Progress Update on Matrix Study of Aged SOFC Performance and Materials Degradation
Contents

- Introduction to Atrex Energy, Inc
- Application of Atrex Energy product
- Technical progress
  - Performance of aged cells
  - Microstructure observation in aged cells
- Further work
- Acknowledgement
About Atrex Energy

- Formerly Acumentrics SOFC division, established in 2000, “Powder to Power” in single facility in MA

- Focus on “rugged” fuel cells, pioneered small tubular SOFC
  - 30 min startup and shutdown
  - Unattended operation in remote locations with >25,000hrs

- PRODUCTS
  - 250W-10kW products
  - 250-1500 W commercial power products (NG, APG, LPG)
  - 3kW and 10kW development products (biofuel, diesel, JP8) for the US military

- FUELS and APPLICATIONS
  - Natural gas, wellhead gas, LPG, JP8, biofuel
  - Critical remote power, cathodic protection
  - Units all utilize remote monitoring for additional reliability
Atrex Energy – Capabilities and Resources

- SOFC – “Powder to Power” all in one 30,000 sq ft facility in Walpole, MA
- Employees include electrical, mechanical, chemical and material, automation, Firmware engineers and manufacturing staff
- Full Scale research, development and testing laboratory
  - Ceramics forming & processing
  - Commercial manufacturing
  - Power electronics
  - Prototype machining
  - Chemical reactor design
  - Thermo-mechanical design and integration
  - Ground up board and firmware development
Remote Power Application

- US Coast Guard Radio Network Towers in Alaska
- LPG flown in by helicopter; fuel efficiency highly desirable
Remote LPG and NG Applications
Atrex Energy Tubular Cell Technology

<table>
<thead>
<tr>
<th>Layer</th>
<th>Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anode</td>
<td>Ni/YSZ</td>
</tr>
<tr>
<td>Electrolyte</td>
<td>YSZ</td>
</tr>
<tr>
<td>Barrier</td>
<td>Doped Ceria</td>
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<tr>
<td>Cathode</td>
<td>LSCF</td>
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<tr>
<td>Interconnect</td>
<td>LaCrO3</td>
</tr>
</tbody>
</table>

Atrex Energy Tubular Cell Technology

Layered materials:
- **Anode**: Ni/YSZ
- **Electrolyte**: YSZ
- **Barrier**: Doped Ceria
- **Cathode**: LSCF
- **Interconnect**: LaCrO3

Fuel Cell diagram:
- **CH₄** feeds into the fuel cell
- **N₂** and **O₂** are inputs for the cathode
- **CO** and **H₂** are outputs at the cathode
- **Interconnect** (LaCrO3)
- **Anode** (Ni/YSZ)
- **Cathode** (LSCF)
- **Electrolyte** (YSZ)

Injector placement:
- **CH₄** injection point
- **N₂** and **O₂** feeding into the cell
- **CO** and **H₂** exit points
Long Term Running Example

Hourly averaged data of the voltage and current output from a field unit.
## Examples of Degradation

<table>
<thead>
<tr>
<th>Stack No.</th>
<th>Tmax /°C</th>
<th>Tmin /°C</th>
<th>Degradation /%/1000hr</th>
<th>Degradation Interval/hrs</th>
<th>Total life time /hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>789</td>
<td>724</td>
<td>0.3%</td>
<td>19425</td>
<td>19429</td>
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<tr>
<td>2</td>
<td>799</td>
<td>771</td>
<td>1.5%</td>
<td>14020</td>
<td>25106</td>
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<tr>
<td>3</td>
<td>769</td>
<td>738</td>
<td>0.4%</td>
<td>22877</td>
<td>29031</td>
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<tr>
<td>4</td>
<td>822</td>
<td>778</td>
<td>0.2%</td>
<td>10270</td>
<td>19506</td>
</tr>
<tr>
<td>5</td>
<td>785</td>
<td>765</td>
<td>0.7%</td>
<td>15063</td>
<td>25282</td>
</tr>
<tr>
<td>6</td>
<td>792</td>
<td>761</td>
<td>1.6%</td>
<td>18481</td>
<td>21913</td>
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<tr>
<td>7</td>
<td>784</td>
<td>740</td>
<td>1.1%</td>
<td>14375</td>
<td>14411</td>
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<tr>
<td>8</td>
<td>782</td>
<td>737</td>
<td>0.6%</td>
<td>20170</td>
<td>20181</td>
</tr>
</tbody>
</table>

Those cells offer opportunities to examine field cells in real applications, in the aspects of cell performance and microstructure change.
Project Background

Atrex Energy provides opportunity in degradation study:

- Field replaceable bundle
- Easy to remove individual cells for post stack testing
- Large quantities of units deployed in field
- Various running conditions for field units

Investigation Method:

- Microscopic analysis
- Electrochemical characterization
- Impedance spectroscopy characterization
Project Overflow

Meta-data collected
Sample matrix populated.
(Source: stack tests 1000≤t<30,000 hrs)

Cells archived
(Source: cell test stands 24<t<4000 hrs)

Cell testing:
current distribution
Cell testing:
detailed spatial analysis
Room temperature
NDT

Materials microanalysis:
SEM EDS
Cells testing:
detailed spatial analysis, impedance spectroscopy

Degradation data appended to meta-data.
Pattern analysis

Atrex FUEL CEELL Testing

BU CELL TESTING
Electrochemical Characterization of Aged Cell Setup and Technique

- **Detailed individual cell study**

  ![Diagram of Detailed individual cell study]

- **Current distribution study/Regular test**

  ![Diagram of Current distribution study/Regular test]
Imaging of Electric Shorts

Heat signature of joule heating from an electric short can be easily picked up by a thermal camera (~0.1W)

Have not found any examples of electrical shorts in production; have found a few examples in old stacks. Useful technique for investigating degradation phenomena

\[ \text{Short in middle of cathode} \]

\[ \text{Short along edge of cathode} \]

\[ \text{Initial } R_{A1C3} = 3.4 \ \Omega \]

\[ \text{Initial } R_{A1C4} = 4.1 \ \Omega \]
Expected Results from Electrochemical Characterization (Upcoming)

- Comparison between low running hours vs. high running hours
- Comparison between low running current vs. high running current
- Comparison between low running temperature vs. high running temperature
Observation in Aged Cell
Inter Connections Compound Decomposition

Cell with 8600 hours running from field
Observation in Aged Cell
Ag Migration

Cell with 8600 hours running from field
Observation in Aged Cell Cathode Decomposition

Cell with 7000 hours running from field
Future Work

- Complete the electrochemical characterization of several cells
- Build correlation between impedance spectroscopy and aging behavior
- Investigate the cell microstructure in more thorough details like 3D reconstruction
- By end of the project period, gain more understanding of degradation for tubular cell and find mitigation solutions.
Acknowledgement

- Project manager: Joe Stoffa
- Harry Abernathy for discussion and guidance for cell degradation

Collaborators

- Boston University: Prof. Srikanth Gopalan and his team

Atrex Energy

- Manufacturing team
- Cell engineering Team

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