MEA Development for a 2MWe PEM Fuel Cell Power Plant Fuelled with By-product Hydrogen from the Chlor-Alkali Process, and its Design, Build and Operation

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DEMCOPEM-2MW: demcopem-2mw.eu
DEMonstration of COmbined heat and power PEM power plant

• European funded (FP7, FCH-JU).
  • Grant no. 621256.

• Consortium:
  • Johnson Matthey Fuel Cells, Swindon, UK: MEA design, development, manufacture, testing & diagnostics.
  • Nedstack, Arnhem, Netherlands: Stack design and assembly.
  • MTSA Technopower, Arnhem, NL: Plant design and construction.
  • Politecnico di Milano, Italy: Power plant simulation, model development and validation.
  • AkzoNobel, Amsterdam, NL: Project Coordination.
Background & Objectives

- Chlor-alkali plants have high energy costs – up to 50% of chlorine cost is due to electricity consumption.
- Chlorine production through electrolysis produces by-product hydrogen: 340Nm³/tonne H₂.
  - This hydrogen can be fed to PEM fuel cells to recover energy.
  - Waste heat from the PEM power plant can be used eg to preheat brine.
- China produces 42% of the world’s Cl₂. 25Mt Cl₂/yr, 180 plants nationwide; up to 1100MWe equivalent hydrogen available. Generally high electricity prices cf. Europe.
- Project aims to build world’s largest PEM power plant (2MWe) at 50% electrical efficiency, 85% efficiency total, including heat.
Project Concept

Products: chlorine, caustic lye

Hydrogen

Chlorine Unit

Power from grid

2MW Electrical Power

PEM-Unit

Water

1.5 MW Heat to preheat brine

Water (‘high purity’)
MEA Design and Development
Fuel Cells at Johnson Matthey

- World’s first dedicated MEA production facility, est. 2002.
- 2005-07: automated volume production of direct methanol fuel cell MEAs introduced.
- 2007-09: automated volume production of phosphoric acid fuel cell components introduced.
- 2012: development of high-volume continuous hydrogen PEM fuel cell manufacture.
  - Including coating, converting, in-line quality inspection.
MEA Design and Development

Previous MEA for Long Life Stationary Power

JMFC previously made an ultra-durable BCS MEA.

- Operating lifetime $>20,000\text{hrs}^1$.
- Manufactured by individual static processes largely by hand.

MEA Design and Development

Volume manufacture-capable MEA

- JMFC developed a continuous roll to roll electrode production method – 27,000 MEAs produced.
MEA Design and Development

Beginning of life MEA performance

- New MEAs matched the performance of the pre-project long life MEA at lower current densities, and exceeded it at higher current densities.
- Possibly due to enhanced gas access to the catalyst-electrolyte interface.
  - more open gas diffusion medium.
  - possibly also an increased porosity of the catalyst layer.

Polarisation at 65°C, ambient pressure, cathode stoichiometry λ=2.0, 85% RH, anode λ=1.5, 85% RH
MEA Performance Stability

- Stability testing:
  - initial 700h of decay at 12 µV/hr,
  - rate of decay levels off to create highly stable performance.
- Following an interruption for diagnostic testing at 1050 hr, voltage climbed by around 34 mV.

- Regeneration in performance may be due to reduction of oxides or other surface contaminants when cathode potential drops when air supply is interrupted, hydrogen crosses the membrane.
MEA Design and Development

Polarisation before and after stability testing

First 1000hrs shows stable performance, some effect of conditioning with resistance lowered.

Air polarisation at 65ºC, ambient pressure, cathode $\lambda=2.0$, 85% RH, anode $\lambda=1.5$, 85% RH

Resistance Corrected Performance

Resistance (RH axis)
Power Plant Construction, Shipping, Commissioning

- Built & Tested at MTSA, Arnhem:

- Shipped to Ynnovate Sanzheng Chemicals, Yingkou, China.

- Opening ceremony October 2016
Power Plant Layout

Three shipping containers:
• Fuel cell stacks and control room.
• Inverters and power handling.
• Mechanical and thermal balance of plant, including humidifiers.

Modular arrangement of cells:
• Six groups of modules, each with a 360kVA inverter.
• Each group has four modules, fourteen stacks per module.
Power Plant - Modelling

Polarisation curve regression

• Power plant simulated in Aspen PLUS.

• Stacks are treated as 0D, made up of average cells, in model block.

• Cell performance is modelled in Aspen Custom Modeler, to give a semi-empirical polarisation curve.

• Coefficients calculated by regression to experimental data from Nedstack FCT’s installations.

• Top right: example of regressed model polarisation curve. Below right: change in polarisation performance over lifetime.

Plant Operation

- Initially, 5 stack groups functioning, 1.7MWe available – one group not started due to inverter failure, repaired early 2017.
- Below left: energy available by month

![Energy Availability Graph]

Above: BoL energy balance, 5/6 groups
Below: Plant availability

![Energy Balance Graph]

![Plant Operative Graph]
Plant Performance and Model Validation

At BoL

- Right: Operating conditions from beginning of life, compared to model.

<table>
<thead>
<tr>
<th>Operating conditions</th>
<th>Measurement</th>
<th>Model</th>
<th>Difference</th>
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<tr>
<td>Air inlet flow</td>
<td>Nm³/h</td>
<td>5314</td>
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<tr>
<td>Stoichiometry cathode / anode</td>
<td>-</td>
<td>2.3 / 2.0</td>
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<tr>
<td>T coolant, FC inlet</td>
<td>°C</td>
<td>60.0</td>
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<tr>
<td>Power DC (gross)</td>
<td>kW</td>
<td>1653</td>
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<tr>
<td>Results</td>
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<tr>
<td>H₂ inlet flow</td>
<td>Nm³/h</td>
<td>972</td>
<td>978</td>
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<td>Temperature air humidifier</td>
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<td>Coolant flow</td>
<td>m³/h</td>
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<tr>
<td>Coolant temperature at stack outlet</td>
<td>°C</td>
<td>64.7</td>
<td>63.9</td>
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<td>Voltage (average)</td>
<td>V</td>
<td>728.7</td>
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<tr>
<td>Current (average)</td>
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<tr>
<td>Auxiliary power</td>
<td>kW</td>
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<td>Available Thermal power (HX2)</td>
<td>kW</td>
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<td>Power AC (net)</td>
<td>kW</td>
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<td>1450</td>
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<td>Efficiency (gross)</td>
<td>%</td>
<td>56.7</td>
<td>56.4</td>
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<tr>
<td>Efficiency (net)</td>
<td>%</td>
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<tr>
<td>Net water production</td>
<td>kg/h</td>
<td>-</td>
<td>534</td>
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</table>
Plant Performance and Efficiency

Electrical and available heat.

Efficiency (%LHV hydrogen). Average electrical efficiency 49%. Heat available is influenced by ambient temperature on site.
Plant Performance and Efficiency

**Cumulative Data**

LH axis: electrical power produced (MW); heat recovered (MWh) and CO₂ emissions avoided (ton). RH axis: hydrogen recovered (ton).
Conclusions

• The chlor-alkali industry can recoup significant costs by installing fuel cell PEM power plants to generate electricity and heat from by-product hydrogen.
• A 2MWe demonstration power plant has been built, commissioned and operated for over a year:
  • 800t H₂ used, 13000t CO₂ equivalent emissions avoided.
  • 50% efficient vs LHV H₂, plus around 26% as available heat.
• A long-life stationary power MEA optimised for high volume manufacture has been developed at JMFC, replacing a mature pre-project design.
• A model of the PEM power plant was created and verified.

• This work was carried out in the framework of the FP7-FCH-JU project “DEMCOPEM-2MW”, cofounded by the FCH JU under grant agreement nº 621256.