Development of Kilowatt-Scale Fuel Cell Technology

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FCP_07_chuang

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Overview

Timeline
- Project start date: 6/01/2008
- Project end date: 5/31/2012
- Percent complete: 15%

Barriers
- Barriers addressed
  - A. Long term catalyst durability
  - E. System thermal management

Budget
- Total project funding
  - DOE share: $1,180,800
  - Contractor share: $296,433
- Funding received in FY08
  $356,916
- Funding for FY07
  $255,912

Partners
- Ohio Coal Development Office
- First Energy Corp.
- Chemstress Corp.
Objectives

• **Overall:** Develop a kilowatt-scale coal fuel cell technology. The results of this R&D efforts will provide the technological basis for developing megawatt-scale coal fuel cell technology.

• 2008:
  – Investigate the factors governing the anode catalyst activity for the electrochemical oxidation of carbon in coal.

• 2009
  – Evaluate the long term anode and cathode catalyst activity as well as interconnect durability
  – Refine the coal injection and fly ash removal systems.
Approaches and Plan (I)

- **Task 1:** Investigate the factors governing the anode catalyst activity for the electrochemical oxidation of carbon in coal.

- **Task 2:** Evaluate the long term anode and cathode catalyst activity as well as interconnect durability.

- **Task 3:** Develop the process for fabrication of large scale fuel cell components.
Approaches and Plan (II)

- **Task 4:** Improve the coal injection and fly ash removal systems.

- **Task 5:** Integrate the fuel cell components into the coal fuel cell stack.

- **Task 6:** Develop a computer control system for the coal fuel cell stack.
### Technical Accomplishments/ Progress/Results

<table>
<thead>
<tr>
<th>Milestones</th>
<th>Progress</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factors governing the anode catalyst activity</td>
<td>The Ni anode exhibit the activity for electrochemical oxidation of solid carbon fuel to CO as a major product at 850 °C</td>
<td>Cu and Ce oxide will be added to the Ni anode to enhance the electrochemical oxidation activity of the anode catalyst</td>
</tr>
<tr>
<td>Evaluation of long term durability of anode, cathode and interconnects</td>
<td>500 h of stable operation of anode, cathode and low cost interconnect has been demonstrated with H₂ fuel and air</td>
<td>The long term test will be conducted using low ash carbon as a fuel</td>
</tr>
<tr>
<td>Develop the process for fabrication of large scale fuel cell components</td>
<td>All of the fabrication equipment have been purchased and tested</td>
<td>Fabrication variables such as heating cycle and quality of slip will be evaluated</td>
</tr>
<tr>
<td>Coal injection and fly ash removal systems</td>
<td>Fabrication of the coal injection and fly ash removal system has been initiated</td>
<td>The system will be tested by the end of 6th quarter</td>
</tr>
</tbody>
</table>
Stability of Low Cost Interconnect

T = 800 °C, Flow rate of He/H₂ = 80/80 cc/min

- No decrease in the Ohmic resistance was observed on the impedance plot after 500 h operation, showing the stability of the interconnect material.
- Increase in polarization resistance due to diffusion limitation of gas phase reactants and products led to decrease in the power density.
- The power density decreased from 0.21 to 0.16 W/cm² over 400 h and remained stable at 0.16 W/cm² over another 100 h.
V-I Performance of Low Ash Carbon Fuel at 800, 825 and 850 °C

(a) He/Low Ash Carbon over Ni/YSZ
Flow Rate He = 50 cc/min

(b) He/H₂/Low Ash Carbon over Ni/YSZ
Flow rate He/H₂ = 80/80 cc/min

Electric power produced by Low Ash Carbon increased by 3.5 times when elevating the temperature from 800 to 850 °C.
Technical Accomplishment - 3

MS Profile and Current vs. Time Plot for Ohio #5 Coke SOFC at 800 °C

Flow rate $H_2 = 80$ cc/min
Flow rate $He = 150$ cc/min

- Major products are CO and CO$_2$.
- Current dropped from 300 mA to almost 0 mA in 40 minutes due to fly ash accumulation on the anode.
Efficiency of Direct Carbon SOFC

- Assumption - Electrochemical oxidation of Ohio#5 coke produced CO₂.
- Efficiency calculated on the basis of data in the previous slide

\[ w_e = A \cdot V \cdot \int i \cdot dt \]

where

\[ i = \text{instantaneous current density (A/cm}^2\text{)} \]
\[ A = \text{Fuel cell active area (cm}^2\text{)} \]
\[ V = \text{Fuel cell voltage (Volt)} \]
\[ dt = \text{time (sec)} \]

\[ \int i dt = 183 \text{ (C/cm}^2\text{)} \]
\[ A = 1 \text{ (cm}^2\text{)} \]
\[ V = 0.56 \text{ (Volt)} \]
\[ w = 102.8 \text{ (J)} \]

\[ \Delta H = \text{LHV} \cdot F_{CO_2} \cdot U \cdot t \]

where

\[ U = \text{fuel utilized (\%)} \]
\[ \text{LHV} = \text{Lower heating value of Carbon (J/mol)} \]
\[ F_{CO_2} = \text{CO}_2 \text{ flowrate (mol/sec)} \]
\[ U = \text{fuel utilized (\%)} \]
\[ t = \text{time (sec)} \]

\[ F_{CO_2} \cdot t = 575 \text{ \mu mol} \]
\[ U = 100\% \]
\[ \text{LHV} = 355.2 \text{ (kJ/mol)} \]
\[ \Delta H = 204.2 \text{ J} \]

The efficiency \( \xi \) was calculated as

\[ \xi = \frac{102.8 \text{ J}}{204.2 \text{ J}} = 50.3\% \]
## Summary Table 1

Comparison of Power Densities for Low Ash Carbon at 800, 825 and 850 °C

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Fuel</th>
<th>Maximum Power (W/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>He/Low Ash Carbon</td>
<td>0.05</td>
</tr>
<tr>
<td>825</td>
<td>He/Low Ash Carbon</td>
<td>0.13</td>
</tr>
<tr>
<td>850</td>
<td>He/Low Ash Carbon</td>
<td>0.18</td>
</tr>
<tr>
<td>800</td>
<td>He/H₂/Low Ash Carbon</td>
<td>0.19</td>
</tr>
<tr>
<td>825</td>
<td>He/H₂/Low Ash Carbon</td>
<td>0.22</td>
</tr>
<tr>
<td>850</td>
<td>He/H₂/Low Ash Carbon</td>
<td>0.26</td>
</tr>
</tbody>
</table>
### Summary Table 2

Comparison of Efficiency of Various Fuels in SOFC

<table>
<thead>
<tr>
<th>T (°C)</th>
<th>Fuel</th>
<th>Efficiency calculated as the ratio of electrical work over enthalpy change of the oxidation (ξ_V %)</th>
<th>Electrochemical Efficiency (ξ_V %)</th>
<th>Net Efficiency 1,c (ξ_{Net} %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>H₂</td>
<td>34.3</td>
<td>57</td>
<td>40</td>
</tr>
<tr>
<td>800</td>
<td>Ohio #5 Coke</td>
<td>50.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>54.6</td>
<td>54.8</td>
</tr>
<tr>
<td>850</td>
<td>Low Ash Carbon</td>
<td>58.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>44.1</td>
<td>44.2</td>
</tr>
<tr>
<td>850</td>
<td>Low Ash Carbon</td>
<td>25.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>44.1</td>
<td>44.2</td>
</tr>
</tbody>
</table>

<sup>a</sup> = Assumed that electrochemical oxidation of carbon resulted in CO₂ only  
<sup>b</sup> = Assumed that electrochemical oxidation of carbon resulted in CO and CO₂ only  
<sup>c</sup> = 100% fuel utilization

Ideal thermodynamical efficiency → ξ_{T,ideal} = \( \frac{\Delta G(T,P)}{\Delta H(T,P)} \) = 1 – \( \frac{T \cdot \Delta S(T,P)}{\Delta H(T,P)} \)

Electrochemical efficiency → ξ_V = \( \frac{V(i)}{E^o} \)

Net efficiency → ξ_{Net} = \( \frac{\Delta G_T}{\Delta H_{298}} \) × \( \frac{V(i)}{E^o} \) × μ

\( V(i) \) = Fuel cell operational voltage, \( E^o \) = Ideal Nernst potential, \( \mu \) = Fuel utilization

Summary Table 3

<table>
<thead>
<tr>
<th>Time (h)</th>
<th>Power Density (W/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>t</td>
<td>0.1</td>
</tr>
<tr>
<td>t+122</td>
<td>0.21</td>
</tr>
<tr>
<td>t+177</td>
<td>0.20</td>
</tr>
<tr>
<td>t+240</td>
<td>0.18</td>
</tr>
<tr>
<td>t+290</td>
<td>0.17</td>
</tr>
<tr>
<td>t+338</td>
<td>0.18</td>
</tr>
<tr>
<td>t+410</td>
<td>0.16</td>
</tr>
<tr>
<td>t+509</td>
<td>0.16</td>
</tr>
</tbody>
</table>

Stability Test Results of a Low Cost Interconnect
Summary 1

• Relevance:
  Development of an effective anode catalyst for the electrochemical oxidation of coal/coke will significantly increase (>50%) the efficiency of the use of fossil fuels for electrical power generation with nearly zero emission.

• Approach:
  – Identification and test of the low cost anode catalysts, interconnect, fuel cell components for the design and fabrication of the coal fuel cell stack.
  – Development of an integrated coal fuel cell stack for the conversion of coal to highly concentrated CO$_2$ and electricity.
Summary 2

• Technical Achievements:
  – Stable performance for 500 h of a low cost interconnect has been demonstrated with \( \text{H}_2 \) fuel and air.
  – Maximum power density of 0.18 W/cm\(^2\) achieved at 850 °C for Low Ash Carbon.
  – Thermodynamic efficiency of more than 50 % has been demonstrated for carbon-based SOFC at 800 °C.

• Technology Transfer/Collaboration:
  – Collaboration with the Ohio Coal Development Office and FirstEnergy Corp.
  – Working with Chemstress for the design of a fuel cell stack.

• Proposed Future Research:
  – Identification of the catalyst composition for the effective electrochemical oxidation of solid carbon fuels.
  – Investigation of the distribution of carbon and flyash particles on the surface of anode catalysts and inside of the fuel cell.
Future Work

• Identify the most effective anode catalyst composition for the long-term electrochemical oxidation of solid carbon fuels at 800 °C.

• Identify the low cost interconnect materials.

• Completion and testing of the coal injection and fly ash removal system. Investigation of the distribution of flyash particles on the anode surface.

• Design, fabrication, and test of a small scale (1-10 kW) coal fuel cell system.

• Key milestones:
  – Identification of the composition of the anode catalysts which catalyzes the formation of CO₂ with more than 80% selectivity at 800 °C.
  – Identification and successful development of interconnects which cost 50% less than the present interconnects.
  – Completion of the design of the fuel cell stack and selection of the key components.
Collaboration

• Partners
  – The Ohio Coal Development Office: focusing on the fundamental research on determination of the fuel cell efficiency.
  – FirstEnergy Corp: addressing practical issues of the scaling up fuel cell stack.

• Technology Transfer:
  – Chemstress Co: developing the design of the large scale fuel cell stack.