Development of Kilowatt-Scale Fuel Cell Technology

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April 9, 2010

Project ID#: FC070

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Overview

Timeline
- Project start date: 6/01/2008
- Project end date: 6/30/2012
- Percent completed: 40%

Barriers
- Barriers addressed
  - Long term catalyst and fuel cell durability
  - System thermal management

Budget
- Total project funding
  - DOE share: $1,180,800
  - Contractor share: $296,433
- Funding received in FY09
  - $250,722
- Funding for FY10
  - $220,922

Partners
- The Ohio Coal Development Office
- FirstEnergy Corp.
Objectives - Relevance

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.

2009
- Evaluate the long term anode and cathode catalyst activity as well as interconnect durability.
- Improve the coal injection and fly ash removal units.

2010
- Determine the effect of CO$_2$ product on the performance of the coal fuel cell.
- Study the long term electrochemical oxidation of coal.
- Investigate the integration of fuel cells in series and parallel for the coal fuel cell stack.
- Test the operating conditions of a steel coal injection unit.
Plan & Approach

Task 1: Investigate the effect of CO$_2$ on the anode catalyst activity and the performance of the coal fuel cell

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.

Task 4: Improve the coal injection and fly ash removal units.

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.
<table>
<thead>
<tr>
<th>Milestones</th>
<th>Progress</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect of CO₂ on the activity and performance of the coal fuel cell.</td>
<td>Exposure of the Ni anode to CO₂ has been demonstrated to improve the fuel cell performance by increasing formation of CO via the Boudouard reaction with solid carbon (C + CO₂ → 2CO).</td>
<td>Cu and Ce oxide will be added to the Ni anode to enhance the activity of the anode catalyst for the electrochemical oxidation of C and CO.</td>
</tr>
<tr>
<td>Test of the long term electrochemical oxidation of coke on the fuel cell.</td>
<td>Long term electrochemical oxidation of coke was demonstrated.</td>
<td>The fuel cell energy conversion efficiency during long term testing will be further analyzed.</td>
</tr>
<tr>
<td>Integration of fuel cells in series and parallel for coal fuel cell stack.</td>
<td>Integration of the fuel cells in parallel were found to produce maximum power densities 30% higher than integration in series.</td>
<td>The performance of the stack cells will be analyzed in coke fuel, evaluating energy conversion efficiency.</td>
</tr>
<tr>
<td>Test of coal injection unit.</td>
<td>Injection of coal with a steel auger was investigated. Coal feeding rates higher than 0.1 g/min are needed to produce highly reactive coke fuel.</td>
<td>Different coal feeding rates and heating profiles will be investigated.</td>
</tr>
</tbody>
</table>
Flowing CO₂ increases the performance of the coke fuel cell

\[ T = 775 \pm 25 \text{ C, Flow rate of } H_2/He = 35/200 \text{ cc/min, CO}_2/He = 35/200 \text{ cc/min} \]

- 3 g of coke on a layer of YSZ pellets in contact with the Ni anode produced a max. power density of 0.09 W/cm² in flowing He, 0.180 W/cm² in flowing 15% v/v CO₂/He and 0.29 W/cm² 15 % v/v H₂/He.
- The ohmic resistance remained constant in flowing CO₂/He for 24 h.
- The power density in flowing He correlates to high polarization resistance.
Technical Accomplishment - 2

Determination of coke fuel cell energy efficiency at 775±25 °C in flowing of 6% CO$_2$

<table>
<thead>
<tr>
<th>Inlet (%)</th>
<th>Effluent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO$_2$</td>
<td>He</td>
</tr>
<tr>
<td>6.08</td>
<td>93.92</td>
</tr>
<tr>
<td>6.08</td>
<td>93.92</td>
</tr>
<tr>
<td>6.08</td>
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<td>6.08</td>
<td>93.92</td>
</tr>
</tbody>
</table>

Thermodynamic efficiency calculation

$$\eta = \frac{W_e}{\Delta H} = \frac{V \int I \cdot dt}{LHV \cdot F_{CO} \cdot U \cdot t} = \frac{0.4 \cdot 297}{282,980 \cdot 6.78 \times 10^{-4} \cdot 0.054 \cdot 20} = 57.3\%$$

$LHV = $ Lower heating value of CO $= 282,980 \left( \frac{J}{mol} \right)$

$F_{CO} = $ Flow rate of CO produced from Boudouard rxn $= 6.78 \times 10^{-4} \ (mol/min)$

$U = $ fuel utilization $= 5.4\%$

$t = $ time $= 20 \ min$
Technical Accomplishment - 3

Long term testing of the fuel cell in coke at 775 ± 25 °C

Note: 1. Voltage changed from 0.35 to 0.5, 0.1, and 0.35 volt, respectively
2. The inlet gas changed from He to He/H₂, He/CO₂, He/CO, respectively, while the voltage was kept at 0.35 volt

Power generation from coke continued over 15 h at 775 °C (+/− 25 °C)
The low voltage load had a decaying current densities versus time, whereas the current densities were relatively constant at high voltage loads.

The composition of effluents changed when the voltage load was lowered to 0.1 (volt).
Technical Accomplishment - 4
Integration of fuel cells in series and parallel

- Ag wire is connected to the cathode current collector.
- Fuel cell housing and tubing is connected to the anode.
Fuel cell stack: series vs. parallel performance at 775± 25 °C

<table>
<thead>
<tr>
<th>Fuel cell/Stack</th>
<th>OCV(V)</th>
<th>max I(A)</th>
<th>max P(W)</th>
<th>Ohmic R(ohm)</th>
<th>Polarization R(ohm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell 1</td>
<td>1.03</td>
<td>1.05</td>
<td>0.223</td>
<td>0.52</td>
<td>1.68</td>
</tr>
<tr>
<td>Cell 2</td>
<td>0.96</td>
<td>1.26</td>
<td>0.247</td>
<td>0.38</td>
<td>2.02</td>
</tr>
<tr>
<td>Parallel</td>
<td>1.00</td>
<td>1.79</td>
<td>0.367</td>
<td>0.38</td>
<td>0.97</td>
</tr>
<tr>
<td>Series</td>
<td>1.98</td>
<td>1.18</td>
<td>0.475</td>
<td>0.81</td>
<td>3.19</td>
</tr>
</tbody>
</table>
Fuel cell stack: Performance (2 cells/housing)

Individual fuel cells

Fuel cell stack

Current (A)

Voltage (V)

Power (W)
Temperature distribution along the auger at steady state (MikroSpec RT-M7500); the color scale is calibrated for 20-200 °C.

Schematic of the coal injection equipment showing steady state temperature distribution
Infrared characterization of coal and coke produced from the coal injection unit

**Experimental procedure**

- **coal**
  - Purging with He for 1 hour (flow rate of 50 cc/min)
  - Heat to 960°C (heating rate: 4°C/min)
  - Screw feed the coal (inlet rate of 0.1 g/min)

- **coke**

**DRIFT spectra of Mansfield unit1 coal and coke**

![Graph showing DRIFT spectra of coal and coke with labeled wavenumbers and peaks at 3064 (CH aromatic), 2930 (CH saturated), 2858 (CH saturated), 1503 (C=C aromatic stretch), 1450 (δCH₃ asym bending), 1380 (δCH₃ asym bending), and 1600 (CC aromatics).]
<table>
<thead>
<tr>
<th>Fuel</th>
<th>Maximum Current (A/cm²)</th>
<th>Maximum Power (W/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>He/coke</td>
<td>0.210</td>
<td>0.09</td>
</tr>
<tr>
<td>He/coke/CO₂ (6% v/v)</td>
<td>0.340</td>
<td>0.10</td>
</tr>
<tr>
<td>He/coke/CO₂ (15% v/v)</td>
<td>0.530</td>
<td>0.18</td>
</tr>
<tr>
<td>He/coke/H₂ (15% v/v)</td>
<td>1.270</td>
<td>0.29</td>
</tr>
</tbody>
</table>

Comparison of power densities in coke flowing He, CO₂, and H₂ at 750°C
Summary

Relevance: Development of a high performance fuel cell 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.

Technical Achievements:

– The performance of the coke fuel cell was found to be higher in flowing CO$_2$ than in flowing He. Thermodynamic efficiency of more than 57% has been achieved for coke fuel cell at 750 °C in 6% v/v CO$_2$.
– Long term testing of fuel cell for 15h has been demonstrated with coke fuel, producing a maximum power density of 0.1 W/cm$^2$ at 775 °C.
– The use of a steel auger for injection of coal was carried out. Heating profiles and coal feeding rates were evaluated.
Future Work

• Identify the most effective anode catalyst composition for the long-term electrochemical oxidation of solid carbon to CO₂ at 700-800 °C.
• Identify the low cost interconnect materials
• Complete testing of the coal injection and flyash removal units. Investigate of the distribution of flyash particles on the anode surface.
• Design, fabricate, 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 (State): Focusing on the fundamental research on determination of the fuel cell efficiency.
  – FirstEnergy Corp (Industry): Addressing practical issues of the scaling up fuel cell stack.

• Technology Transfer:
  – Chemstress Co (Industry): Designing of the large scale fuel cell stack.