DEMCOPEM-2MW COGENERATIVE PEM FUEL CELL UNIT FOR HYDROGEN RECOVERY FROM CHLOR-ALKALI INDUSTRY IN CHINA: FIRST MONTHS OF OPERATION AND PRELIMINARY DATA ANALYSIS

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SUMMARY

✓ DEMCOPEM-2MW PROJECT
✓ MW-SCALE COGENERATIVE PEM UNIT
✓ FIRST MONTHS OF OPERATION
✓ MODELLING AND ENERGY BALANCES OF THE PLANT
✓ CONCLUSIONS
DEMCOPEM-2MW EU PROJECT

Design, construction and demonstration of a combined heat and power (CHP) PEMFC power plant \(2\text{MW}_{\text{DC el}}\) and integration into a chlor-alkali industrial plant recovering byproduct hydrogen

**OBJECTIVES (2015-2019)**

- **High net conversion efficiency** (50% electric and 85% total)
- **Long lifetime** of system and fuel cells (16,000 h up to 40,000 h target)
- Development of large-volume manufacturing process for high-quality MEAs
- **Economical plant design** (< 2500 €/kWₑ)
- Fully automated operation
- Ensure plant reliability by developing protocols for fuel cells monitoring and rapid replacement of faulty stacks (on-stream availability of > 95%)
- Contribute to the general goals of the FCH-JU for installed fuel cell capacity
PROJECT PARTNERS

Johnson Matthey Fuel Cells

High quality MEA assembly
Manufacturing process development
Performances, robustness, lifetime and costs optimization

AkzoNobel

Project coordinator
Expertise in chlor-alkali plants

Nedstack

PEM fuel cell stack development and production

POLITECNICO MILANO 1863

Power plant simulation model development, calibration and validation
Analysis of experimental measurements

MTSA

Development, production and maintenance of customer-specific equipment for energy processes
**PROJECT ACTIVITIES**

**PEM CELLS AND STACKS DEVELOPMENT LARGE SCALE INDUSTRIAL PRODUCTION**

Development of large-volume manufacturing process for high-quality MEAs.
Improvement of MEAs and stacks according to on-field experience.

**PEM SYSTEM INTEGRATION, OPERATION and LIFETIME MAINTENANCE**

Optimization of operating conditions and system development.
Maintenance and operation in relevant industrial environment.

**SYSTEM MODELLING and DATA ANALYSIS**

Modelling of system operating conditions and performances for measured data validation, identification of possible issues and further optimization.

**COORDINATION / DISSEMINATION / COMMUNICATION / EXPLOITATION**
The Chlor-alkali process is suitable for integration with low temperature fuel cells.

Up to 50% of chlorine production cost is due to electrical energy.

Excess hydrogen (340 Nm$^3$/ton$_{Cl}$) can efficiently feed a fuel cell plant.

Installation is in **China:**

- high electricity price
- issues with electricity supply shortages
- large chlor-alkali plants market - ca. 180 plants – $>1000 \text{MW}_\text{el}$ PEM potential

Scale-up based on previous experiences (Nedstack & MTSA)

- **70 kW$_\text{el}$** PEM Power Plant at AkzoNobel (Delfzijl, NL, 2007)
- **1 MW$_\text{el}$** PEM Power Plant at Solvay (Antwerp, BE, 2011)
PLANT OPERATION

Construction and shipment of the plant in mid 2016 from MTSA factory (NL)

Opening ceremony on 14 October 2016 at plant location of Ynnovate Ltd in Yingkou, China

➢ More than one year of plant operation: data analysis

https://www.youtube.com/watch?v=W8QE8iEXAyM
PLANT STRUCTURE

HYDROGEN

HYDROGEN LOOP

Hydrogen humidifier

Heating loop pump

Hydrogen blower

Air humidifier

Air blower

DEMIs WATER

DEMI WATER

make-up pump

Demi water tank

Coolant circulation pump

Coolant loop

HX 1

HX 2

HX 3

HX 4

EXHAUST AIR

USEFUL HEAT

ELECTRICITY

PEM Fuel Cell

HYDROGEN HUMIDIFIER

HEATING LOOP

COOLANT LOOP

Cooler

S. Campanari – EFC 2017 – Naples – 12-15 December 2017
The previously described plant is arranged in three containers units, resulting in the world largest stationary PEM fuel cell system in operation (2 MW_{el}).
The plant has been operative since September 2016 and reached full-load capacity in January 2017.

The plant has been active for more than 8400 hours (vs. 10400 calendar hours).

Initial plant operation with some limitations

Plant is often operated at part load (not all modules running) depending on hydrogen availability

Thermal energy is calculated from measurements - although currently not recovered by the chlor-alkali plant.
Globally, the plant produced about 9 GWh without significant interruptions, making available 5 GWh of thermal energy at about 65°C.

Hydrogen is a byproduct from the industrial plant. More than 500 tons of hydrogen otherwise lost have been recovered, with an average electric efficiency of $\eta_{EL} \sim 49\%$ and $\eta_I \sim 76\%$.
The measured **BOL electric efficiency** was 55%\textsubscript{LHV} and during the first year of operation the **average net electrical efficiency** has been \textasciitilde49-50%\textsubscript{LHV} (56-57%\textsubscript{LHV} gross).

Additional 26%\textsubscript{LHV} (average) could be recovered as **thermal energy** leading to a global first law efficiency of nearly 76%\textsubscript{LHV} (peaks over 80%).

**Thermal energy recovery is strongly influenced by the harsh winter climate in Yingkou, China. Thermal efficiency ranges from 32\% to 12\%.**

➢ **Average performances are aligned with the project expectations.**
Lumped model developed in Aspen Custom Modeler, for integration with the balance of plant in Aspen Plus.

Modular modelling approach reproduces the layout of the plant:

STACKS ➔ MODULES ➔ GROUPS

Empirical formulation of the i-V curve, validated against experimental data

- Considers reactants stoichiometry ($x_{H2}$, $x_{O2}$), exchange and limit current density ($i_0$, $i_L$), linear long-period voltage decay ($t_{BoL}$-$t_{EoL}$)
- In its first version, neglects T and RH effects: stacks at constant T and RH thanks to the cooling water circuit and humidifiers

\[
V(i, x_{H2}, x_{O2}) = A + B \ln \left( \frac{x_{H2}}{x_{H2, st}} \right) + C \ln \left( \frac{x_{O2}}{x_{O2, st}} \right) + Di + E \ln \left( \frac{i}{i_0} + 1 \right) + F \ln \left( \frac{i}{i_L} \right) - G \ t \left( t_{BoL}, t_{EoL} \right)
\]
The complete PEMFC power plant model is compared with field data.

Voltage deviation at plant start-up

<table>
<thead>
<tr>
<th>Property</th>
<th>Model-Measurements deviation [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>15 Sep 16</td>
</tr>
<tr>
<td>Active groups</td>
<td>5/6</td>
</tr>
<tr>
<td>Current [A]</td>
<td>-1.8%</td>
</tr>
<tr>
<td>Voltage [V]</td>
<td>+1.8%</td>
</tr>
<tr>
<td>Auxiliaries power [kW]</td>
<td>-1.2%</td>
</tr>
<tr>
<td>Coolant flowrate [m³/h]</td>
<td>-0.6%</td>
</tr>
<tr>
<td>Stack temp. [°C]</td>
<td>-1.3%</td>
</tr>
</tbody>
</table>

- Good agreement at Beginning of Life
- Limited agreement after 1 month of operation, mainly due to an initial settlement of voltage and to the effect of reversible decay in each operating run (not included in the model)
From long-term operation estimations, based on plant simulation, the electric efficiency loss during lifetime (about 6%) is partially recovered as additional heat.

Results of modelling activities for BOL have been positively validated on on-field data.

A large quantity of low temperature heat (@ ~63°C) could be exploited by an external user. The amount is dependent on environmental temperatures due to system heat losses.

Compression and DC/AC conversion are the most significant losses.
CONCLUSIONS & OUTLOOK

The coupling of a large scale PEM fuel cell system with a chlor-alkali industrial plant for byproduct hydrogen recovery is under demonstration with satisfying results.

➢ The DEMCOPEM 2MW plant has been built on time and is currently in operation.

➢ BOL performances are aligned with the expectations (net electric efficiency over 50%, large thermal recovery capability) and plant availability is high.

➢ Part load operation and forced standby are mainly due to hydrogen availability, a situation which has recently been solved.

➢ Modelling activities yield results which are aligned with measured data.

Next steps:

➢ Analysis of plant performance data during the second year of operation and analysis of reversible decay phenomena

➢ Partial substitution of stacks with improved versions (MEAs development)

➢ Analysis of options for efficiency improvement (including thermal energy usage, not currently performed due to requirements of the industrial plant).
Thank you for your attention!

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