

V.L.3 Extended Durability Testing of an External Fuel Processor for SOFCs*

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*Congressionally directed project

- 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.

Fiscal Year (FY) 2011 Objectives

The main goal of this project is to perform extended durability testing of the external fuel processor (EFP) for a one megawatt (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

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) and transient response of the EFP subsystems. Table 1 shows the technical targets for the project.

TABLE 1. Technical Targets

Characteristic	Units	2005 Status	DOE 2011 Targets	RRFCS 2011 Targets
Cold start-up time to full load @ -20°C ambient	minutes	< 90	< 30	60
Transient response (10 to 90% load) Load rate of change	Minutes (% per min)	< 5 (16)	1 (80)	2 (40)
Durability	hours	20,000	40,000	8,000
Survivability (min and max ambient temperature)	°C °C	-25 +40	-35 +40	-40 +40
Sulfur content in product stream	ppbv (dry)	< 10	< 4	< 100

FY 2011 Accomplishments

- Prepared samples from the post-test inspection of synthesis gas subsystem for analysis.
- Completed commissioning of the desulfurizer subsystem.
- Completed 4,649 hours of the 8,000-hr desulfurizer subsystem durability test.
- Commissioned mechanical and electrical hardware for the start-gas subsystem.
- Started commissioning of the control system software for the start-gas subsystem.



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 compressed air to generate all the gas streams required by the SOFC power plant for start-up/shut-down (non-flammable reducing gas referred to as 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 such as nitrogen and 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 desulfurizer subsystem under test in February 2011 in the outdoor test facility.

The durability testing includes:

- Synthesis-gas subsystem testing 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 operation in an outdoor (hot and cold) environment. This subsystem is used only during start-up and shut-down 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.



FIGURE 1. Desulfurizer Subsystem Being Tested in the Outdoor Test Facility (-23°C)

- 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.

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 2011

Synthesis-Gas Subsystem

The synthesis-gas subsystem was disassembled after completion of the 1,000-hour durability test. The catalyst was removed from the reactor and samples were submitted for chemical and physical analyses. Small samples of the subsystem's metal components were prepared for chemical and physical analyses to quantify metal loss and corrosion. Results from these analyses had not been received by the time of this report.

Desulfurizer Subsystem

The desulfurizer subsystem was the second of the three subsystems to be tested. It generates pressurized, desulfurized natural gas (DNG) from high-pressure pipeline natural gas. The RRFCS target for maximum allowable sulfur level in the DNG is 100 parts per billion (ppb) on a volume basis.

The software packages for the desulfurizer subsystem's control and safety systems were commissioned and verified for automatic operation. This enables unattended operation to support long-term (8,000-hr) durability testing. The desulfurizer subsystem is being operated in the outdoor test facility to determine the impact of ambient temperature on start-up and system operation. The testing also determined the transient response to load changes and subsystem durability.

The desulfurizer subsystem uses a natural gas burner to provide warm gas (300°C) to heat up the sorbent beds for start-up. The heat-up from 20°C required about 12 hours. This time increased to 27 hours when the heat-up was performed at -23°C, the coldest temperature recorded through the winter season at the outdoor test facility in North Canton, Ohio. The heat-up time at the very cold condition was longer than desired. The procedure for desulfurizer subsystem heat-up is being modified to reduce the time required to heat up from very cold conditions.

Once the sorbent was at temperature, it was maintained in a standby state using electric heaters. When in the standby state, gas flows were initiated for start up of the desulfurizer subsystem. Start-ups were performed at ambient temperatures ranging from -23 to 30°C. The start-up time required to begin producing DNG typically ranged from 56 to 74 minutes for these temperatures. These results were considered acceptable by RRFCS.

The transient response for the desulfurizer subsystem was tested over a load change from 10% to 40% of the design DNG flow rate. The upper range used for the load change was limited by the natural gas compressor and not the desulfurizer subsystem. The time required by the desulfurizer subsystem for the load change was 25 seconds. This gives a load rate of change of 72% per minute. This exceeded the RRFCS target of 40% per minute. The plots

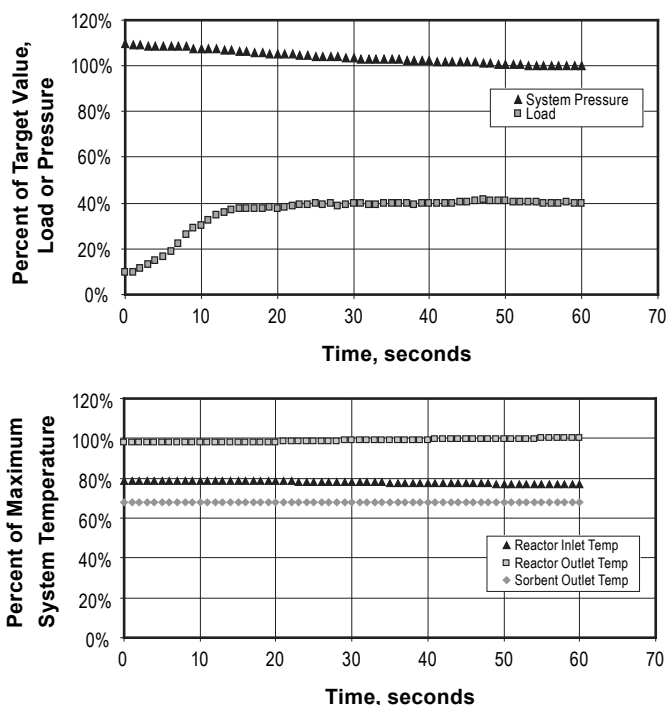


FIGURE 2. Desulfurizer Subsystem's Transient Response to Load Change

in Figure 2 show the load change as a function of time along with the response of the system pressure and temperatures. The pressure declined slightly at the higher load while the temperatures remain fairly constant. All the process variables showed a well controlled response to the rapid change in load.

The desulfurizer subsystem has been operating over the past eight months. It had logged a total of 4,649 hours on stream by the beginning of June 2011. The subsystem has maintained the sulfur level in the DNG to less than 10 ppb (the lower detection limit of the on-line sulfur analyzer) for the vast majority of the durability test period. This was lower than the RRFCS target of 100 ppb. The subsystem has successfully endured four trips due to auxiliary system failures (natural gas compressor, flare stack, and site power) and also has undergone two planned shutdowns to remove test-coupon samples. The plot in Figure 3 shows the sulfur level and the total hydrocarbons in the DNG leaving the desulfurizer subsystem. A small fraction of the hydrocarbons in the natural gas feed are converted into carbon dioxide and water to provide the heat required to support the desulfurization process.

The desulfurizer subsystem continues to operate and is expected to achieve the 8,000-hour durability target by mid-November (2011).

Start-Gas Subsystem

The mechanical and electrical commissioning for the start-gas subsystem has been completed. The operation of

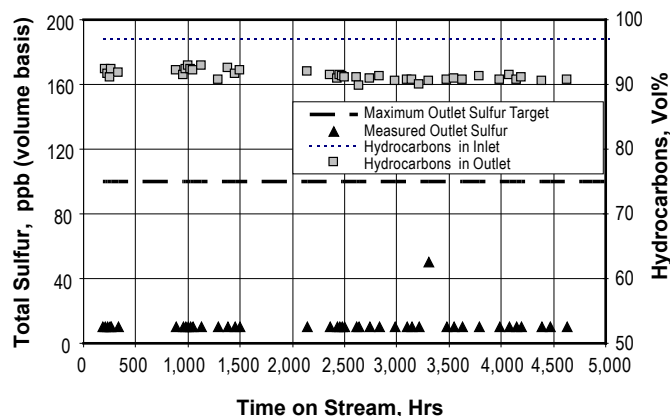


FIGURE 3. Sulfur Level and Total Hydrocarbons in Desulfurized Natural Gas

all control and safety system hardware was verified. Work continues on commissioning the control system software to allow automatic operation. Automatic operation of the start-gas subsystem had not been achieved by the time of this report. However, the subsystem was successfully started and operated at the full load condition in the manual mode of operation.

Conclusions

The desulfurizer subsystem durability testing has logged 4,649 hours of the planned 8,000- hour test. It is working well with test results showing that performance is meeting or exceeding RRFCS requirements:

- Transient response (load rate of change) was 72% per minute.
- Sulfur level was less than 10 ppb.
- Start-up times ranged from 56 minutes to 74 minutes for ambient temperatures ranging from -23 to 30°C.

The start-gas subsystem is ready for final commissioning activities. Once they are completed, durability testing will begin.

Future Directions

2011

- Complete commissioning of control system software for the start-gas subsystem (fourth quarter 2011).
- Complete the 8,000-hour desulfurizer subsystem durability test (fourth quarter 2011).

2012

- Begin durability testing of start-subsystem (first quarter 2012).
- Reduce heat-up time at cold conditions for desulfurizer subsystem (first quarter 2012).
- Complete durability testing of start-gas subsystem (second quarter 2012).
- Complete inspections of start-gas and desulfurizer subsystems (second quarter 2012).
- Issue final report for project (second quarter 2012).

FY 2011 Publications/Presentations

1. Presentation at 2011 Hydrogen Program Annual Merit Review and Peer Evaluation Meeting in Arlington, Virginia by A. Upadhyayula on May 20, 2011.
2. Presentation at Fuel Cell Seminar & Exposition 2010 in San Antonio, Texas by M. Perna on October 20, 2010.