Dispenser Reliability

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Project End Date: Project continuation and direction determined annually by DOE

Overall Objectives

- Improve hydrogen dispenser reliability through accelerated life testing.
- Compare reliability performance of dispenser components at -40°C and -20°C.
- Perform material analysis of components to create a comparison of non-exposed parts, failed parts, and parts that have seen different temperatures.

Fiscal Year (FY) 2019 Objectives

- Complete the -40°C and -20° cycle testing on the National Renewable Energy Laboratory's (NREL's) accelerated life testing apparatus (ALTA).
- Perform material analysis on non-exposed and exposed hydrogen components to research trends in polymer susceptibility to hydrogen toward component failure modes.

Technical Barriers

This project addresses the following technical barriers from the Technology Validation and Safety, Codes and Standards sections of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan[1]:

Technology Validation:

- D. Lack of Hydrogen Refueling Infrastructure Performance and Availability Data.

Safety, Codes and Standards:

- G. Insufficient Technical Data to Revise Standards.

FY 2019 Accomplishments

- Achieved 1,000+ cycles at -40°C and -20°C on ALTA.
- Tracked failures and common best practices that could be used to avoid reliability issues in the field.
- Completed chemical characterization analyses and physical property degradation studies for polymers in components pressure cycled in cold (-20°C and -40°C) hydrogen.

[1] https://www.energy.gov/eere/fuelcells/downloads/fuel-cell-technologies-office-multi-year-research-development-and-22

INTRODUCTION

Hydrogen station reliability currently lags far behind consumer expectations. To support widespread fuel cell electric vehicle (FCEV) deployment, operators must improve reliability. One of the largest contributors to station reliability issues is the dispenser, in particular the components exposed to prechilled hydrogen. An improved understanding of component life cycles at low temperatures is needed so that resources can be allocated to redesign unreliable parts.

APPROACH

NREL and Sandia National Laboratories (SNL) are working together to tackle component reliability within hydrogen dispensers. NREL is responsible for performing accelerated life testing of components typically found in the prechilled section of the dispenser. SNL is responsible for the material analysis of the components.

For NREL's work, the objective is to measure the mean fills between failures and mean kilograms between failures of hydrogen components subjected to pressures, ramp rates, and flow rates similar to light-duty FCEV fueling at -40°C and -20°C. The five types of components under test include nozzles, breakaways, filters, normally closed valves, and normally open valves. Devices from two manufacturers for each component type will be tested at the two temperature levels. Therefore, the testing will yield 20 different mean fills between failures and mean kilograms between failures results by the end of the experiment.

To support NREL's ALTA studies of components, SNL disassembles the exposed components to remove polymer O-rings and gaskets and performs chemical characterization analyses and investigates physical property degradation. Baseline properties for polymers will be established by characterizing properties for polymeric O-rings and gaskets removed from untested components. Chemical characterization will use analytical methods such as Fourier transform infrared (FTIR) spectroscopy (for identifying chemical functional groups and establishing changes in polymer after hydrogen exposure) and dynamic mechanical thermal analysis (DMTA) (for changes in modulus and glass transition temperatures). Physical degradation of the polymers is to be followed by density and mass changes, and optical and micro-computed tomography imaging for voids, microcracks, and other defects after exposures. Exposure of polymers to cycled hydrogen under low-temperature conditions in tested components will be used to identify polymer chemistries most susceptible to hydrogen attack and their failure modes across components.

The ALTA will allow for eight "dispenser like" systems to be tested simultaneously. The systems are packaged with two dispenser sets in series and four sets in parallel to complete the full system. A single test setup is shown in Figure 1. The figure shows the five components under test in addition to a pressure transducer and temperature transducer on each individual test setup. The accelerated testing is achieved by putting multiple test setups into one test apparatus and testing them all simultaneously. Figure 2 shows how the individual test setups are positioned in the test apparatus to achieve accelerated life testing. Note that a controllable research dispenser and a recirculation loop were implemented into the test apparatus on the front end and back end, respectively.

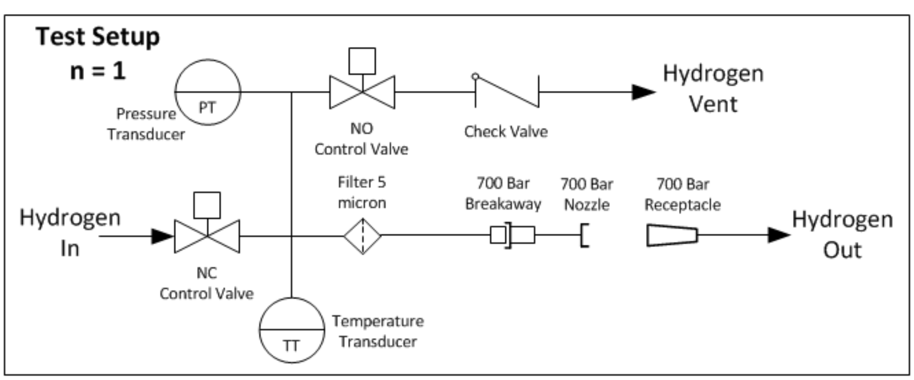

Figure 1. Overview of one test setup

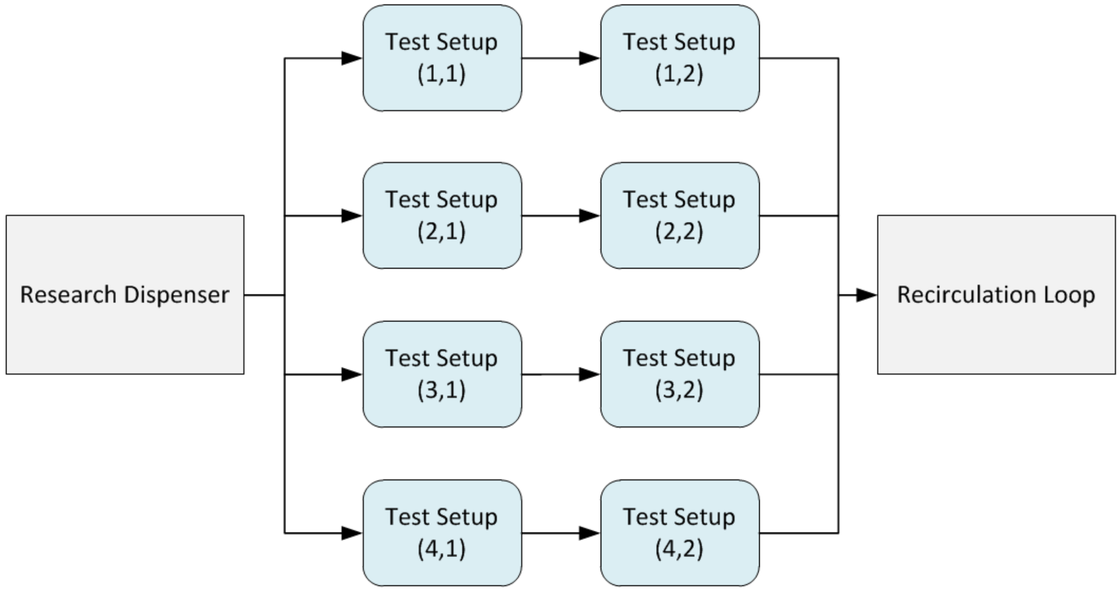

Figure 2. Complete system with eight dispenser test setups

RESULTS

System Repeatability

The National Fuel Cell Technology Evaluation Center (NFCTEC) at NREL collects and analyzes retail hydrogen station data for hydrogen stations in California. This project was able to leverage an average fill profile using NFCTEC data to ensure that the ALTA mimicked what was happening in the field. Figure 3 shows the average pressure ramp rate of a retail hydrogen fill (dashed line) versus the average fill from the ALTA over ~500 cycles. In this report, cycles and fills are used interchangeably as equivalents so one retail equivalent fill = one cycle on ALTA. The agreement of the pressure ramp rate ensures that the components experience the same pressure ramp and high-pressure ending that is observed in the field. On the temperature side, the system was required to keep the components between -33°C and -40°C for the -40°C testing. For the -20°C testing the range was set to -17.5°C to -26°C. The ALTA showed good repeatability over the duration of the -40°C and -20°C testing.

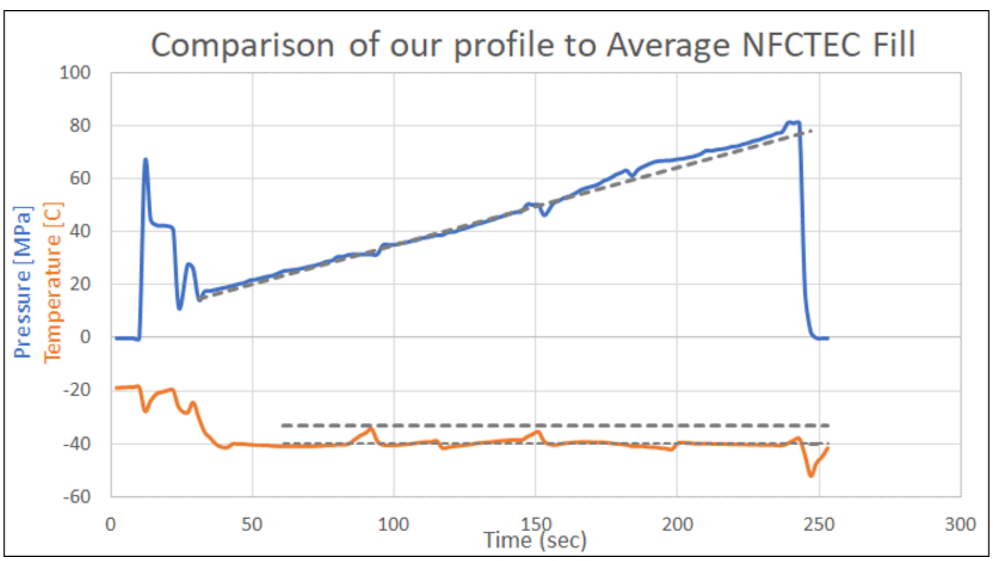

Figure 3. Comparison of ALTA fill versus NFCTEC retail station data

Cycle Testing

NREL completed the -40°C and -20°C cycle testing in FY 2019. The most interesting aspects of the testing were observed in the -40°C testing and that will be the topic of discussion in this section. The -20°C cycle testing was completed by the end of FY 2019; however, the team did not complete the statistical analysis comparison against -40°C reliability results in FY 2019. Those results will be made public via the Annual Merit Review (AMR) in 2020 and with the final project report, which is scheduled to be released before the 2020 AMR.

Discussion on Lessons Learned from the -40°C Testing

The first component failure was a normally closed valve that failed at 108 cycles. About 124 kg had been allowed to pass through the valve at that point of the testing. The first failure was a result of a valve stem that needed to be retorqued to the correct setpoint. With this observation, the NREL team tested all the valves involved in the testing to see how many were outside of the torque specification. The team discovered that two-thirds of the valve were out of specification, with all of them being under torqued (aka loose). This result leads to a recommendation by the team for station operators to perform quality assurance checks (prior to installation) on their valves after receiving them from the manufacturer.

The next significant finding came in the form of hydrogen leaks that would show up after a number of cold cycles but then disappear when the team tried to troubleshoot the leak. Figure 4 illustrates this phenomenon. The x-axis of the graph is the cycle count and the y-axis of the graph shows the combustible gas detector levels inside a single bay of the ALTA. The graph shows that the leak would grow over time before finally hitting a "hi-hi" alarm that would shut the system down (cycle 368 in Figure 4). At that time, NREL staff would be informed of the leak and would start manually troubleshooting the system to determine the cause of the leak. During that time, the component would warm up enough to reseal itself and the leak would no longer be present. Retail stations that experience a high volume of customers for a short duration could experience this in the field.

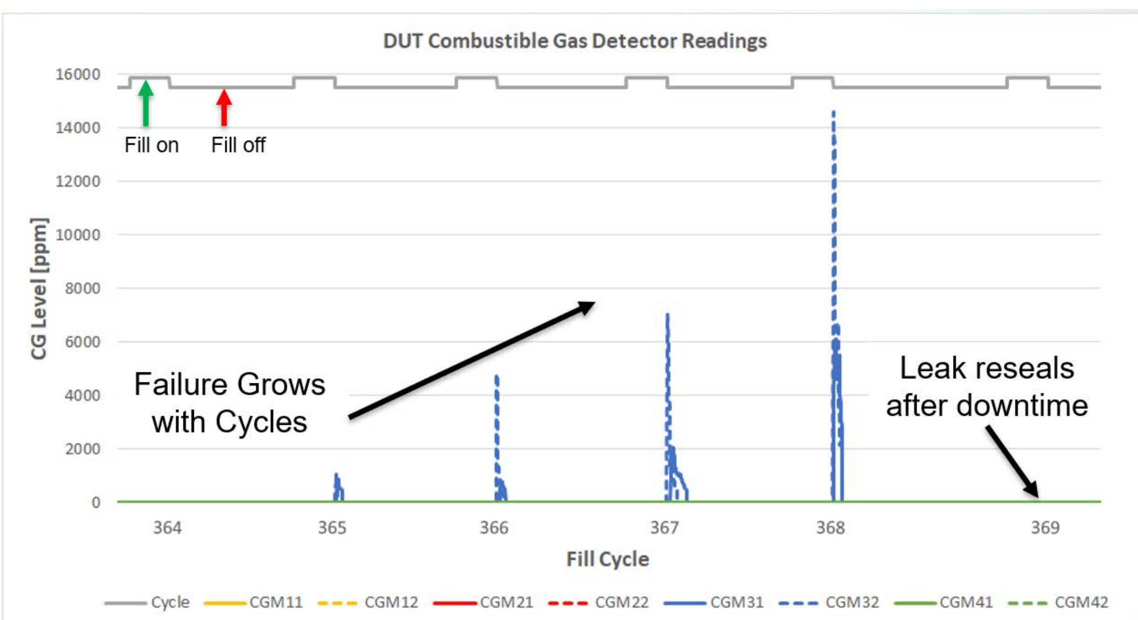

Figure 4. Hydrogen leaks resealing after system warmup

Components on ALTA were exposed to 1,017 fill cycles for the completed testing at the T40 setpoint. The measured mass of hydrogen through each component for this testing was 1,023 kilograms. During these fills, there were 21 component failures that shut down testing due to combustible gas detectors sensing elevated hydrogen levels in ALTA. Of these 21 failures, 15 were from a normally closed air operated valve leaking at the stem and gland nut interface. These failures were typically fixed by retorquing the gland nut to manufacturer's specifications instead of removing the valve from service. Because of this specific leak issue, the normally closed valves were the most likely to fail. The next most likely component to leak was the breakaway followed by the nozzle. No failures were experienced on the normally open valves or the filters during T40 testing.

Material Testing

SNL received five different sets of components from NREL. The first and second sets consisted of untested samples of five different types of full components from four manufacturers. The components were removed form the manifold at NREL and shipped to SNL to be used for (1) deriving disassembly procedures for retrieval of polymers, and (2) generating baseline chemical and physical data for polymers that have not been exposed to hydrogen. Careful disassembly procedures were derived and documented for each component type without destroying or damaging the polymeric O-rings. The same procedures were applied to disassemble tested components from sets 3, 4, and 5. Baseline data was compared to that generated for polymers retrieved from components exposed to hydrogen at -40°C and -20°C for 1,000 hours. Chemical and physical characterization included FTIR spectroscopy (chemical changes in polymer), DMTA (glass transition temperature and modulus), optical microscopy (for surface texturization effects), compression set (for permanent deformation in elastomers), micro-computed tomography (for voids, cracks, and sub-surface defects), and nanoindentation (for hardness and crosslink density changes).

CONCLUSIONS AND UPCOMING ACTIVITIES

NREL needs to carry out the statistical analysis comparing the reliability of components after 1,000+ cycles with the results of -40°C and -20°C cycle testing.

SNL will finish compiling all the data from all the sets of components and document findings on common polymer failure modes in the various components. Based on changes in properties compared to untested components, polymers most susceptible to hydrogen and likely to cause failures across components will be identified. SNL will report on chemical property (including microstructural, crystallinity, glass transition temperature) and physical property (including density, hardness, compression set, and mechanical strength) degradation for at least two common polymers retrieved from tested components.

NREL and SNL will write a final report detailing the reliability and material analysis results.

FY 2019 PUBLICATIONS/PRESENTATIONS

1. M. Peters, N. Menon, M. Ruple, J. Martin, and E. Winkler, "Dispenser Reliability," presentation at the DOE Hydrogen and Fuel Cells Program 2019 Annual Merit Review and Peer Evaluation Meeting, Washington, DC, April 2019.
2. N. Menon, M. Peters, E. Hecht, and T. Longfield, "Dispenser Reliability Accelerated Life Testing—Material Analyses," poster presentation at the DOE Hydrogen and Fuel Cells Program 2019 Annual Merit Review and Peer Evaluation Meeting, Washington, DC, April 2019