VII.1 Hydrogen Component Validation

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

Overall Objectives

- Operate hydrogen compressors and collect data to understand failure modes, repair and maintenance requirements, and performance in variable conditions
- Perform deep-dive failure analysis and feed results back to component manufacturers
- Collect and analyze contaminants found in hydrogen piping of compressors

Fiscal Year (FY) 2015 Objectives

- Operate compressors for a combined 2,000 h
- Collect contaminant samples from at least three compressors and have them analyzed

Technical Barriers

This project addresses the following technical barriers from the Technology Validation section of the Fuel Cell Technologies Office (FCTO) Multi-Year Research, Development, and Demonstration (MYRDD) Plan:

(D) Lack of Hydrogen Refueling Infrastructure Performance and Availability Data (detailed compressor reliability data and analysis)

Contribution to Achievement of DOE Technology Validation Milestones

This project will contribute to achievement of the following DOE milestones from the Technology Validation section of the FCTO MYRDD Plan:

- Milestone 3.4: Validate station compression technology provided by the delivery team. (4Q, 2018)

FY 2015 Accomplishments

- Generated 800 h of compressor performance and reliability data that can be used to improve station modeling efforts
- Determined seal weakness to be the main cause of failures and communicated this finding to compressor manufacturers
- Identified a mechanism for indicating preemptive seal failure
- Documented repair times and costs to inform station operators and modelers of expected station downtimes and financial burdens due to compressors
- Collected and analyzed composition of contaminant found in process piping

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INTRODUCTION

The Hydrogen Component Validation task tests components used in hydrogen fueling stations at nominal working pressures with the aim of collecting performance and reliability data. Components are integrated into actual fueling stations to replicate field conditions. Testing at NREL's private stations allows engineers to perform deep-dive analyses without inconveniencing fuel cell electric vehicle customers. Findings are communicated to manufacturers to improve designs, to modelers to develop more accurate models, and to DOE to inform research direction.

FY 2015 testing was focused on the leading cause of station downtime, hydrogen compressor failure. Three units—two diaphragms and one air piston—were tested at NREL's two hydrogen stations. One was highly instrumented and operated on a dedicated testing scheme, while the other two were only operated as needed. NREL engineers documented compressor failure and performance data. Failure data was composed of information on failure mechanisms, resulting station downtime, and repair costs. Performance data consisted of information on power and energy consumption at varying pressure discharge levels and in a range of ambient conditions. This task will increase the scope and breadth of publicly available data regarding compressors.

APPROACH

Each compressor was integrated into a hydrogen production, compression, storage, and dispensing system to best replicate field conditions. Device Under Test 1 (DUT1) was a diaphragm compressor that was highly instrumented to collect internal pressure, temperature, power, and energy data. It was operated under a cooperative research and development agreement with a compressor manufacturer. Testing focused on collecting performance data over long operating periods (up to 20 h/d) at consistent discharge pressures ranging up to 6,000 psi. DUT2 was a diaphragm compressor that operated at pressures similar to those of DUT1. DUT3 was an air-driven compressor that operated at discharge pressures up to 12,500 psi. NREL engineers only operated DUT2 and DUT3 as needed and only collected failure data from these two devices. Compressor failure data was corroborated locally among DUT1, DUT2, and DUT3, and nationally using data from the National Fuel Cell Technology Evaluation Center at NREL.

Additional work was conducted in contaminant analysis. Residue from the inside of process lines on a compressor was sampled and analyzed using Fourier transform infrared spectroscopy. The chemical composition of the residue has been determined from DUT1. NREL engineers are currently reaching out to station operators to obtain field samples of residues for analysis.

RESULTS

Testing in FY 2015 yielded four key results.

- Data logging on DUT1 collected a year's worth of performance and reliability data.
- DUT1, DUT2, and DUT3 tests suggest that seals are the main failure mechanism.
- Seal failures can be detected before catastrophic failure, reducing downtime and repair time.
- Special equipment and lead times were documented for major compressor failures.

DUT1 ran for more than 800 h in FY 2015, compressing more than 1,800 kg of hydrogen. An average efficiency of 3.5 kWh/kg was calculated from the energy consumption[1]. NREL engineers piped a recirculation loop from the discharge of the compressor to the inlet pressure regulator. This allowed for long duration testing without a need for additional hydrogen and made it possible for operators to keep the discharge pressure constant. Figure 1 shows an aggregate of a year's worth of data with DUT1 operating at multiple discharge pressures. Power consumption of the 30 HP motor varied at 200 W/ksi with discharge pressure, averaged 13.1 kW, and had a standard deviation of 0.6 kW over the course of the year.

DUT1 performance was also analyzed over varying ambient temperatures (Figure 2). Power consumption was

[1] Constant suction pressure, power factor of 0.8, includes pump and radiator (1.86 kW).

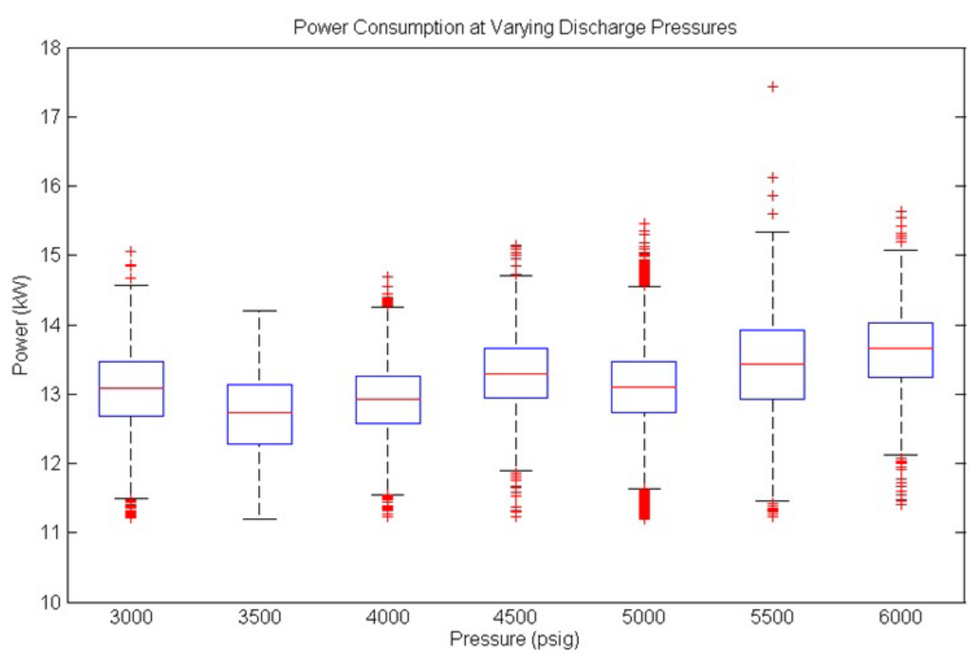

FIGURE 1. DUT1 power consumption in FY 2015 categorized by discharge pressure

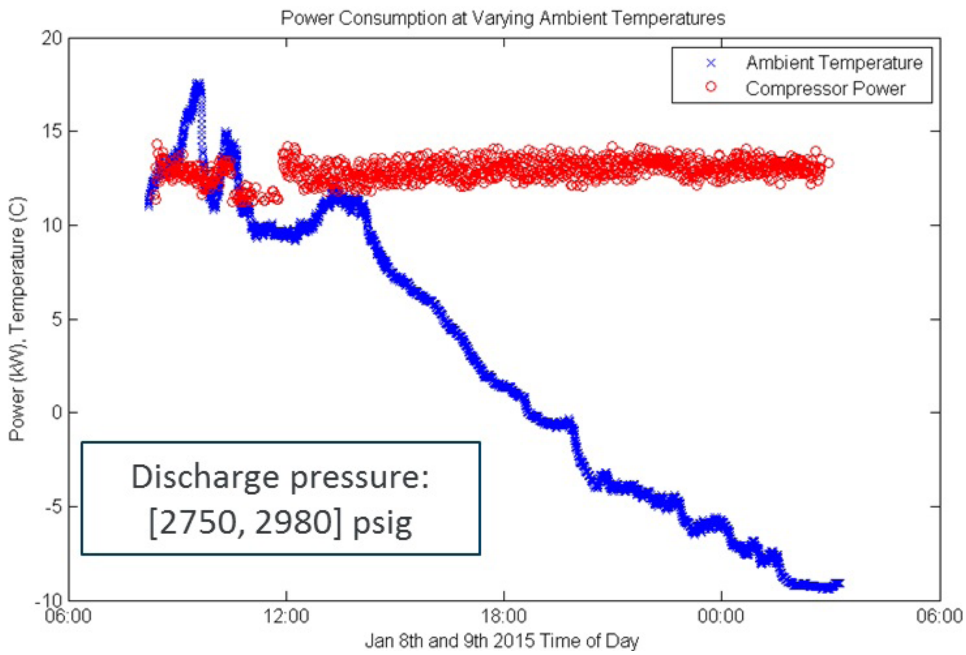

FIGURE 2. DUT1 power consumption (red) and ambient temperature (blue) over a 20-h operating cycle

found to be constant, while the ambient temperature dropped from 18°C to -9°C.

Five major seal failures occurred in FY 2015, with four in compressor heads and one on a check valve. Failures ranged from pieces being severed to discoloration and slight deformation. Seal failures in compressor heads occurred in both diaphragm compressors (DUT1 and DUT2). In three of the four failures, the oil over-pump valves were set to improper values, increasing the pressure and temperature of the compressor heads beyond levels found in normal conditions. Over-pump valves are typically set at the factory, but set points can change during operation.

Leak detection circuits for seals are common on diaphragm compressors, but they do not alert a user of a problem until a major seal failure occurs. NREL engineers found that regular monitoring of leak detection circuits can catch seal failures early reducing repair times by a factor of two. High-resolution data collection on DUT1 allowed for historical analysis of seal failures and significantly contributed to this conclusion. Additionally, following advice from the compressor manufacturer, NREL engineers constructed a pressure manifold for determining set points for in situ over-pump valves. The manifold consists of a check valve for holding pressure, a pressure indicator for showing pressure, and needle valve for releasing pressure.

Repair time effort and documentation is not highly publicized for hydrogen compressors. Repairs often require highly specialized parts and tools that can lead to increased downtime. NREL engineers documented the people, hours, specialized parts, and unique tools required to perform common compressor repairs. Station operators can use this information to reduce downtime by planning repairs and ordering parts with long lead times.

A small sample of black residue found inside process tubing was analyzed for composition. It was found that the sample consisted mostly of a certain type of vacuum grease made from siloxane supplied by the compressor manufacturer. NREL's Fuel Cell System Contaminants Material Screening Data tool indicates that siloxane is harmful to fuel cells, thus different vacuum grease should be used.

CONCLUSIONS AND FUTURE DIRECTIONS

Conclusions derived from work in FY 2015 include the following.

- Compressor performance and reliability data over varying operating pressures and ambient temperature is consistent.
- Seal failures are the most common failure mode for compressors.
- Preemptive detection of seal failures can lead to drastically reduced downtime.
- Keeping certain uncommon spare parts and tools in stock can speed up repair times.
- Vacuum grease containing siloxane should not be used on seals contacting hydrogen.

Future work on this task will include increasing operation hours on all compressors, installing a new linear piston compressor, and incorporating power meters on DUT2 and the new compressor. Additionally, NREL engineers are reaching out to station operators for more samples of contaminants found in compressors for analysis.

FY 2015 PUBLICATIONS/PRESENTATIONS

1. Terlip, D.; Peters, M.; Harrison, K. "Hydrogen Component Validation," 2015 DOE Hydrogen and Fuel Cells Program and Vehicle Technologies Office Annual Merit Review and Peer Evaluation Meeting, June 2015. (presentation)