VII.2 Performance and Durability Testing of Volumetrically Efficient Cryogenic Vessels and High Pressure Liquid Hydrogen Pump

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

Project Start Date: January 1, 2014
Project End Date: December 31, 2016

Overall Objectives

- Demonstrate small (63.5 L internal volume), high aspect ratio (34 cm outer diameter and 100 cm length) cryogenic pressure vessels with high volumetric and gravimetric hydrogen storage performance (50 gH_2/L and 9% H_2 weight fraction)
- Demonstrate durability (1,500 thermomechanical cycles) of thin-lined high fiber fraction pressure vessels
- Measure liquid hydrogen (LH_2) pump performance after 6,000 refuelings (24 tonnes of LH_2)

Fiscal Year (FY) 2015 Objectives

- Install sensors for measurement of liquid hydrogen venting, electricity consumption, and hydrogen temperature at pump outlet
- Complete construction of pressure vessel test facility
- Install containment vessel
- Fabricate two thin-lined high fiber fraction vessels
- Cycle and strength test two thin-lined high fiber fraction vessels

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 (MYRDD) 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 milestone from the Technology Validation section of the Fuel Cell Technologies Office MYRDD Plan:

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

FY 2015 Accomplishments

- Fabricated first thin-lined high fiber fraction vessel
- Pressure tested first thin-lined high fiber fraction vessel
- Instrumented liquid hydrogen pump with venting, electric power, and outlet temperature sensors
- Completed civil construction of pressure vessel test facility
- Received institutional LLNL approval to conduct pressure and cycle testing inside an ASME-rated steel containment vessel
- Wrote a detailed (100+ pages) safety plan and had it reviewed by the DOE Safety Panel

INTRODUCTION

Cryogenic pressure vessels have demonstrated the highest performance for automotive hydrogen storage, with density (43 gH_2/L), weight fraction (7.3%), cost ($12/kWh), and safety advantages (~8X lower expansion energy than compressed gas and secondary protection from vacuum jacket) [1,2]. This project will explore the potential for reaching high volumetric (50 gH_2/L target) and gravimetric (9% H_2 weight fraction target) storage performance within a small (63.5 L internal volume), high aspect ratio (34 cm outer diameter and 100 cm length) cryogenic pressure vessel with long durability (1,500 thermomechanical cycles) refueled by a liquid hydrogen pump to be tested for degradation after delivery of 24 tonnes of LH_2.

APPROACH

Reaching the very challenging weight and volume targets set for this project demands innovative cryogenic pressure vessel design. Spencer Composites Corporation, in collaboration with LLNL, is developing thin-lined, high fiber fraction cryogenic pressure vessels. At a target liner thickness of 1.5 mm and 80% fiber fraction, these thin-walled vessels may be able to reach the weight and volume targets when installed within a thin vacuum gap and refueled at high density (up to 80 gH_2/L) with the LH_2 pump.

RESULTS

Early in 2015 we were able to produce the first thin-lined (1.8 mm) high volumetric efficiency (81%) Type 3 (metal-lined, fiber-wrapped) 700-bar pressure vessel (Figure 1). Weighing 32 kg, it does have the performance necessary to meet the project targets (50 gH_2/L, 9% H_2 by weight) according to current projections for liquid hydrogen pump and compact vacuum insulation performance.

Soon after manufacture, the thin-lined vessel was pressure tested at cryogenic temperature. The vessel was insulated and then filled with liquid nitrogen inside a containment cell within LLNL's high pressure laboratory (Figure 2). Pressurization then proceeded by pumping compressed ambient temperature nitrogen into the vessel. The vessel underwent three high pressure excursions before eventually failing at 1,560 bar, slightly short of the 1,600 bar target (Figure 3). These high pressure excursions resulted from the relatively small size of LLNL's high pressure cascade vessels, insufficient to pressurize the experimental vessel to the target pressure in a single gas transfer process, and from the difficulty to control the nitrogen input due to temperature variations. Future pressure tests will be conducted with hydrogen at the new pressure vessel test facility and will therefore not be affected by this limitation.

We also instrumented the liquid hydrogen pump with a power analyzer, mass flow meter at the dewar vent line, and temperature sensor at the pump outlet (Figure 4). Investment in these indicators was necessary for a full performance and degradation evaluation.

All civil construction was also completed for the pressure vessel test facility (Figure 5). Construction included a 9.1 m by 9.1 m concrete pad where the containment vessel and heat exchanger (for ambient temperature refueling) will be installed in the future (summer-fall of 2015). In addition to

FIGURE 1. First thin-lined (1.8 mm) high volumetric efficiency (81%) Type 3 (metal-lined, fiber-wrapped) 700-bar experimental pressure vessel prototype

FIGURE 2. Cryogenic pressure test of thin-lined, high volumetric efficiency experimental pressure vessel prototype

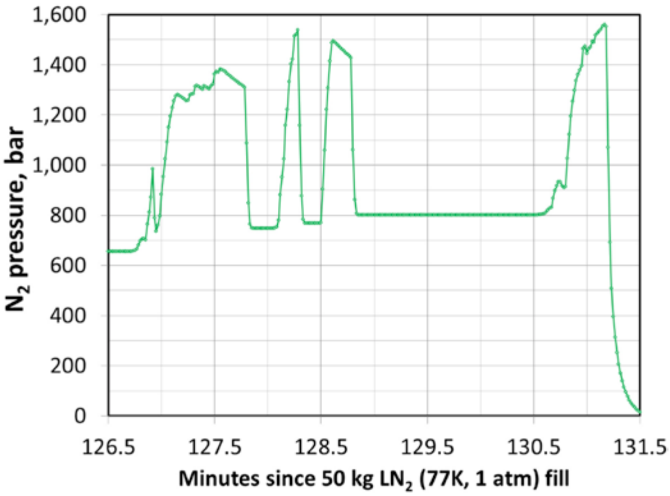

FIGURE 3. Pressure as a function of time during cryogenic strength testing of thin-lined experimental pressure vessel prototype

this, we also installed an air compressor, a control room, and lines for high pressure cryogenic hydrogen, instrumentation, electricity, and air for running explosion-proof pneumatic valves.

Experimental vessels manufactured for this project are not (ASME, Department of Transportation, International Organization for Standardization) certified. We therefore need to test them inside a containment vessel to protect personnel in case of accidental failure. After extensive

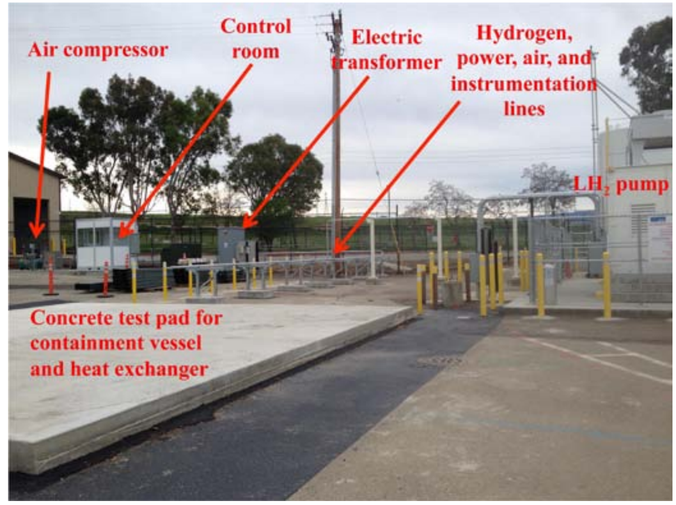

FIGURE 5. Civil construction for LLNL's pressure vessel test facility located next to liquid hydrogen pump. Construction includes an air compressor, a control room, an electric transformer (installed in 2013), and lines for high-pressure cryogenic hydrogen, instrumentation, electricity, and air. The 9.1 m by 9.1 m concrete pad is the future location of the containment vessel and a heat exchanger for ambient temperature refueling.

modeling of blast waves resulting from experimental vessel failure, we specified a 65 bar, ASME rated metallic (SS304) containment vessel with 32 mm wall thickness. Modeling results of blast wave propagation upon experimental vessel failure were presented to LLNL pressure vessel and containment experts, who have approved the operation.

FIGURE 4. New instrumentation installed on the liquid hydrogen pump including (a) power analyzer, (b) vent line mass flow meter, and (c) temperature sensor at the pump outlet

The containment analysis results were documented in a safety note, which is currently undergoing review for final signature.

All aspects of safe operation were also documented in a 100+ page safety plan that includes: failure modes and element analysis, piping and instrumentation diagram, site layout, safety distances for hydrogen, component specifications, and design calculations. The safety plan was reviewed by the DOE Safety Panel, whose members praised it for its completeness and level of detail.

CONCLUSIONS AND FUTURE DIRECTIONS

- This project attempts to identify volumetric and gravimetric performance limits for cryogenic pressurized storage at small size (63.5 liters) and high aspect ratio (34 cm outer diameter and 100 cm length).
- Vessel durability over 1,500 thermomechanical cycles will be demonstrated before pressure testing to minimum burst pressure.
- Durability and strength of the experimental vessel will be tested inside an ASME-rated 65 bar stainless steel containment vessel.
- Pump durability will also be tested by measuring performance after pumping 24 tonnes of LH_2 and comparing it to the initial performance.

SPECIAL RECOGNITIONS AND AWARDS/ PATENTS ISSUED

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FY 2015 PUBLICATIONS/PRESENTATIONS

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2. Guillaume Petitpas, Salvador M. Aceves, "The Isentropic Expansion Energy of Compressed and Cryogenic Hydrogen," International Journal of Hydrogen Energy, Volume 39, pp. 20319–20323, 2014.

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