V.0.5 Extended Durability Testing of an External Fuel Processor for SOFC*

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*Congressionally directed project

Objectives

The main goal of this project is to perform extended durability testing of the external fuel processor (EFP) for a 1-MWe solid oxide fuel cell (SOFC) power plant concept being developed by Rolls-Royce Fuel Cell Systems (US) Inc. (RRFCS). The specific objectives are to:

- Conduct long-term tests in relevant environments for the three EFP subsystems that support operation of a 1-MWe SOFC power plant. The subsystems include:
  - Synthesis-gas subsystem
  - Start-gas subsystem
  - Desulfurizer subsystem
- Determine long-term performance of key components such as catalysts, sorbents, heat exchangers, control valves, reactors, piping, and insulation.
- Evaluate the impact of ambient temperatures (hot and cold environment) on performance and component reliability.
- Determine system response for transient operation.

Technical Barriers

This project addresses the following technical barriers from the Fuel Cells section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) Durability
(C) Performance
(G) Start-up and Shut-down Time and Energy/Transient Operation

These barriers will be addressed as they relate to the three External Fuel Processor subsystems.

Technical Targets

This project addresses milestone 59 in the Fuel Cells section of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration (RD&D) Plan. Milestone 59 is to "evaluate fuel processing subsystem performance for distributed generation against system targets for 2011." These targets will be addressed as they relate to durability, performance (gas quality - sulphur in product stream), and transient response of the EFP subsystems.

Characteristic	Units	2005 Status	DOE 2011 Targets
Cold start-up time to full load @ -20°C ambient*	minutes	<90	<30
Transient response (10 to 90% load) Load rate of change	Minutes % / min	<5 16	1 80
Durability	hours	20,000	40,000
Survivability (min and max ambient temperature)	°C °C	-25 +40	-35 +40
Sulfur content in product stream	ppbv (dry)	<10	<4

* or at values limited by weather conditions

Accomplishments

The following work has been completed since last year's annual report (June 2009):

- Hydrogen Safety Plan was issued and approved by DOE's Hydrogen Safety Panel.
- Completed fabrication of outdoor test facility.
- Installed desulfurizer and start-gas subsystems in outdoor test facility.
- Commissioned control software, mechanical and electrical hardware for desulfurizer subsystem.
- Commissioned control software, mechanical and electrical hardware for synthesis-gas subsystem.
- Completed 1,000-hour durability test of synthesis-gas subsystem.

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Introduction

RRFCS is developing a 1-MWe SOFC power plant for stationary power application. An integral part of the SOFC power plant is the EFP. It uses pipeline natural gas and air to generate all the gas streams required by the SOFC power plant for start-up/shutdown (non-flammable reducing gas or start gas), low-load operation (synthesis gas) and normal operation (desulfurized natural gas). Thus it eliminates the need for on-site storage of high-pressure, bottled gases of nitrogen or hydrogen.

Approach

The approach for this project is to conduct durability tests in relevant environments using full-scale components for the EFP of a 1-MWe SOFC power plant. The components were designed and built as part of another project and made available for the durability testing. An outdoor test facility was constructed as part of a third project so that the EFP could be tested under hot- and cold-weather conditions that would be expected for a 1-MWe SOFC power plant operating in northeast Ohio. Figure 1 shows a photograph of the EFP in the outdoor test facility.

The durability testing includes:

- Synthesis-gas subsystem operation for multiple start-ups and 1,000 hours of operation in a heated, indoor enclosure. This subsystem is used only during low-load operation of the SOFC to balance the thermal input and is required to operate for only a few hundred hours per year. Therefore the 1,000-hour test will simulate a 5-year service life.
- Start-gas subsystem testing for multiple start-ups and 1,000 hours of steady-state operation in an outdoor (hot and cold) environment. This subsystem is used only during start-up and shutdown of the SOFC and is required to operate for only a few hundred hours per year. Therefore the 1,000-hour test will simulate a 5-year service life.
- Desulfurizer subsystem testing for 8,000 hours in an outdoor (hot and cold) environment. This subsystem operates whenever the SOFC is making power therefore it is expected to operate for much longer periods compared to the other two subsystems. The 8,000-hour test represents the time period between yearly maintenance intervals.

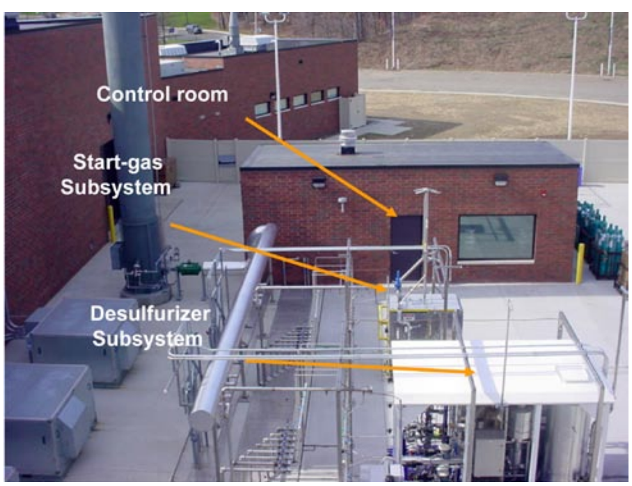

FIGURE 1. Desulfurizer and Start-gas Subsystems Installed in Outdoor Test Facility

After completing the durability tests, post-test analyses of the hardware will be performed. Subsystem components (catalysts, sorbents, piping, reactors, insulation, valves, heaters, heat exchangers, nitrogen membrane, etc.) will be inspected for deposits, signs of wear, damage, corrosion, and erosion. Physical and chemical analyses will be performed on components as required.

The durability tests will demonstrate that the EFP subsystems are ready for a full-scale SOFC system demonstration.

Results for 2010

Synthesis-Gas Subsystem

The synthesis-gas subsystem was installed inside a room temperature test enclosure to simulate its operating environment which is inside the SOFC enclosure. The start-gas subsystem and desulfurizer subsystem were installed in the outdoor test facility since that environment would be representative of their operation outside of the SOFC enclosure in an unheated area.

The synthesis-gas subsystem was the first subsystem to be tested. It was designed to generate hydrogen from natural gas and air to support low-load operation of the SOFC. It was tested to determine its start-up characteristics and the impact of operating time on performance. The synthesis gas reactor was heated to 350°C using warm air. The heat-up required 62 minutes. Once the catalyst was at temperature the natural gas flow was initiated. Within 40 seconds the reactor began to produce hydrogen and after 120 seconds the hydrogen concentration was approaching the target level. The hydrogen production during start-up trended closely with the catalyst outlet temperature. Figure 2 shows the results from the start-up of the synthesis-gas subsystem. The total start-up time was 64 minutes. This was slightly above the 60 minute target however the start-up procedure can be modified to significantly reduce the time for heat-up and thus meet the required performance.

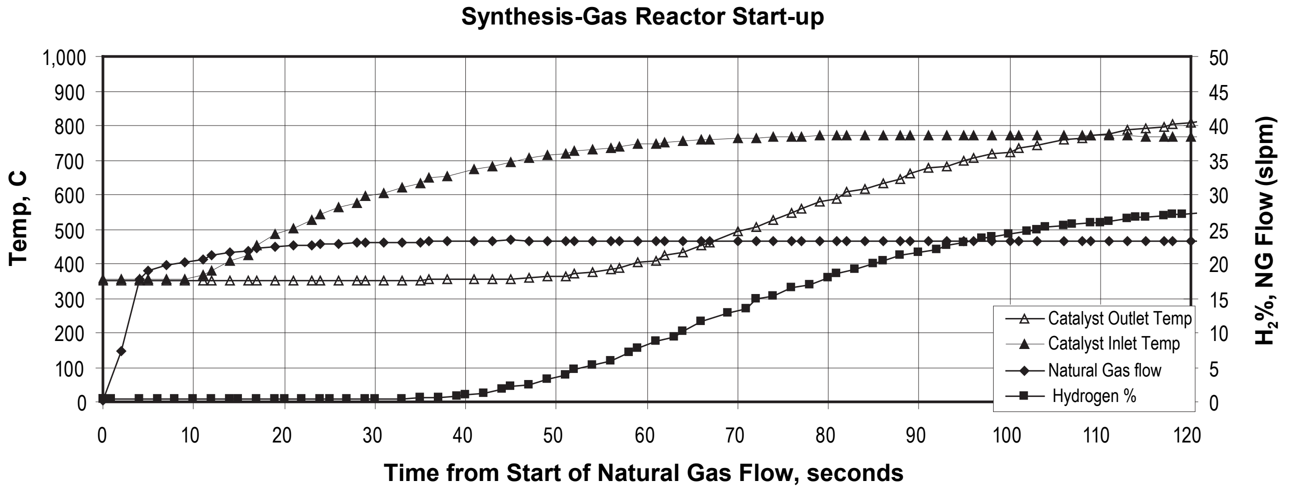

FIGURE 2. Synthesis-Gas Subsystem Start-up

After start-up, the synthesis-gas subsystem was operated for 1,000 hours to characterize its durability. The reactor was cycled periodically between minimum load (15%) and maximum load (100%) conditions. The hydrogen content in the product gas slowly declined overtime (see Figure 3). At the completion of the test, the hydrogen concentration had dropped to about 85% of the initial target value (15% decline per 1,000 hours). This was within the acceptable range for the synthesis-gas subsystem for the SOFC application.

The transient response for the synthesis-gas subsystem was evaluated during a load change from 17% to 50% load. The load change was performed over a 55-second period. This gave a load rate of change of about 36% per minute. This was very close to the target value of 40% per minute. A faster load rate of change is likely possible with additional tuning of the control valves. The plot in Figure 4 shows the transient response for the synthesis-gas subsystem. The hydrogen concentration in the product gas remained near the target value during the transient while the outlet temperature increased from 815 to 855°C during the same period.

The synthesis-gas subsystem was disassembled after the 1,000-hour test was completed. The reactor vessel and its internal components were found to be in good conditions with no signs of corrosion, erosion or melting. The heaters, thermocouples and control valves showed no signs of significant degradation. A light coating of carbon was observed at the outlet of the catalyst and in the outlet piping. The carbon deposition on the catalyst may have contributed to the observed reduction in hydrogen yield over time.

Samples of the catalyst were removed from the reactor and will be submitted for chemical and physical analyses. Surface area, pore volume, precious metals, carbon and sulfur contents will be determined. Small samples of the reactor components will be analyzed to quantify any metal loss due to hydrogen dusting or corrosion.

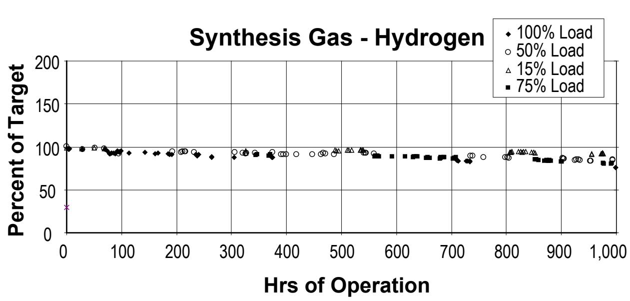

FIGURE 3. Synthesis-Gas Subsystem Hydrogen Produced as a Percent of Target

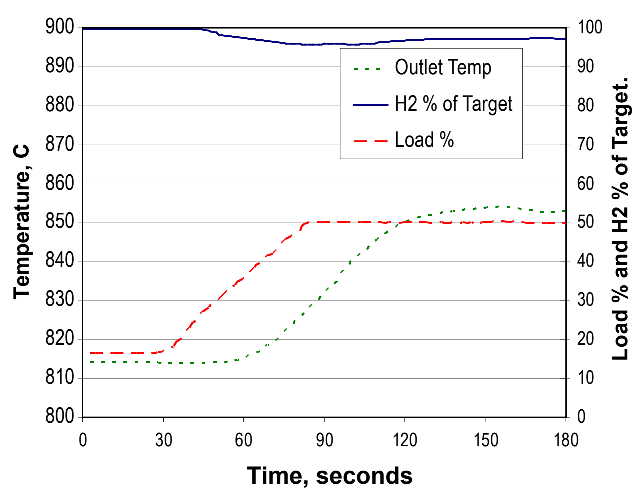

FIGURE 4. Synthesis-Gas Subsystem Transient Response

Desulfurizer Subsystem

The desulfurizer subsystem has been installed into the outdoor test facility. Natural gas and compressed air lines were connected to supply the reactant gases to the subsystem. The outlet of the subsystem was connected to a ground flare for the safe disposal of the desulfurized natural gas since a 1-MWe SOFC is not available to use the gas.

The desulfurizer subsystem's mechanical and electrical hardware were commissioned. All hardware is operating properly. The control software also was commissioned. Its function was tested in the semi-automatic mode through all six operational states. Once the control software has been commissioned in the fully-automatic mode the desulfurizer subsystem will be ready for durability testing.

Start-Gas Subsystem

The start-gas subsystem was installed into the outdoor test facility. Natural gas and compressed air lines were connected to supply reactant gases to the subsystem. The outlet of the subsystem was connected to a ground flare for safe disposal of the start-gas since a 1-MWe SOFC was not available to use the gas. The start-gas subsystem is ready for mechanical and electrical commissioning.

Conclusions

The durability testing of the synthesis-gas subsystem was competed and test results showed that the performance was at or very near the target values. These include:

- Start-up time of 64 minutes.
- Transient response (load change rate) 36% per minute.
- Hydrogen concentration declined 15% per 1,000 hours.
- No signs of corrosion, erosion or melting of the synthesis-gas subsystem components were observed.

Future Directions

2010

- Complete post-test inspections of synthesis-gas subsystem (third quarter Fiscal Year [FY] 2010).
- Complete commissioning of start-gas and desulfurizer subsystem (third quarter FY 2010).
- Begin durability testing of start-gas and desulfurizer subsystems (fourth quarter FY 2010).

2011

- Complete durability testing of start-gas and desulfurizer subsystems (third quarter FY 2011).
- Complete inspections of start-gas and desulfurizer subsystems (fourth quarter FY 2011).
- Issue final report for project (fourth quarter FY 2011).

FY 2010 Publications/Presentations

1. Presentation at 2010 Hydrogen Program Annual Merit Review Meeting by M. Perna.

2. Presentation to DOE's Hydrogen and Fuel Cell Technical Advisory Committee (HTAC) June 2010 by M. Perna.