VII.B.4 Hydrogen Component Validation

Danny Terlip
National Renewable Energy Laboratory (NREL)
15013 Denver West Parkway
Golden, CO 80401
Phone: (303) 275-4180
Email: danny.terlip@nrel.gov

DOE Manager: Jason Marcinkoski
Phone: (202) 586-7466
Email: Jason.Marcinkoski@ee.doe.gov

Subcontractors:
- Smart Chemistry, Sacramento, CA
- Spectrum Automation, Arvada, CO

Project Start Date: October 2012
Project End Date: Project continuation and direction determined annually by DOE

Overall Objectives

- Reduce fuel contamination introduced by forecourt station components.
- Improve station reliability and uptime.
- Increase the publicly available energy and performance data of major station components.

Fiscal Year (FY) 2017 Objectives

- Understand common failures at hydrogen stations.
- Understand the source of particulate contamination in hydrogen stations.
- Quantify the costs incurred when operating a hydrogen station.

Technical Barriers

This project addresses the following technical barrier from the Technology Validation section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration 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 milestone from the Technology Validation program section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

- Milestone 3.4: Validate Station Compression technology provided by delivery team (4Q, 2018).

FY 2017 Accomplishments

- Quantified the energy consumption of major components of the Hydrogen Infrastructure Testing and Research Facility (HITRF).
- Mapped the chiller energy usage based on the amount of hydrogen dispensed and the ambient temperature.
- Designed and performed an experiment that quantified the impact of cleaning methods on removing metal particulates from hydrogen tubing after it is cut and conditioned for installation.

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INTRODUCTION

The Hydrogen Component Validation task is focused on addressing three challenges currently facing forecourt hydrogen stations today. These challenges were prioritized from an H2USA Fueling Stations Working Group brainstorming session: fuel contamination introduced by forecourt station components, station reliability and uptime, and lack of publicly available energy and performance data of major station components. Improvement in each one of these topic areas is critical for successful station operation, positive fuel cell driver experience, and a robust hydrogen economy.

APPROACH

NREL is working to better understand particulate contamination in the hydrogen process stream by distributing contaminant collection packets to forecourt station operators. When a maintenance event occurs, the participating station operators collect samples from hydrogen tubing or components and send the samples to NREL to be analyzed. NREL noticed macroscopic metal particulates in samples taken from many of the failed parts. The metal particulates were analyzed and shown to be similar to 300 series stainless steel. Most wetted metal in a typical hydrogen station is 300 series stainless. One of the most likely sources of particulates is debris from the cutting, beveling, and threading process of tubing. This process often utilizes a sulfur based lubricant that can remain on the tubing if not cleaned properly (sulfur irreversibly degrades fuel cell performance). NREL designed an experiment with 18 tube samples that considered two different sizes of tubing, 3/8 in outside diameter (OD) and 9/16 in OD and three different cleaning methods: (1) compressed air and rag, the most common method; (2) tube brush and rag; and (3) sonication, which is not feasible for hydrogen station tubing. The tube samples were installed in a filling system with a 0.2 micron filter behind it. Two kilograms of hydrogen were passed through each tube. Filters were weighed for mass change and examined with a microscope.

NREL installed power meters on two hydrogen compressors and the hydrogen pre-cooling system at the HITRF. The HITRF supervisory control and data acquisition (SCADA) system is collecting power and energy data as each of these components operates to support the HITRF. NREL engineers are analyzing the data and collaborating with other DOE researchers to better understand operating costs of forecourt hydrogen stations and possible precursors to equipment failures that can be used to indicate the need for pre-emptive maintenance.

RESULTS

Many of the contaminant samples NREL collected from both retail hydrogen stations and the HITRF contained metal shards. Figure 1 shows examples of metal particulate contaminants that were collected. The image on the left shows metal shards embedded in a valve seat. The image in the middle shows metal impregnated in a compressor rider band. The image on the right shows metal shards magnetically attracted to a compressor check valve (austenitic stainless steels are typically nonmagnetic, yet heat treating and physical deformation, as may take place in a compressor environment, have been shown to magnetize austenitic steels and may be responsible for magnetizing the metal particulates here).

NREL compared the mass change of filters, the number of particles, and the size of particles across cleaning methods and tubing size. The filters from tubing cleaned with the air and rag method had the highest mass change and highest number of particles, indicating the most contamination. Filters from tubing cleaned with the sonication method had the lowest mass change, indicating the least amount of particles by mass. Filters from the samples cleaned by tube brush had the lowest number of particles. The largest particles were found in the filters from tubing cleaned by the air and rag method. Filters from the 3/8 in OD tubing had a higher mass change than filters from the 9/16 in OD tubing did. The results were inconclusive for the number of particles collected on filters between 3/8 in OD tubing and 9/16 in OD tubing. Results for two samples (6 and 8) were thrown out due to an operator error in the testing procedure. Figure 2 and Figure 3 show the mass change and the number of particulates for each of the tests.

NREL engineers installed power meters on two hydrogen compressors and one pre-cooling system compressor. The HITRF SCADA system is collecting the amount of power and energy consumed by each component at one second intervals. NREL engineers perform detailed analysis on the data resulting in quantitative performance information. Figure 4 shows one instance of performance data for the NREL HITRF station. The metric is electric energy consumption (including balance of plant) per kilogram of hydrogen produced, compressed, or dispensed. The graphic shows a cost per component for each kilogram of hydrogen assuming a typical electricity rate for Los Angeles, $0.184/kWh. The performance metric and subsequent cost reported for the dispenser includes the pre-cooling system and assumes one vehicle fill per hour.

As noted in Figure 4, the performance metric for the dispenser (including pre-cooling) is highly variable. The two factors affecting the variability are the ambient temperature and the mass of hydrogen chilled per unit of time. NREL collected this data for the single heat exchanger block (27 cu ft) and 6.75 kW chiller that circulates R404a. The results are shown in Figure 5.

FIGURE 1. Three contaminant samples collected as part of Hydrogen Component Validation task

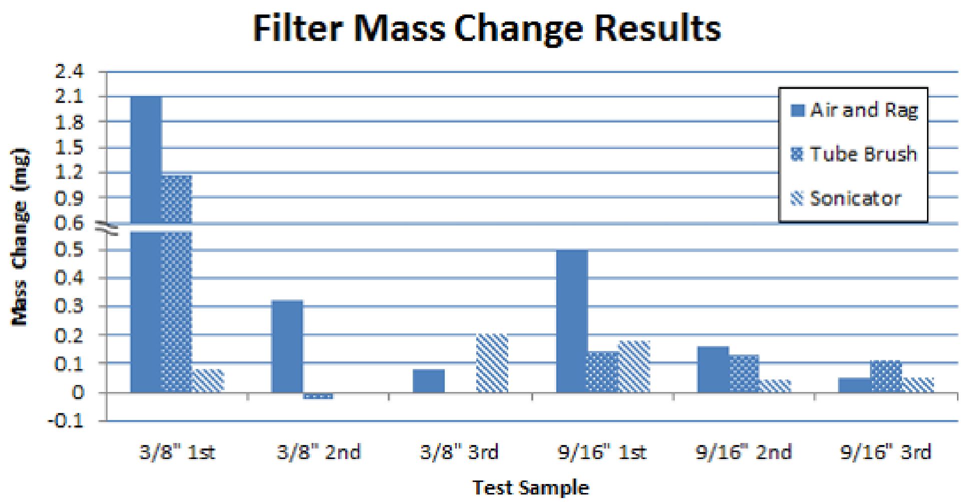

FIGURE 2. Mass change for filters of the 18 tubes. The 3/8 in air and rag tubes were tested first, then the 3/8 in tube brush, then the 3/8 in sonicator. The same order was then followed for the 9/16 in tubes.

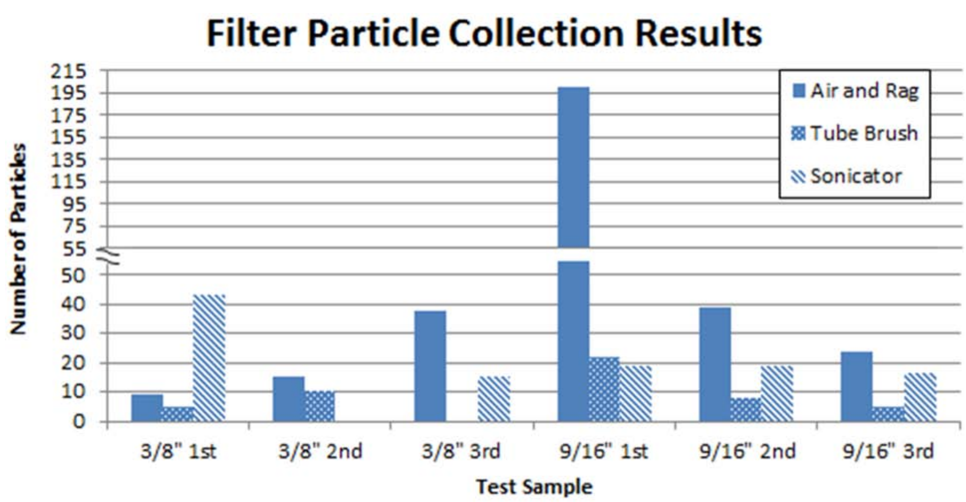

FIGURE 3. Particle count for filters of the 18 tubes. The 3/8 in air and rag tubes were tested first, then the 3/8 in tube brush, then the 3/8 in sonicator. The same order was then followed for the 9/16 in tubes.

CONCLUSIONS AND UPCOMING ACTIVITIES

The Hydrogen Component Validation project addresses two challenges facing forecourt hydrogen stations today: particulate contamination from various sources and energy consumption of major station components. Both tasks involve collecting data from forecourt hydrogen stations and the NREL HITRF. Data and conclusions from these activities are communicated through presentations and research publications.

The particulate contamination project was developed to collect field samples of particulate matter, determine the origin, and publish the results to identify major issues impacting a high percentage of stations. Currently 11 stations are participating and NREL is reaching out to more stations as they become operational. NREL identified metal particulates as a significant portion of particulate contamination, and performed a study to determine the impacts of cleaning methods to remove metal particulates after tube cutting, beveling, and threading.

Regardless of the tubing size or cleaning method, any metal particulate can cause a problem in hydrogen stations or fuel cell electric vehicles, where they may be accelerated to high velocity and destroy filters or prevent a valve from operating properly. The specification for cleanliness of

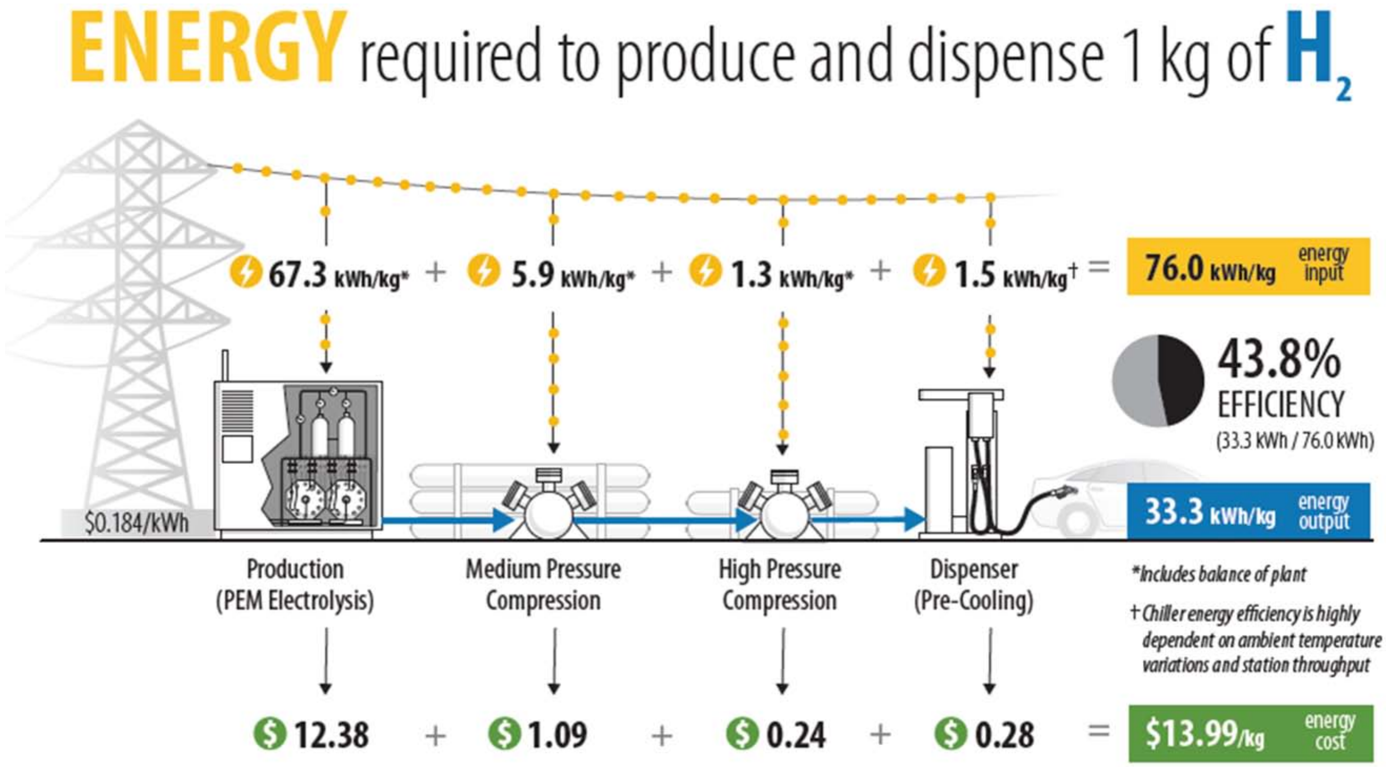

FIGURE 4. Energy consumption for major components at the HITRF. An electricity price of $0.184/kWh, typical of Los Angeles, is taken to show the cost of producing 1 kg of hydrogen at 700 bar and -40°C.

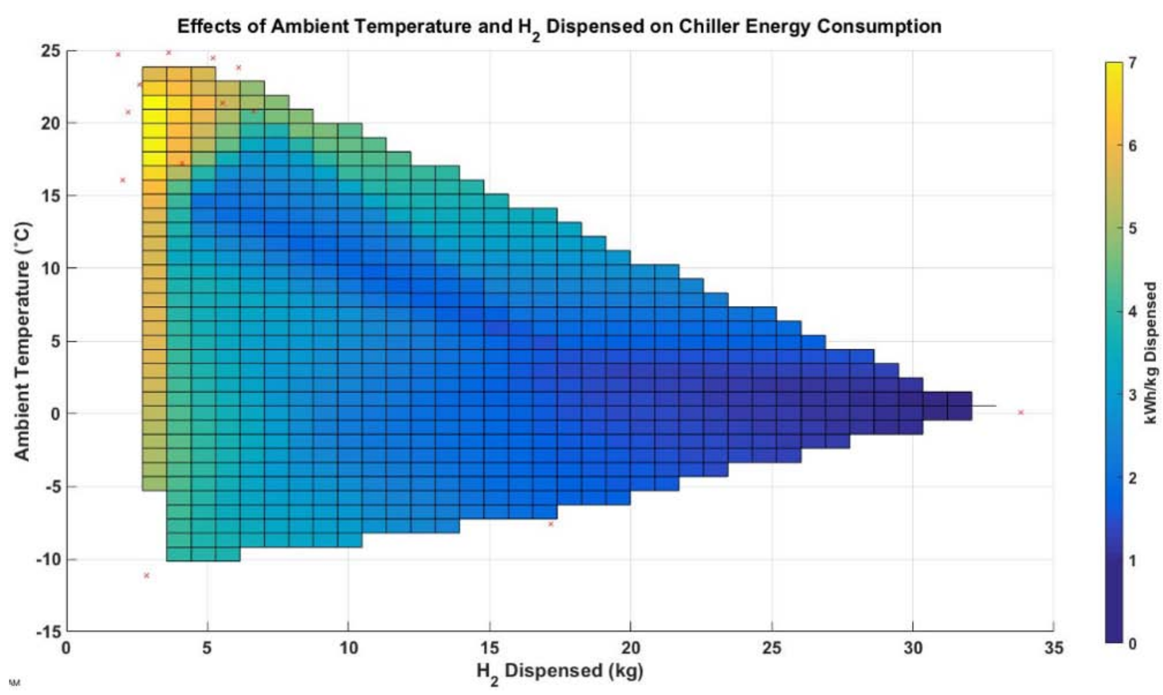

FIGURE 5. Chiller performance data showing electrical energy consumption per mass of hydrogen chilled (or dispensed). The vertical axis shows that pre-cooling becomes more costly with increasing ambient temperature, while the horizontal axis shows that pre-cooling becomes less costly with the amount of hydrogen dispensed.

hydrogen dispensed to fuel cell electric vehicles (SAE J2719) allows a maximum of 1 mg of particulate matter per 1 kg of hydrogen. Hydrogen stations could contain 100 or more of these tubes with cuts and conditioning on both sides. Thus it can be seen that particulate contamination from tube cutting and conditioning can result not only in station reliability problems but also can result in a station dispensing hydrogen that is outside of specification. Future work will determine the impact of other likely sources of particulate contamination.

As the number of stations and fuel cell electric vehicles change, retail hydrogen stations are currently experiencing variable utilization. It is critical for station operators to understand the cost of operation under low and high utilization to ensure financially sustainable operations. Power and energy consumption of major station components impacts operating costs at hydrogen stations. NREL has installed power meters on two hydrogen compressors and the hydrogen pre-cooling system. The HITRF SCADA system continually records data during operation and NREL engineers analyze the data. The analysis is used to inform modeling efforts of hydrogen stations. Future work will involve analyzing the data for possible precursors to failure and impacts for reducing operating costs at hydrogen stations.

FY 2017 PUBLICATIONS/PRESENTATIONS

1. "Hydrogen Component Validation," Terlip, Danny. Annual Merit Review 2017. Washington D.C., 7 June 2016.

2. "Adapted Tube Cleaning Practices to Reduce Particulate Contamination at Hydrogen Fueling Stations," Terlip, Danny; Martin, Joshua; Hartmann, Kevin; accepted for publication at ICHS Conference, September 2017.