VI.D.1 Storage of Hydrogen in Cryogenic Capable Pressure Vessels

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Objectives

- Construct and test cryogenic capable pressure vessels.
- Demonstrate cryogenic capable vessel on board a vehicle.
- Obtain performance data to meet 2007 targets for onboard storage.

Technical Barriers

This project addresses the following technical barriers from the Storage section (3.3.4.2) of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) System Weight and Volume
(E) Charging/Discharging Rates
(H) Balance of Plant (BOP) Components
(O) Hydrogen Boil-Off

Contribution to Achievement of DOE Technology Validation Milestones

This project will contribute to achievement of the following DOE Technology Validation milestones from the Technology Validation section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan:

- **Milestone 3: Demonstrate (on a vehicle) compressed and cryogenic storage tanks achieving the 2007 energy and mass density targets.** Our cryogenic pressure vessel to be demonstrated in a hydrogen vehicle meets the DOE 2007 weight and volume (vessel only) goals.

Accomplishments

- Installed insulated pressure vessel in a pickup truck in FY 2004 and demonstrated flexible refueling with liquid and compressed H_2.
- Designed and built a new insulated pressure vessel that works in the horizontal position and is projected to meet the 2010 DOE weight goal and the 2007 DOE volume goal (vessel only).
- Tested prototype insulated pressure vessel to verify vacuum space performance, pressure performance, and satisfactory operation at cryogenic temperatures (down to 20 K).

Introduction

One of the fundamental hurdles to the widespread commercialization of hydrogen (H_2) vehicles is storing enough hydrogen on-board for a reasonable range (more than 300 miles). LLNL is working on a hydrogen storage concept that may demonstrate an advantage over existing technologies. The concept is an insulated pressure vessel which can store liquid hydrogen (LH_2) with dramatically improved thermal endurance, the main challenge facing conventional low-pressure LH_2 tanks, for example, those developed over the past 30 years by BMW and Linde. In addition, insulated pressure vessels offer refueling and infrastructure flexibility since they can fill with ambient temperature compressed gaseous hydrogen (GH_2), to reduce fuel cost or energy intensity while expanding the number of potential refueling locations.

Approach

We are designing, testing and demonstrating cryo-compressed containers, which achieve the high density of liquid hydrogen without the evaporative losses typical of LH_2 containers. If fueled exclusively with LH_2, our insulated pressure vessels provide high storage density and low evaporative losses. If fueled flexibly with compressed hydrogen and liquid hydrogen, insulated pressure vessels reduce the energy necessary for hydrogen densification. Insulated pressure vessels can efficiently be applied to hydrogen storage materials (carbon adsorbents) in addition to physical hydrogen storage.

Results

Last year we demonstrated our insulated pressure vessel technology on a Ford Ranger pickup truck powered by a hydrogen internal combustion engine (Figure 1) with funding from the South Coast Air Quality Management District. The vessel has a 9 kg LH_2 capacity within a 135 liter internal volume. In addition to the pressure vessel used in the truck, we built five pressure vessels of this design for certification testing. The integration of the insulated pressure vessel into this vehicle required multiple changes to the fueling system to accommodate both LH_2 and GH_2. The truck was tested at Lawrence Livermore National Laboratory and SunLine Transit (Thousand Palms, California), and refueled multiple times with LH_2 and GH_2, validating operation on both. Truck operating parameters, including driving distance, fuel use, fuel pressure, temperature, and fill level were continuously recorded in a computerized data acquisition system.

FIGURE 1. Insulated Pressure Vessel Installed in a Hydrogen Fueled Pickup Truck

This year we built a new insulated pressure vessel design (151 liter internal volume, Figure 2) that stores more fuel (10.7 kg LH_2) than the previous generation, in a total package that is considerably more compact. The dimensions of the inner vessel and the outer vacuum shell are shown in Figure 3. This design is projected to meet the DOE 2007 volume target (1.2 kWh/liter, tank only) and the 2010 DOE weight target (2 kWh/kg). The vessel has a maximum pressure rating of 34.5 MPa (5,000 psi), and will be installed in the trunk of a hydrogen-powered Toyota Prius hybrid vehicle converted by Quantum, Inc. of Irvine, CA.

FIGURE 2. New Design for Insulated Pressure Vessel

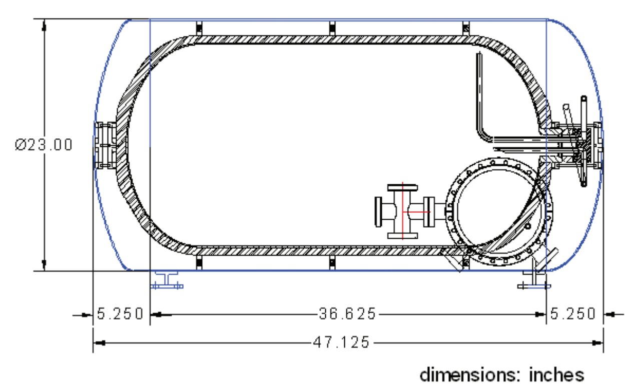

FIGURE 3. New Design for Insulated Pressure Vessel Showing Dimensions for the Inner Vessel and the Outer Vacuum Vessel (in blue)

FIGURE 4. Cryogenic Testing of Insulated Pressure Vessel at LLNL High Pressure Laboratory

We are thoroughly testing this new insulated pressure vessel design (Figure 4) to guarantee good thermal and structural performance with no leaks or loss of vacuum. The Toyota Prius vehicle was delivered to LLNL in June 2006 and we are currently installing the vessel in the vehicle.

Conclusions and Future Directions

- We have demonstrated a cryogenic-compatible container in a pickup truck. The truck was refueled multiple times with both compressed and liquid hydrogen, demonstrating the flexible refueling capability. The container meets the 2007 DOE target for weight.
- Our second generation cryogenic-compatible container has multiple improvements with respect to the previous design. The new design is projected to meet the DOE 2010 weight target and the 2007 volume target. It also works in the horizontal position.
- Our new insulated pressure vessel will be demonstrated in a Toyota Prius hydrogen hybrid vehicle to demonstrate long range and good thermal performance.

Special Recognitions & Awards/Patents Issued

1. Lightweight Cryogenic-Compatible Pressure Vessels for Vehicular Fuel Storage, Salvador M. Aceves, Gene Berry, Andrew H. Weisberg, U.S. Patent 6,708,502 B1, March 23, 2004. World Patent WO 2004/029503 A2, April 8, 2004.

2. Storage of H2 by Absorption and/or Mixture within a Fluid, Gene Berry and Salvador Aceves, World Patent WO 2005/015076 A1, February 24, 2005.

FY 2006 Publications/Presentations

1. Advanced Concepts for Vehicular Containment of Compressed and Cryogenic Hydrogen, Salvador M. Aceves, Gene D. Berry, Andrew H. Weisberg, Francisco Espinosa-Loza, Scott A. Perfect, Proceedings of the 16th World Hydrogen Energy Conference, Lyon, France, June 10-15, 2006.

2. The Use of Hydrogen Combustion for Power Generation, D. Walther, C. Fernandez-Pello, and R. Dibble, S. Aceves and D. Flowers, Paper AIAA-2005-5753, 3rd International Energy Conversion Engineering Conference and Exhibit, San Francisco, California, Aug. 15-18, 2005.

3. The Case for Hydrogen in a Carbon Constrained World, Gene D. Berry and Salvador M. Aceves, Invited discussion paper, ASME Journal of Energy Resources Technology, Vol. 127, pp. 89-94, 2005.

4. Vehicular Storage of Hydrogen in Insulated Pressure Vessels, Salvador M. Aceves, Gene D. Berry, Joel Martinez-Frias, Francisco Espinosa-Loza, In press, International Journal of Hydrogen Energy, 2006.

5. Hydrogen Absorption in Fluids: An Unexplored Solution for Onboard Hydrogen Storage, Gene D. Berry, Lawrence Livermore National Laboratory Report UCRL-TR-209650, Livermore, CA, February 2005.

6. Advanced Hydrogen Containers, Andrew Weisberg, Invited presentation, American Physical Society, March 2005.

7. Cryogenic Hydrogen Storage, Salvador Aceves, Invited Presentation, Materials for the Hydrogen Economy, September 2005.