Unitized Regenerative Fuel Cells for Hydrogen Energy Storage Systems

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Outline

1. Background / Scope

2. R&D on Unitized Regenerative Fuel Cell (URFC)

3. R&D on Hydrogen storage with metal hydride

4. Summary
A Synergy between Hydrogen and Electricity

Grid Connected RE-Hydrogen System

- Hydrogen may be used as fuel in almost every application where fossil fuels are being used today.
- Hydrogen is useful as an energy carrier, because energy storage density is significantly high with compressed form, liquefied form, or metal hydride.
- From sustainability point of view, a synergy between hydrogen and electricity and renewable energy sources is particularly promising.
- Hydrogen production with water electrolysis must be suitable for renewable energy sources.

Grid Independent RE-Hydrogen System

Totalized Hydrogen Energy Utilization System (THEUS)

To enhance the versatility of hydrogen energy in the industrial, the commercial, and the transportation sectors through THEUS.
Outline

✓ URFC and MH tank have been evaluated as key components of hydrogen energy system in stationary applications.

✓ A bench-scale URFC was installed and would be evaluated as an energy conversion system.

✓ MH tank was developed by own and evaluated in a long time operation.

✓ In particular, we have been focusing on the thermal energy recovery from the both operations of URFC and MH tank.
Overview of Unitized Reversible Fuel Cell (URFC)

**URFC System**

**Advantages**
- Long-term and large quantities of energy storage compared to current secondary batteries.
- Continuous running permits to make a rate of operation double compared to individual use of FC and Ely.
- Acquisition of oxygen as by-products

**Cell reactions**

**Electrolysis**
- Overall: \( \text{H}_2\text{O}(l) \rightarrow \text{H}_2(g) + \frac{1}{2}\text{O}_2(g) \)
- \( \text{H}_2 \) electrode (cathode): \( 2\text{H}^+ + 2e^- \rightarrow \text{H}_2(g) \)
- \( \text{O}_2 \) electrode (anode): \( \text{H}_2\text{O}(l) \rightarrow 2\text{H}^+ + \frac{1}{2}\text{O}_2(g) + 2e^- \)

**Fuel Cell**
- Overall: \( \text{H}_2(g) + \frac{1}{2}\text{O}_2(g) = \text{H}_2\text{O}(l) \)
- \( \text{H}_2 \) electrode (anode): \( \text{H}_2(g) \rightarrow 2\text{H}^+ + 2e^- \)
- \( \text{O}_2 \) electrode (cathode): \( \frac{1}{2}\text{O}_2(g) + 2\text{H}^+ + 2e^- \rightarrow \text{H}_2\text{O}(l) \)

**Possible applications**
- Hydrogen energy storage system for load leveling at buildings
- Remote hospital
- Lake water purification
- Remote UPS system
Installation of a bench-scale URFC

Overview

- Installed in March 2014
- Supplied from Takasago Thermal Engineering Co.
## Specifications of bench-scale URFC

### System

<table>
<thead>
<tr>
<th>Operation</th>
<th>Input power (rated)</th>
<th>4.5 kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrolysis</td>
<td>Gas production rate</td>
<td>H₂: 1.0Nm³/h, O₂: 0.5Nm³/h</td>
</tr>
<tr>
<td></td>
<td>Gas pressure</td>
<td>H₂: 0.9MPa(G)ₘₐₓ, O₂: Atmospheric</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operation</th>
<th>Power output (rated)</th>
<th>0.8 kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel cell</td>
<td>H₂ utilization</td>
<td>&gt;90%</td>
</tr>
<tr>
<td></td>
<td>H₂ pressure</td>
<td>&lt;0.05MPa(G)</td>
</tr>
</tbody>
</table>

### Cell/stack

<table>
<thead>
<tr>
<th>Component</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Membrane</td>
<td>Nafion 115</td>
</tr>
<tr>
<td>Electrocatalyst</td>
<td>H₂ side: Pt</td>
</tr>
<tr>
<td></td>
<td>O₂ side: Pt/Ir-black</td>
</tr>
<tr>
<td>Active area</td>
<td>250 cm²</td>
</tr>
</tbody>
</table>
Schematic draw of gas/liquid flows around URFC

**Component**

<table>
<thead>
<tr>
<th>Component</th>
<th>Rated power consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling water pump (Pump-1)</td>
<td>90 W</td>
</tr>
<tr>
<td>Water circulation pump (Pump-2)</td>
<td>60 W</td>
</tr>
<tr>
<td>H2 circulation pump (Pump-3)</td>
<td>26 W</td>
</tr>
<tr>
<td>Air blower (BLW)</td>
<td>500 W</td>
</tr>
</tbody>
</table>

- Hydrogen is recirculated.
- Air is humidified using a membrane humidifier.
Electrolysis operation - \( i-V \) characteristics

At 40°C

The effect of temperature on the performance was relatively large, while the effect of pressure was small.
The cell/stack performance was significantly influenced by the operating temperature, which should be higher than 60 °C.
Continuous operation

Since the operation interface was well-organized, the system could be operated and switched easily. Switching time was 5-10 min.
Experimental set-up of MH tank

Metal hydride bed in AIST

Schematic of the experimental set-up
Metal Hydride Tank

(Metal hydride alloy)
- Japanese version -
Composition: MmNi₅
Total weight: 50 kg
Size: 500 μm
Reaction heat $\Delta h$
Absorption: 28.93 kJ/molH₂
Desorption: 27.87 kJ/molH₂
Individual absorption/desorption test results

Operating conditions
(Absorption: 9 hour)
H₂ flow rate: 11.0 NL/min
Circulation water: 32 °C, 1.12 l/min
(Desorption: 13 hour)
H₂ flow rate: 7.6 NL/min
Circulation water: 12 °C, 0.46 l/min

Absorption

Desorption

\[ Q_{cw} = 6.84 \text{ MJ}, \, \varepsilon = 89.4\% \]

\[ Q_{cw} = 6.62 \text{ MJ}, \, \varepsilon = 89.8\% \]

Recoverd thermal energy from coolant: \( Q_{cw} \)

Reaction heat recovery rate: \( \varepsilon = (Q_{cw}/Q_{MHreact}) \times 100 \)

\[ \varepsilon = (Q_{cw}/Q_{MHreact}) \times 100 \]

\[ Q_{MHreact} = V_{H2} \times \Delta h \]

H/M=0.18-0.94
MH utilization ratio: 94%
GH₂: 5920 NL
Absorption-desorption continuous test results

(a) P-C isotherm

(b) Temperature of coolant

Reaction heat recovery rate, $\varepsilon$

Day1 AB  87.4 %     DS 73.3 %
Day2 AB  75.4 %     DS 72.5 %
Day3 AB  76.2 %     DS 72.3 %
Summary

In this study, we investigated the performance of URFC and MH tank as key components of hydrogen storage system.

- The bench-scale URFC could operated quite successfully.
- The performance of each operation mode in URFC was comparable with that of individual apparatus of PEM electrolyzer and PEMFC.
- MH tank was developed and tested in daily cycle operation.
- Reaction heat recovery rate was excellent as over 70 %.
- The connection between URFC and MH tank was completed, and consolidated test is ongoing.
Thank you very much for your attention!

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