VII.B.5 Liquid Hydrogen Pump Performance and Durability Testing

Salvador M. Aceves (Primary Contact), Guillaume Petitpas, Julio Moreno-Blanco, Juan Manuel Garcia-Guendulain
Lawrence Livermore National Laboratory (LLNL)
7000 East Avenue
Livermore, CA 94550
Phone: (925) 422-0864
Email: aceves6@llnl.gov

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

Subcontractors:
- Spencer Composites Corporation, Sacramento, CA
- Linde LLC, Hayward, CA

Project Start Date: January 2014
Project End Date: December 2017

Overall Objectives

- Measure liquid hydrogen (LH_2) pump performance parameters including: hydrogen flow rate, refuel density, electricity consumption, boil-off, hydrogen temperature and pressure during fill, pump degradation, maintenance requirements, and incidents.

Fiscal Year (FY) 2017 Objectives

- Complete construction of LLNL's hydrogen test facility by installing and commissioning a heat exchanger manufactured by Linde.
- Demonstrate durability (1,000 thermomechanical cycles) of cryogenic vessel prototype manufactured by BMW.

Technical Barriers

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

(C) Hydrogen Storage

(D) Lack of Hydrogen Infrastructure Performance and Availability Data

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 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

- Cycle tested experimental vessel prototype 456 times with cryogenic hydrogen to 700 bar.
- Measured pump performance while delivering 1.65 tonnes of cryogenic pressurized hydrogen.
- Installed heat exchanger in test facility enabling ambient temperature hydrogen refueling.
- Initiated testing of cryogenic vessel supplied by BMW by conducting 100 cycles with cryogenic hydrogen to 300 bar.

✧ ✧ ✧ ✧ ✧

INTRODUCTION

An experimental vessel was cycle tested 456 times to 700 bar with cryogenic pressurized hydrogen while simultaneously measuring pump performance: flow rate, refuel density, electricity consumption, boil-off, hydrogen temperature and pressure during fill, pump degradation, maintenance requirements, and incidents. In this 19-day experiment, the LH_2 pump delivered 1.65 tonnes of hydrogen to the experimental vessel over eight days of cycle testing. This report focuses on pump performance during the 456 fill cycles conducted in the experiment. Vessel test results have been reported elsewhere [1].

APPROACH

Experiments were conducted at LLNL's Hydrogen Test Facility (Figure 1) [2]. Built over the last four years at the south end of the LLNL campus, the Hydrogen Test Facility includes an 875 bar LH_2 pump manufactured by Linde, a liquid hydrogen dewar with 12.5 m^3 capacity, a 40 kW heat exchanger for delivery of ambient temperature hydrogen, a 2.8 m^3 containment vessel rated for 60 bar maximum pressure, two vent stacks (for high-pressure and low-pressure hydrogen discharges), a control room for remote operation, connecting high-pressure cryogenic lines,

FIGURE 1. Hydrogen Test Facility at LLNL showing the main components

and instrumentation (for measuring temperature, pressure, hydrogen level, electricity consumption, and vacuum).

The experimental pressure vessel was built for maximum volumetric and gravimetric storage performance (project targets 50 g H_2/L, 9% H_2 by weight). Vessel characteristics include 65 L capacity, 700 bar maximum operating pressure, 32 kg total weight, and high volumetric efficiency (81% vs. 70% typical of today's 700 bar vessels). The prototype vessel was wrapped in multilayer insulation, instrumented, and cycle tested inside the containment vessel (Figure 2).

RESULTS

Key results from the 19-day experiment include the following:

- The experimental vessel was cycled 456 times before failing by developing a crack through the liner. During these cycles, the pump delivered 1,658 kg of hydrogen into the experimental vessel. The 456 cycles were completed over eight days of operation and four dewar refuels.
- The pump consistently demonstrated high hydrogen throughput (96 kg/h average and 100+ kg/h peak hydrogen flow rate). This is a key parameter for reducing refueling cost per vehicle, as pump capital cost can be amortized over many vehicles served.
- The experimental vessel was consistently refueled in under 3 min at ~3.7 kg hydrogen per refuel. While the prototype vessel is small (65 L), these results show promise for future practical refueling times (<5 min) in larger vessels with 5–8 kg of hydrogen capacity.
- The pump shows low electricity consumption at an average of 1.1 kWh/kg H_2 active power during the fill. This is considerably lower than for available alternatives (on-site gas compression), minimizing station electricity consumption. Apparent electricity consumption is higher, at 1.5 kVAh/kg H_2.
- We identified several sources of boil-off: (1) LH_2 delivery to station dewar, (2) heat transfer into the station dewar, (3) pump cool-down and warm-up, (4) pump losses, and (5) LH_2 run-off from pump dewar. We measured boil-off originating from Mechanisms 1–4 by instrumenting the vent stack with a mass flow meter. Run-off from the pump dewar (Mechanism 5) does not vent through the main stack and therefore was not measured. Instead, it was estimated with assistance from Linde.
- The results indicate that the station lost 430 kg of hydrogen (25.9% of dispensed hydrogen) to boil-off during the 19-day experiment. This, however, is not a reliable indication of LH_2 pump performance when integrated into a commercial fueling station, since the pump was only operated eight days for vessel cycling, pre-cooled three days for testing without any vessel fills, and remained idle for eight days. Lower boil-off losses (16%) are measured for a typical day of operation where 300 kg of hydrogen were dispensed. Substantial reductions in boil-off to as little as 3.6% are projected for an improved delivery system where the LH_2 truck is not depressurized after dewar refueling, and the LH_2 pump is in close proximity to the station dewar.
- We evaluated pump performance degradation by comparing initial (Cycle 1) and final (Cycle 456) values of electricity consumption and pump outlet temperature, considering that increases in either of these would

FIGURE 2. Prototype thin-lined experimental pressure vessel (left), and multilayer insulation-wrapped and instrumented prototype vessel being introduced into containment vessel for cycle testing (right)

indicate degraded pump performance. Initial and final cycles showed comparable pump operation, leading to the conclusion that no performance degradation was identified during the experiment.

- Incidents identified during the experiment include (1) two occasions of excessive boil-off upon station dewar fill, (2) overheating of LH_2 pump oil after two hours of operation, (3) a data acquisition error, (4) loose bolts on the flange connecting the hydraulic piston and the LH_2 pump, (5) temperature sensor failure, and (6) experimental prototype vessel failure. All these incidents were quickly resolved, and none of them resulted in unsafe operating conditions. In general, the pump demonstrated excellent reliability, consistently performing as expected with minimum supervision or maintenance.

CONCLUSIONS AND UPCOMING ACTIVITIES

Upcoming activities include durability testing of a cryogenic pressure vessel provided by BMW (1,000 cycles; 100 completed to date) while simultaneously determining LH_2 pump performance to 300 bar. These objectives will be met by (1) establishing a protocol for accelerated testing of cryogenic pressure vessels and (2) running the cryogenic vessel through the test protocol while measuring all relevant LH_2 pump experimental parameters. These parameters are critical for a full characterization of cryogenic vessel technology, and will be reported and shared with other institutions for determining costs and benefits.

SPECIAL RECOGNITIONS & AWARDS/ PATENTS ISSUED

1. Salvador M. Aceves, Elias Rigoberto Ledesma-Orozco, Francisco Espinosa-Loza, Guillaume Petitpas, Vernon A Switzer, “Compact insert design for cryogenic pressure vessels,” US Patent 9,677,713, 2017.

REFERENCES

1. Salvador M. Aceves, Guillaume Petitpas, “Thermomechanical Cycling of Thin Liner High Fiber Fraction Cryogenic Pressure Vessels Rapidly Refueled by Liquid Hydrogen Pump to 700 Bar,” DOE Hydrogen and Fuel Cells Program Annual Progress Report, 2016, https://www.hydrogen.energy.gov/pdfs/progress16/iv_d_2_aceves_2016.pdf

2. Salvador M. Aceves, Guillaume Petitpas, “Performance and Durability Testing of Volumetrically Efficient Cryogenic Vessels and High-Pressure Liquid Hydrogen Pump,” DOE Hydrogen and Fuel Cells Program Annual Progress Report, 2016, https://www.hydrogen.energy.gov/pdfs/progress16/vii_c_4_aceves_2016.pdf