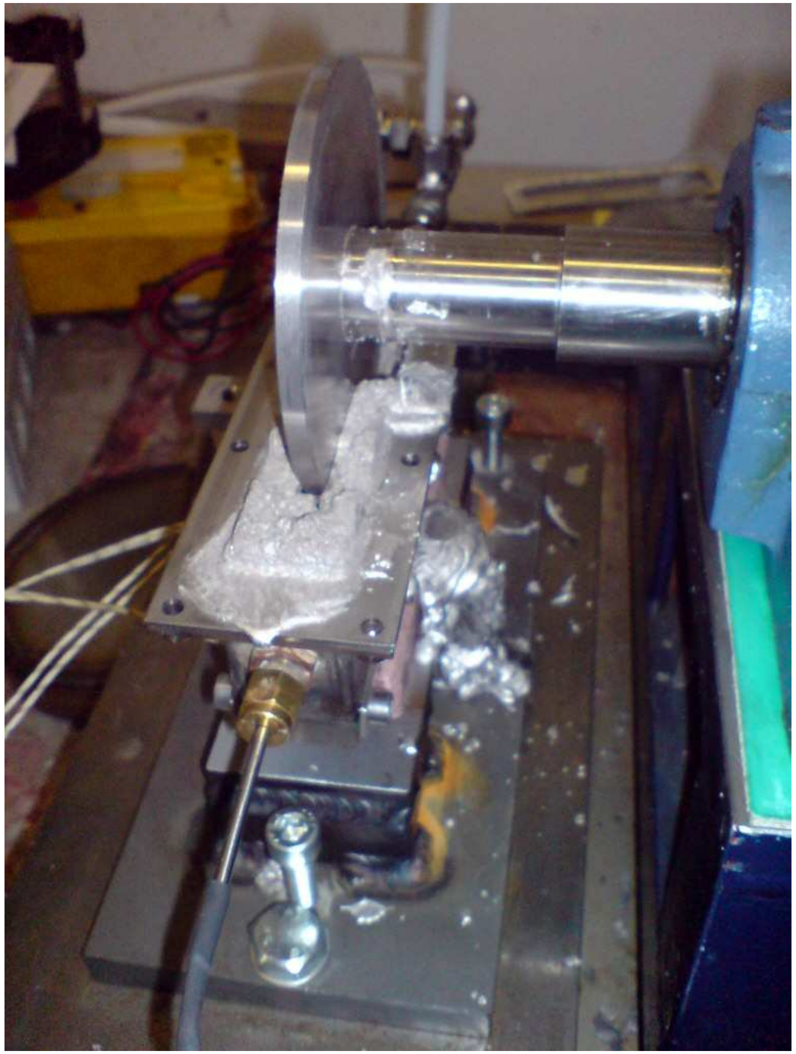
- The envisaged cell stack (D~0.5 m) requires ~2000 Amps.
- Conventional slip rings are bulky and generate significant frictional and resistive losses.
- A low-melting alloy (Cerebend) bath at first performed well but quickly developed a mousse-like consistency



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

Rig Design: Rotary rig

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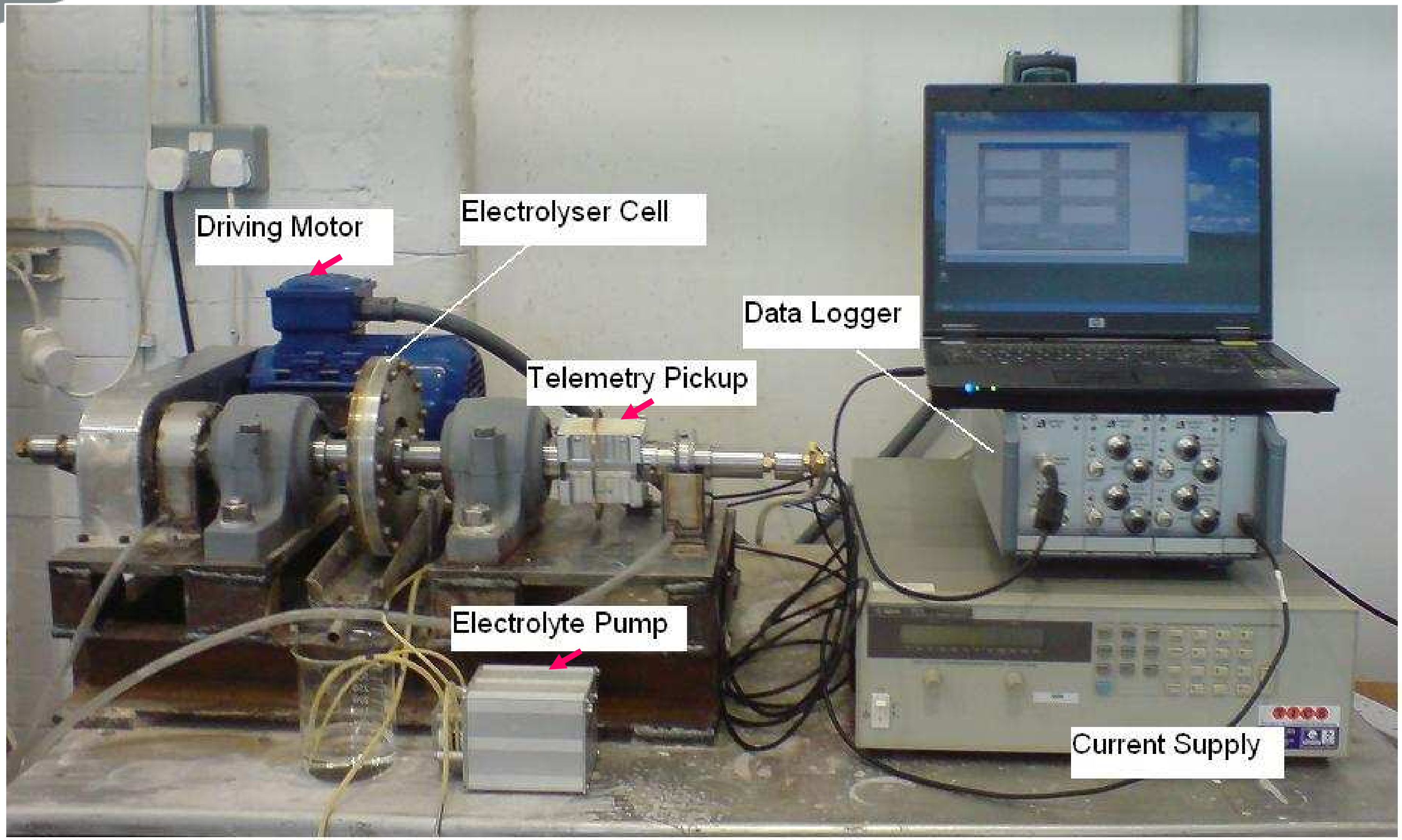

Rig Design: Schematic of the Cell

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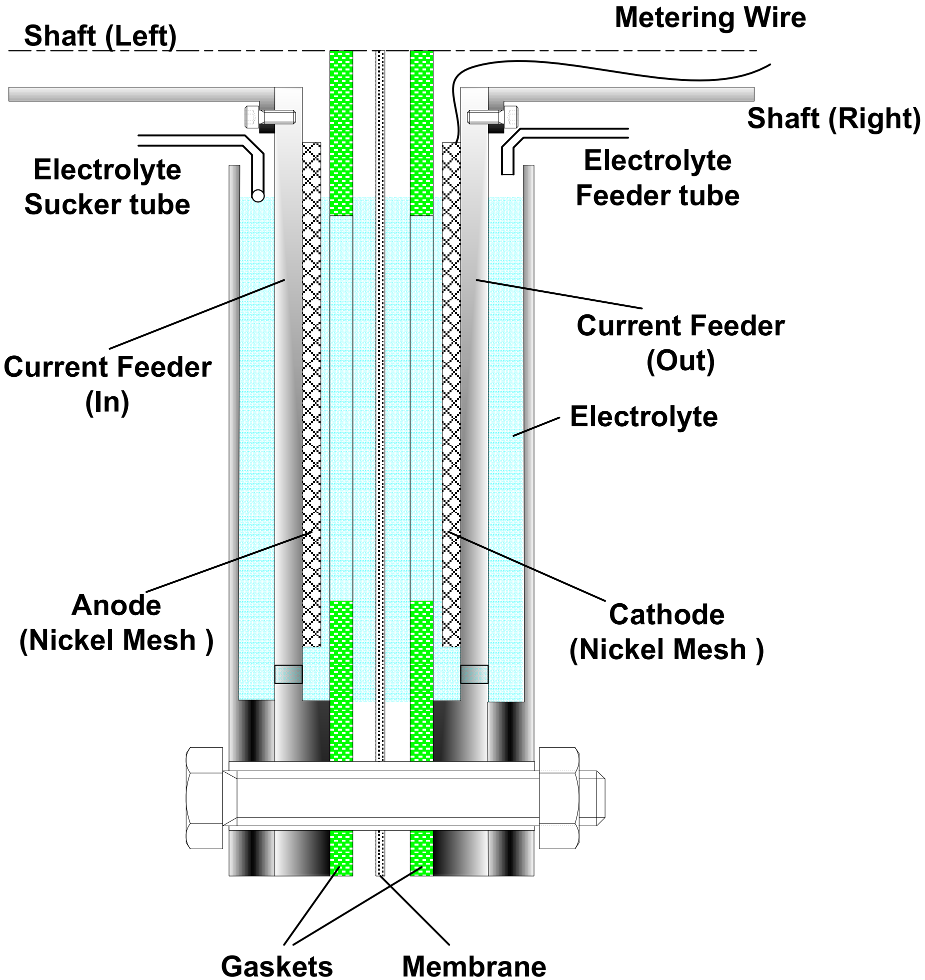

Rig Design: Electrode and diaphragm

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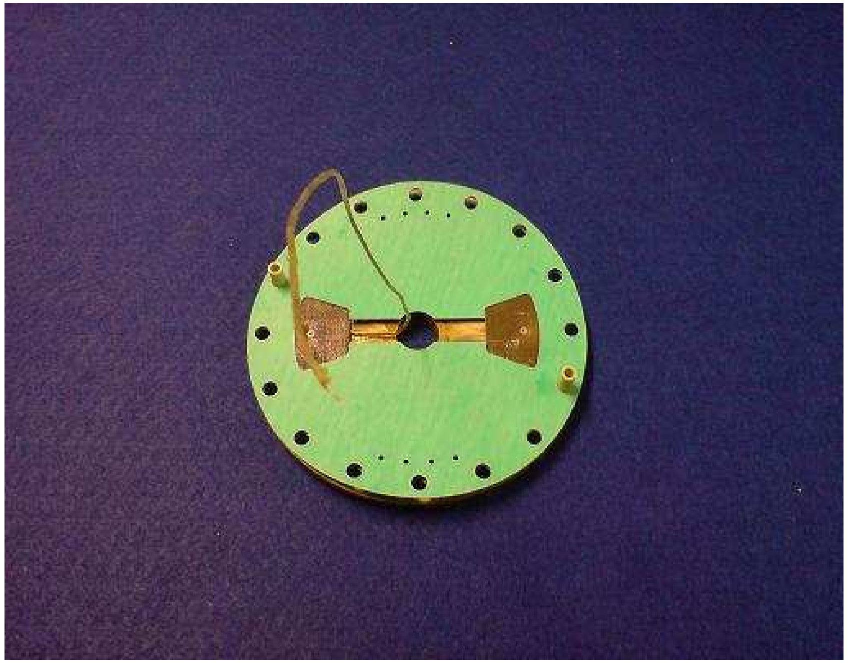

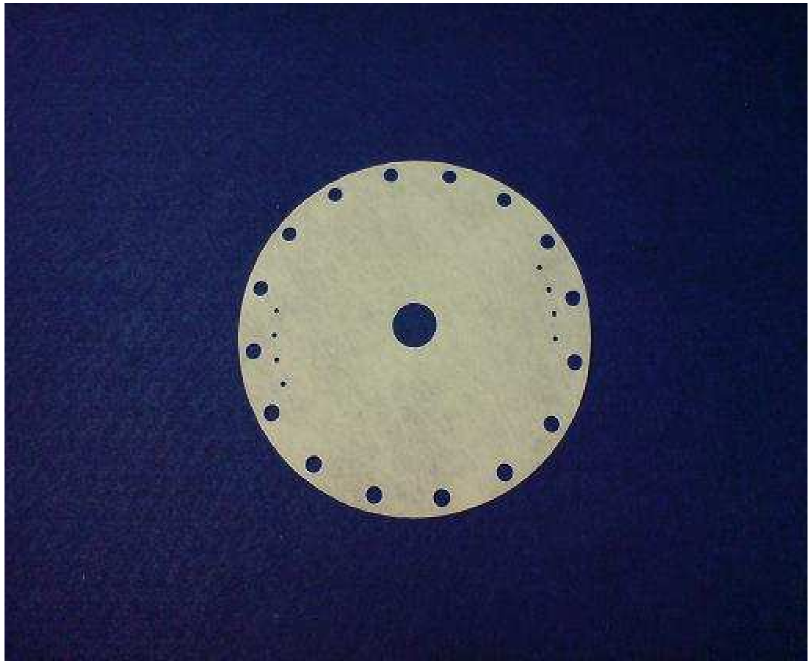

Static rig results: Effect of inter-electrode space

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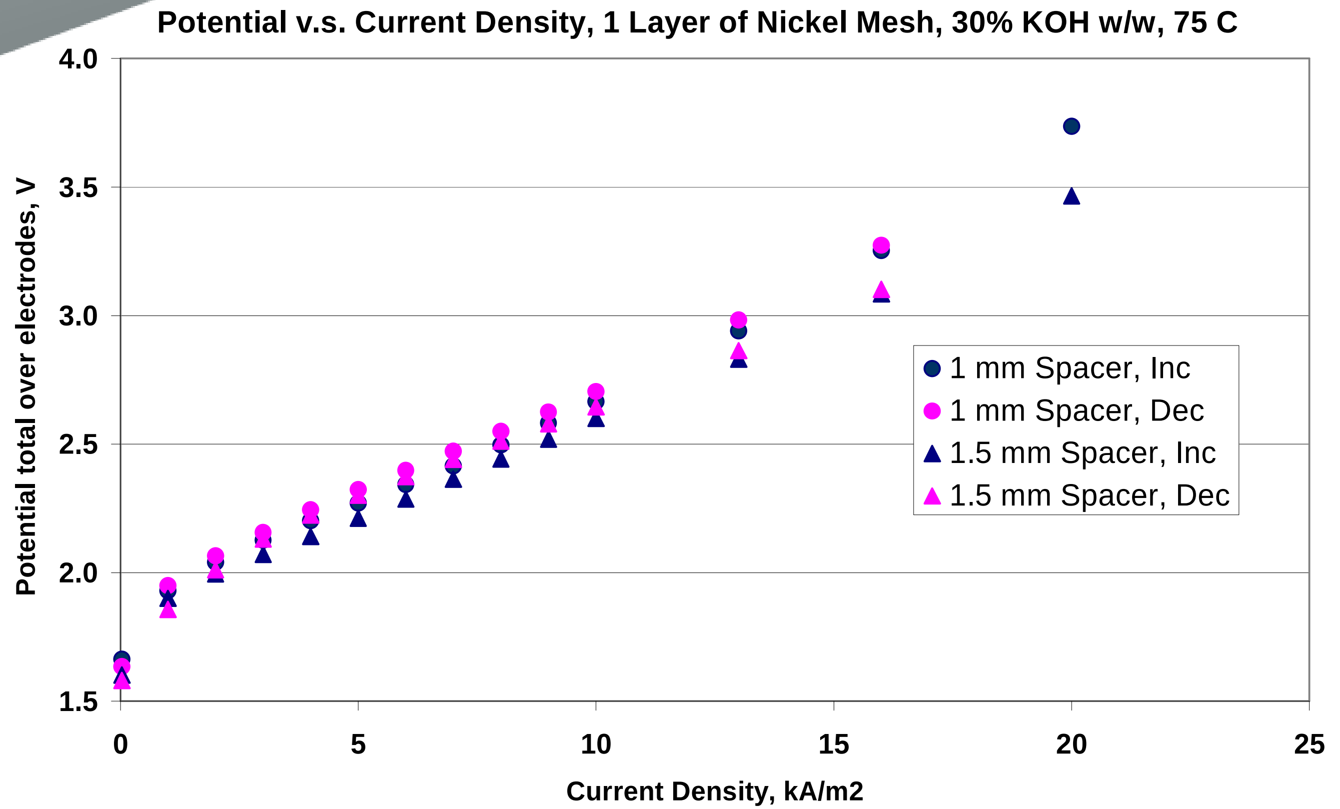

Extra space for gas removal reduces cell voltage

Static rig results: Effect of inter-electrode space

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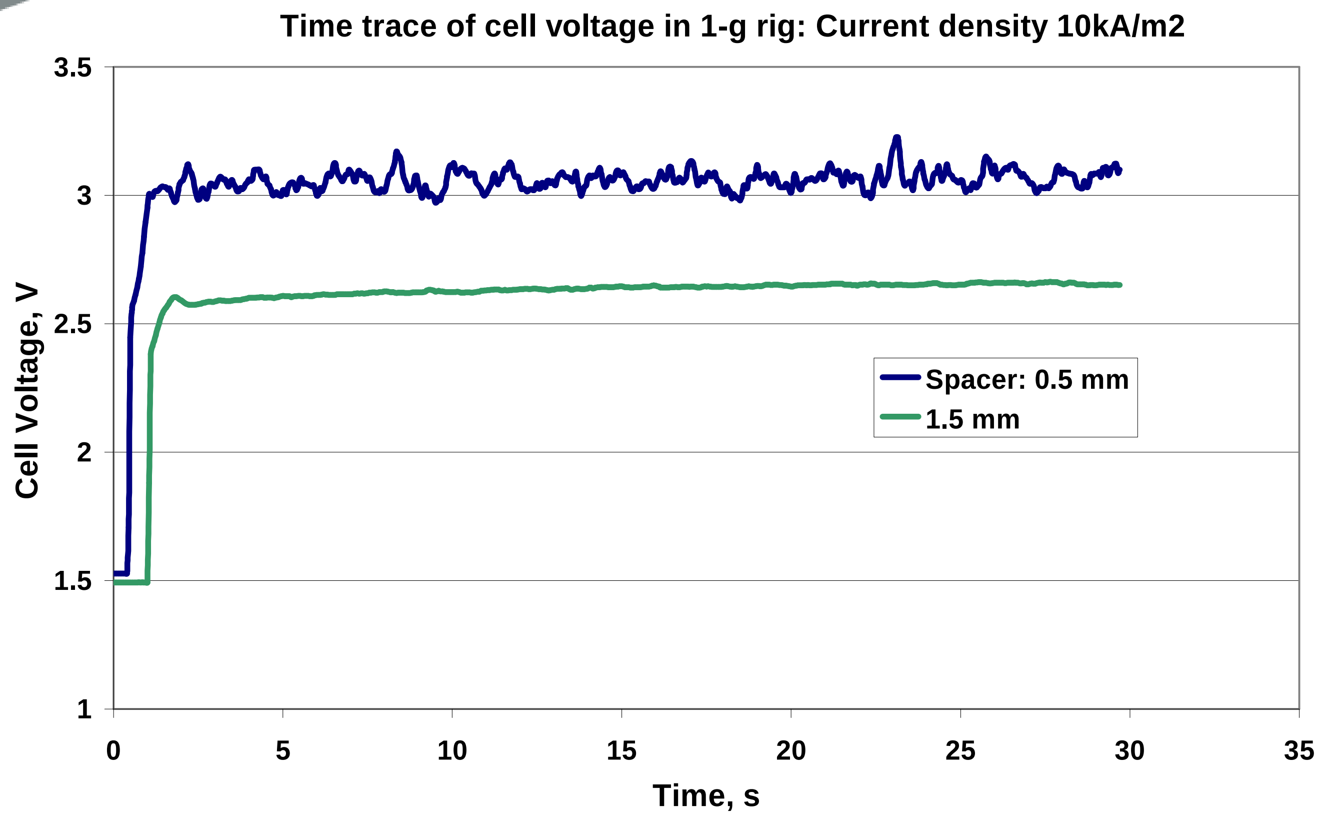
Electrode: 1 layer Ni mesh; 30% KOH, 80 C.



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

Static rig results: Electrode material

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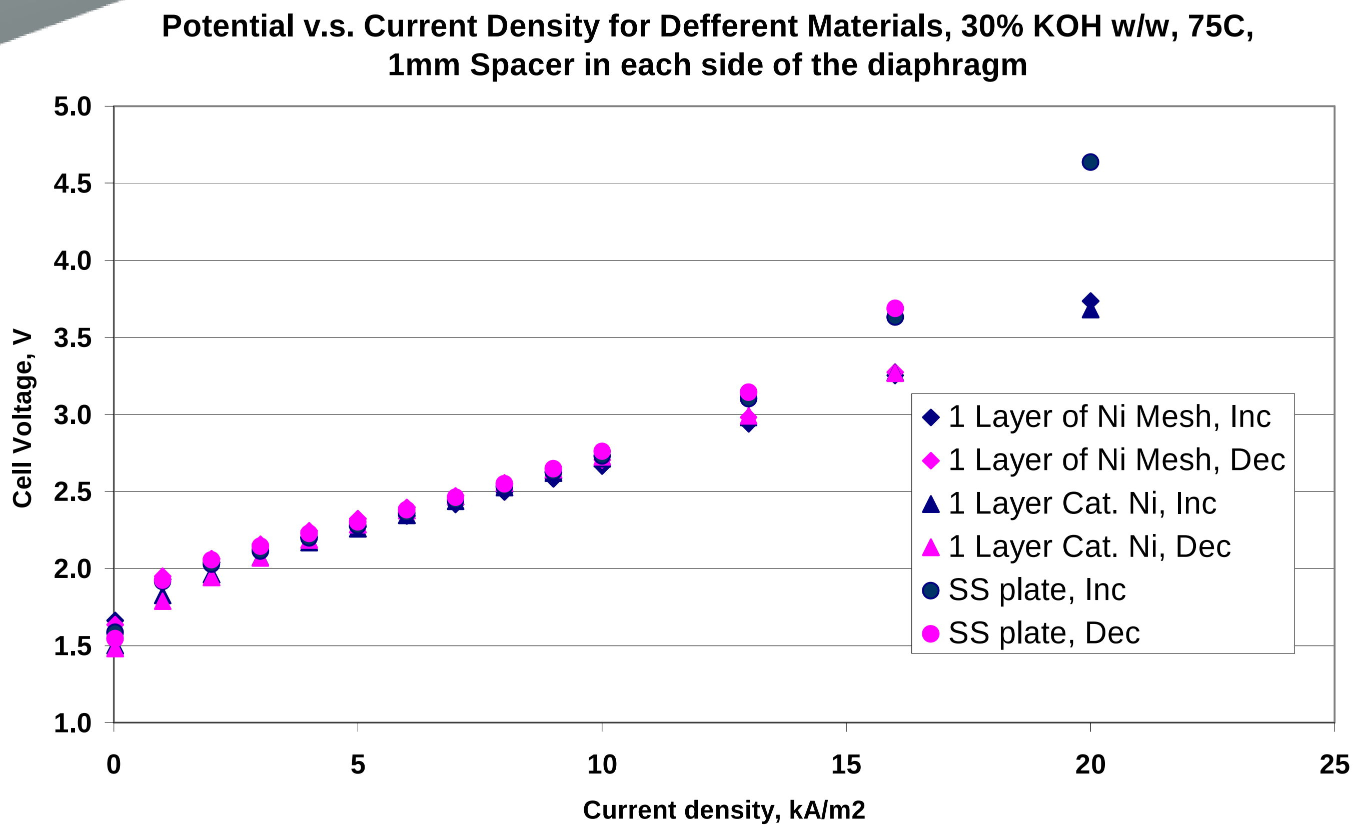

Increase of actual area of electrodes helped to reduce the cell voltage, catalyst coating has little effect

Static rig results: Electrode structure

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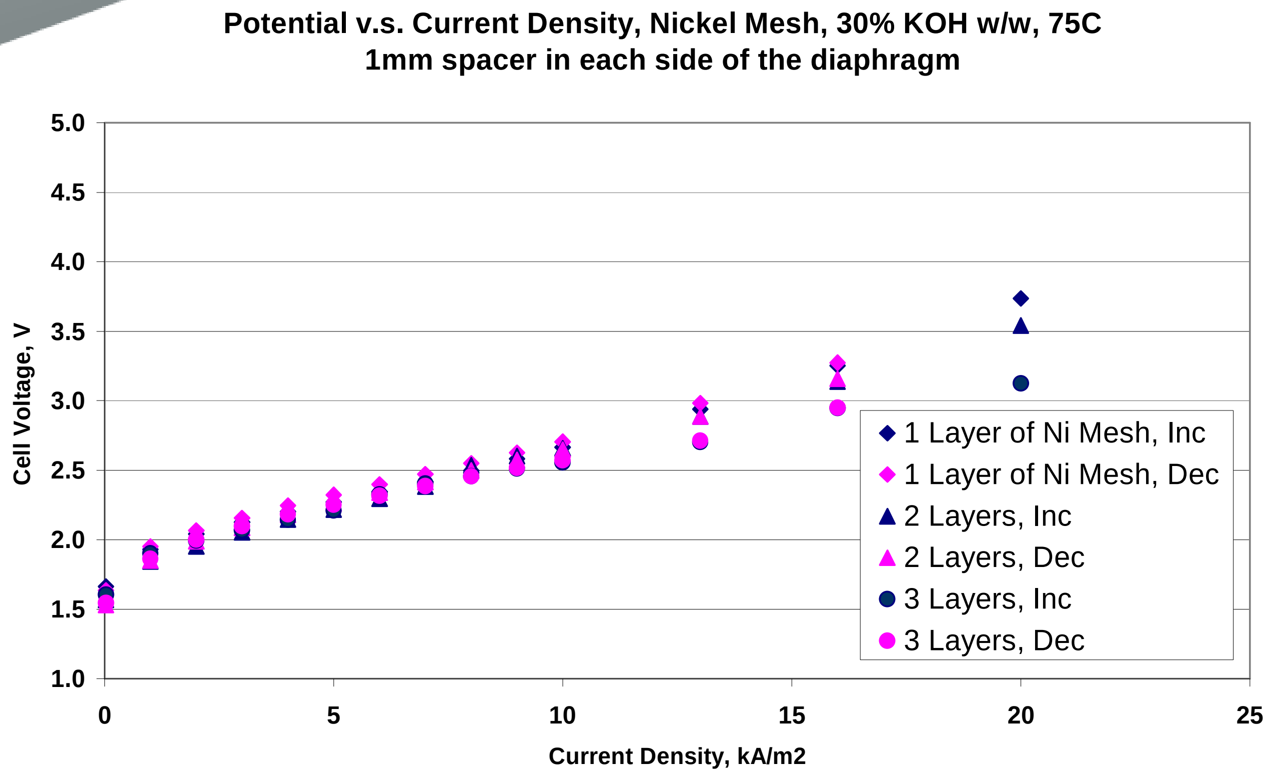

Extra mesh layers reduces cell voltage especially at high current density

Static rig results: Alkaline concentration

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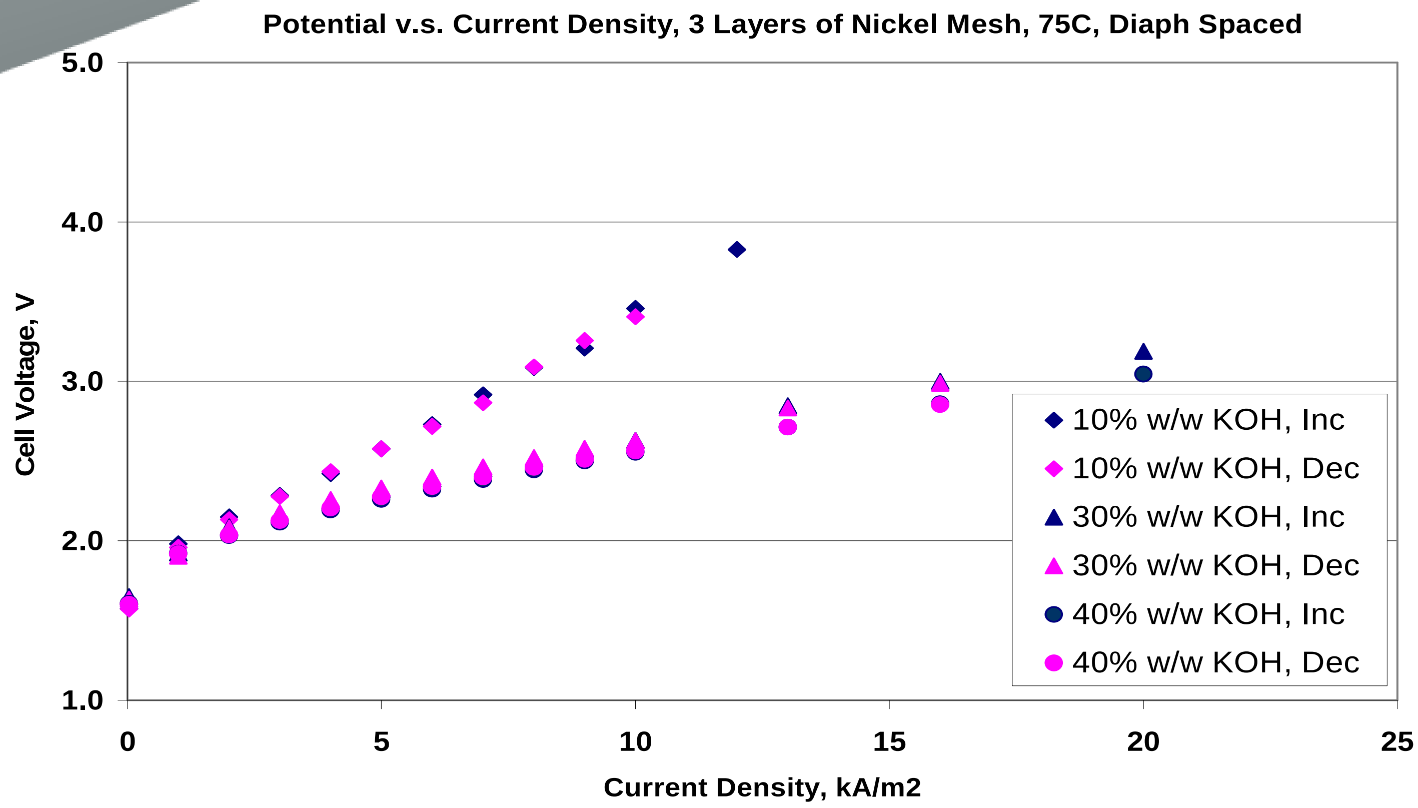

Optimum electrolyte concentration is around 30%

Static rig: 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

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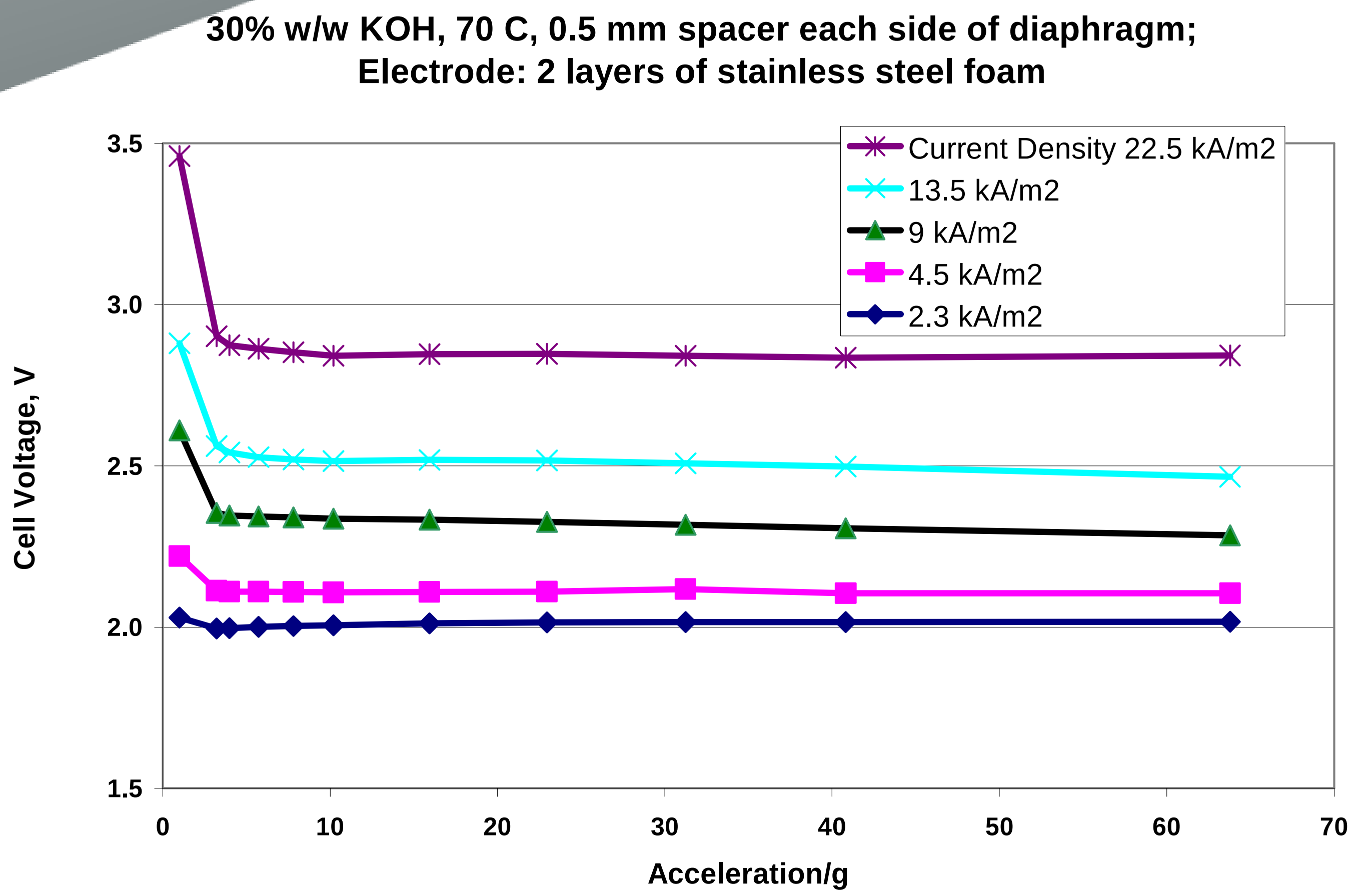

Higee benefit achieved up to ~10 g

Rotary rig results: Multi-layer nickel mesh

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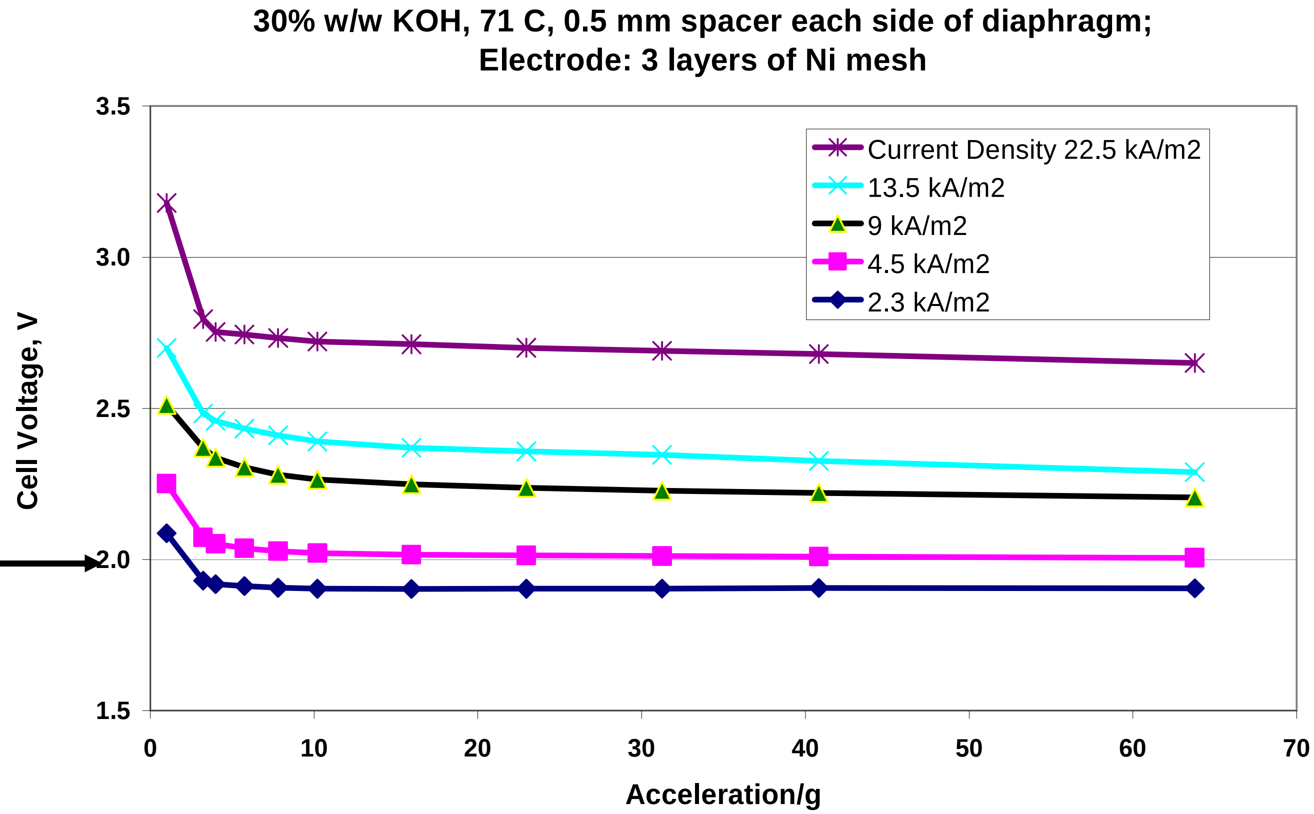

Commercial pressurised electrolyser @ 4000 A/m2 e.g. H2 IGen 300/1/25

Higee benefit achieved up to ~10 g

Rotary rig results: Electrolyte concentration and temperature

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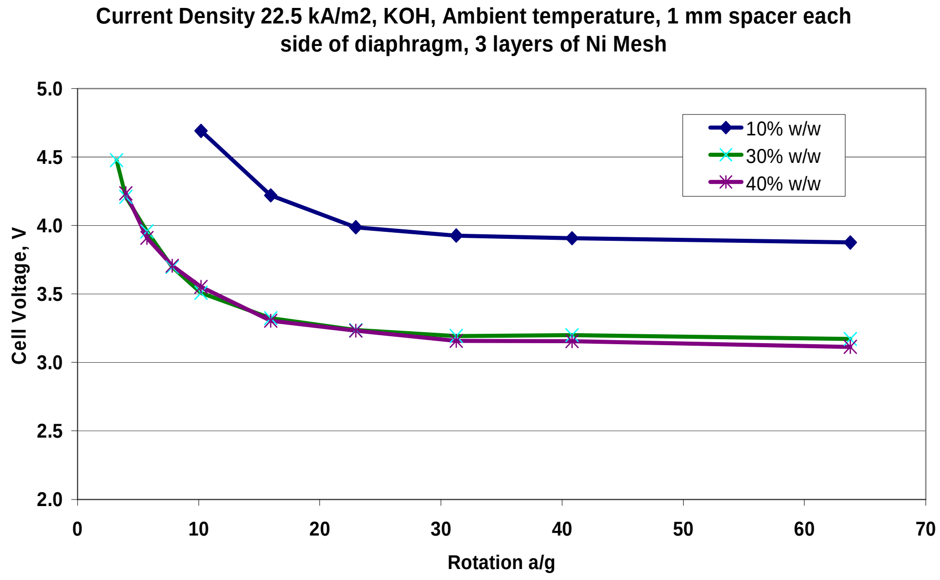
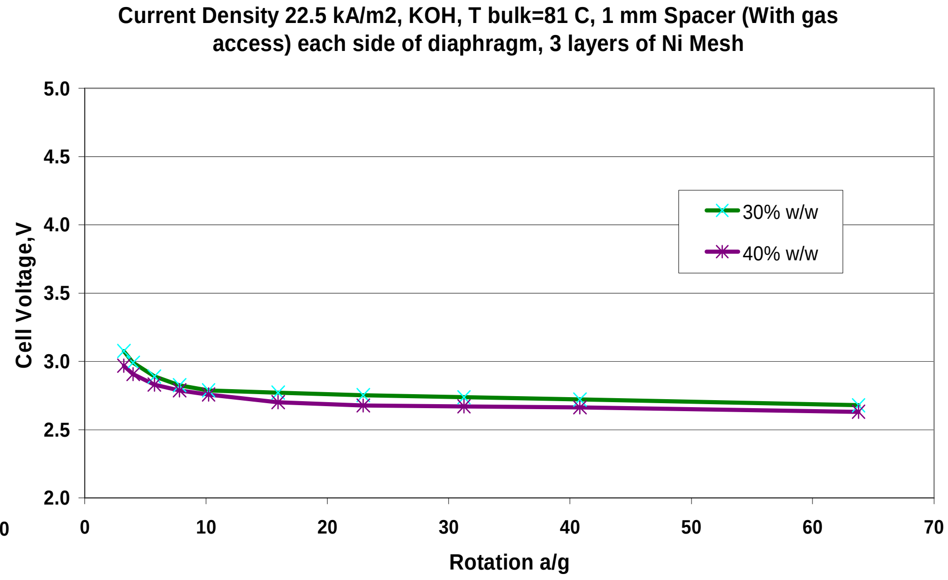
Ambient temperature



T_bulk=81 C



Optimum electrolyte concentration was around 30%

Rotary rig results:
Electrolyte temperature

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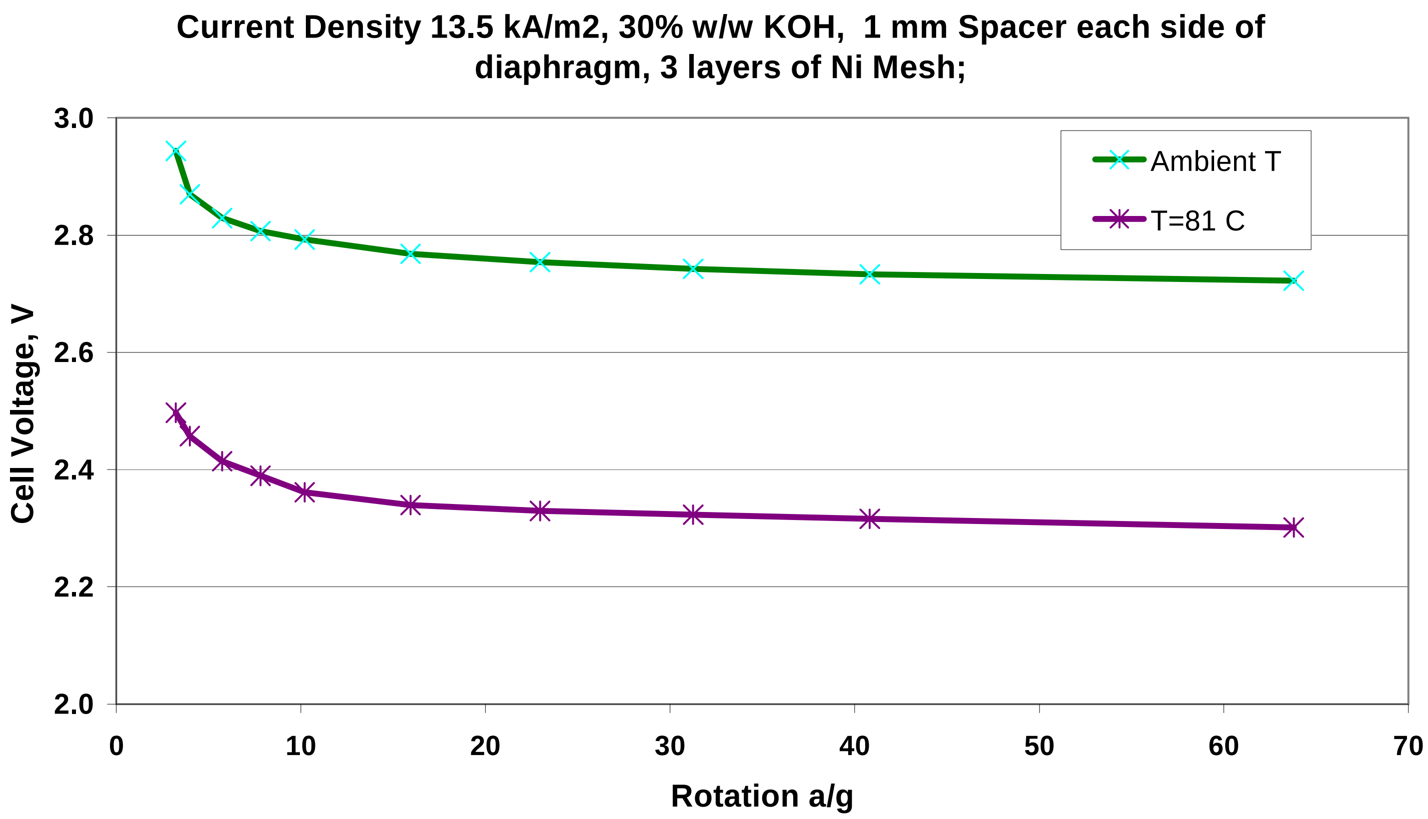

Rotary rig results: Spacer geometry

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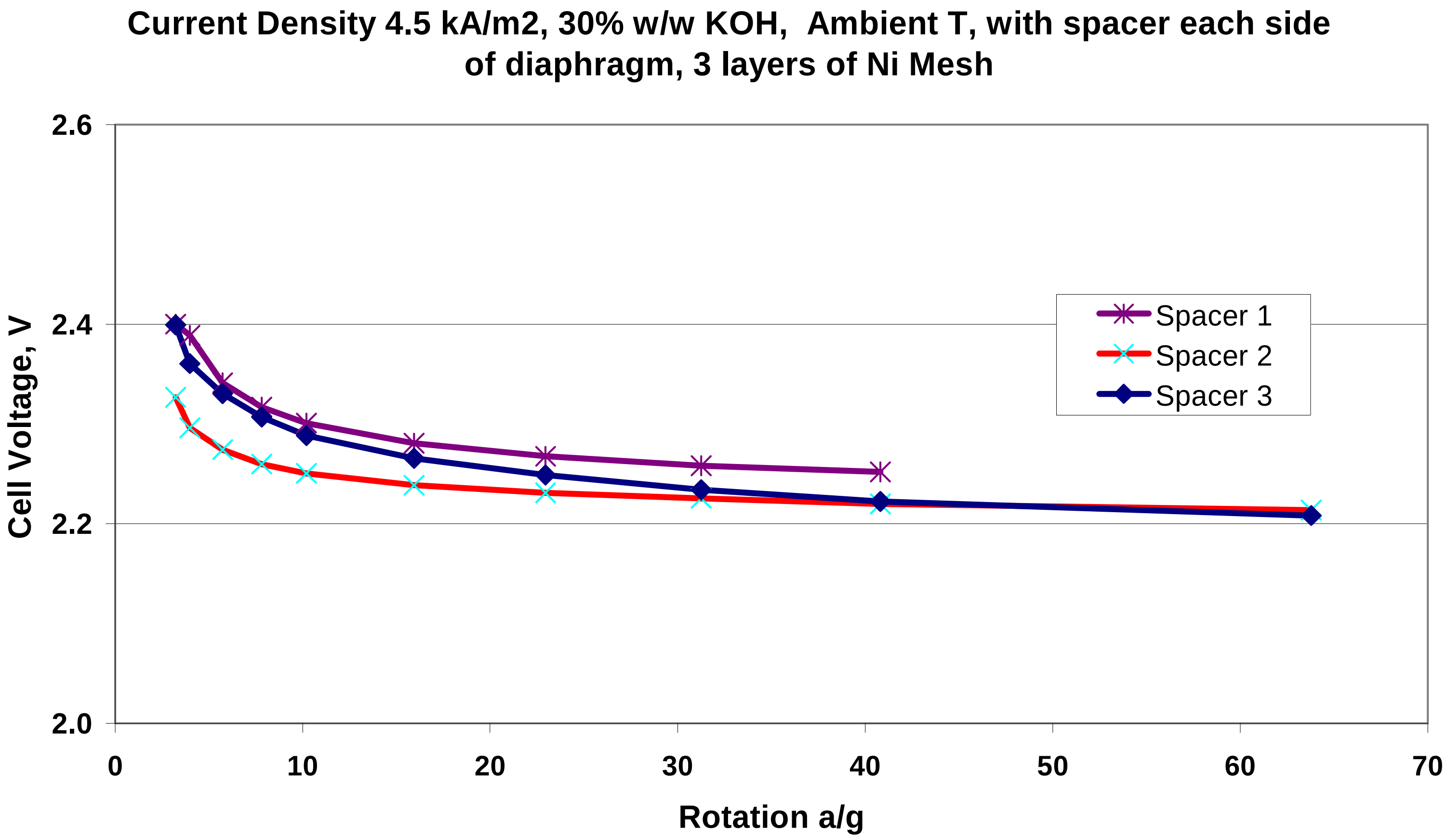

Rotary rig results:
Electrode structure/Material

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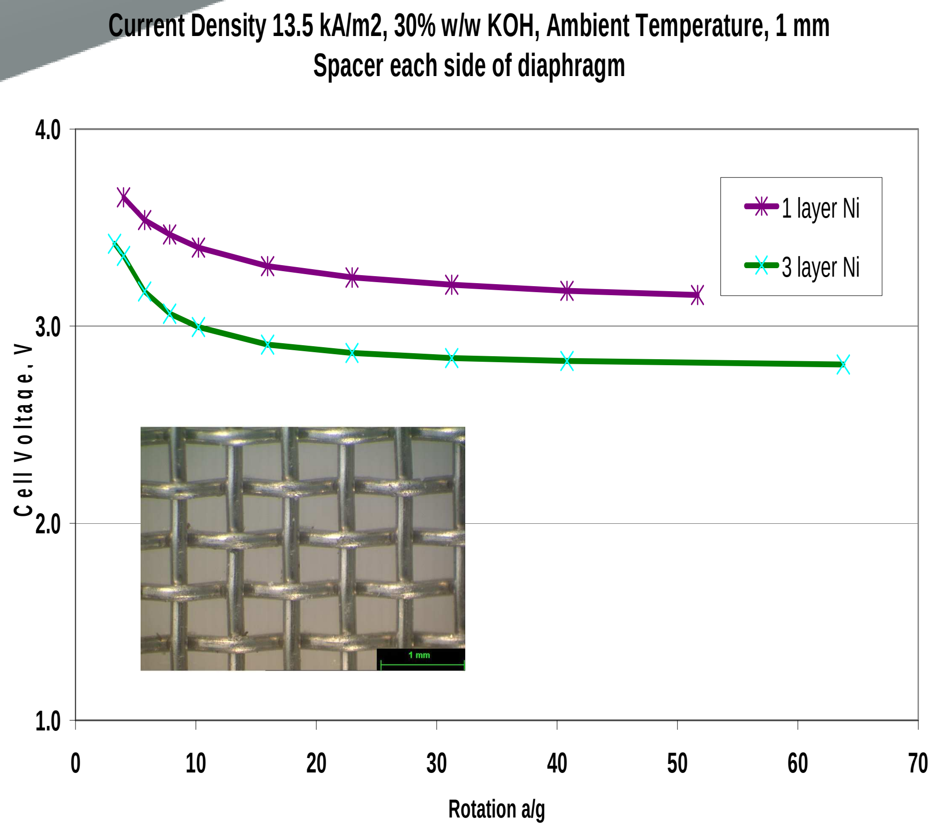

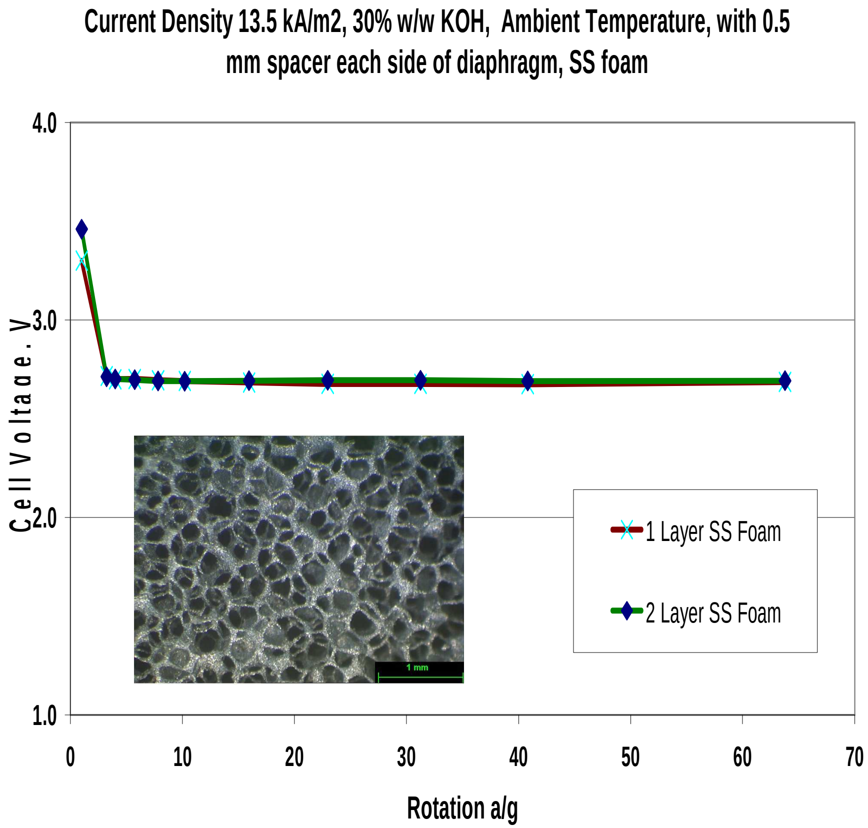

Multi-layer beneficial?

Nickel mesh-Yes; Stainless steel foam-No

Rotary rig results:
Traces of cell voltage

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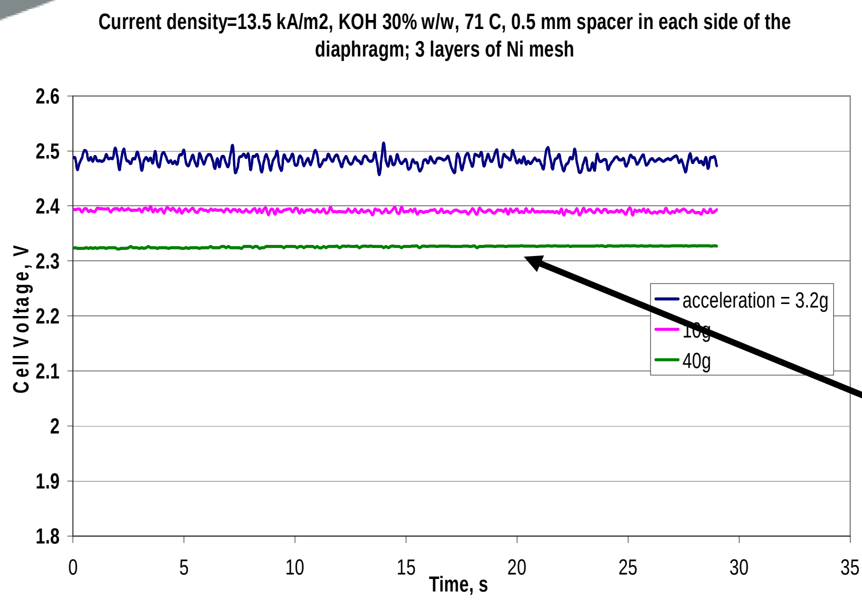
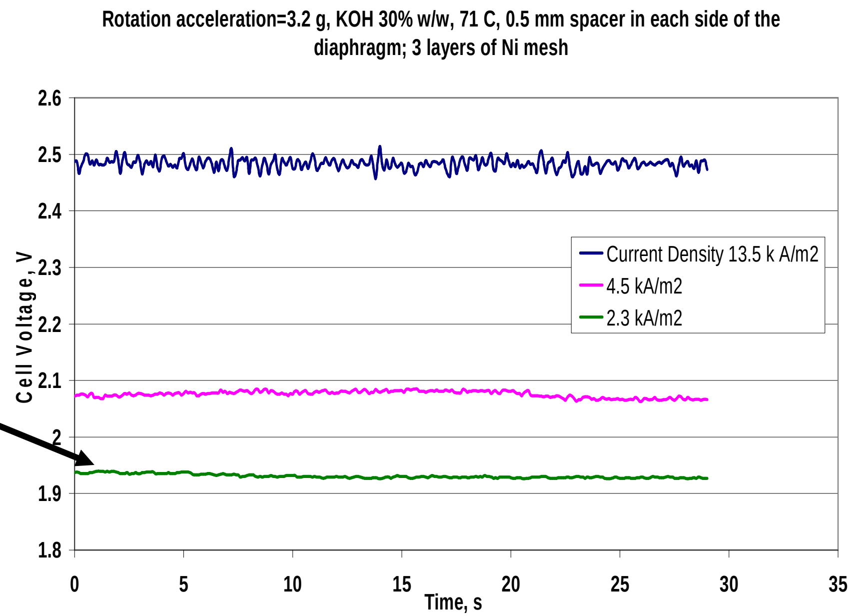
CD=13.5 kA/m2



Acceleration=3.2 g



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

Comparisons of Energy efficiency

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	Energy Required System kWh/kg	HHV of Hydrogen (equivalent to 142 MJ/kg) kWh/kg	System Efficiency %	Production Pressure psig
Stuart: IMET 1000	53.4	39	73	360
Teledyne: EC-750	62.3	39	63	60-115
Proton: HOGEN 380	70.1	39	56	200
Norsk Hydro: Atmospheric Type No.5040 (5150 Amp DC)	53.5	39	73	435
Avalence: Hydrofiller 175	60.5	39	64	up to 10,000
This study	**53.2**	**39**	**73**	**14.7**

- Data source: (Johanna Ivy, 2004. Summary of Electrolytic Hydrogen Production: Milestone Completion Report. NREL/MP-560-36734)
- This study: pure nickel/stainless steel; atmospheric pressure

Conclusions

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- 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.

Acknowledgements

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