Hydrogen Storage in Insulated Pressure Vessels

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Objectives

- Demonstrate the advantages of insulated pressure vessels in terms of improved packaging, reduced evaporative losses and reduced costs.
- Demonstrate safety of insulated pressure vessels by conducting certification tests.
- Write standards for assuring the safety of insulated pressure vessels.
- Demonstrate insulated pressure vessel technology in two pickup trucks.

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Storage section of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

- A. Cost
- B. Weight and Volume
- C. Efficiency
- D. Durability
- E. Refueling Time
- F. Codes & Standards
- G. Life-Cycle and Efficiency Analyses
- H. Sufficient Fuel Storage for Acceptable Vehicle Range
- J. Lack of Tank Performance Data
- K. BOP Components
- L. Hydrogen Boil-Off

Approach

- Conduct experiments to verify safety of insulated pressure vessels.
- Conduct analysis to verify safety of insulated pressure vessels.
- Study existing standards for hydrogen storage in vehicles.
- Test performance of two insulated pressure vessels on pickup trucks.

Accomplishments

- Performed SAE cryogenic drop and bonfire tests. The insulated pressure vessels successfully passed both tests.

- Signed a contract with the South Coast Air Quality Management District (SCAQMD) for $800,000 in complementary funding to conduct a demonstration.
- Generated an overall fuel system design for a truck at SunLine Transit.
- Studied current standards for hydrogen tanks. We have generated a preliminary list of tests for insulated pressure vessel certification based on current standards for hydrogen tanks.
- Tested 5000-psi vessels at cryogenic temperature. The pressure vessels were burst tested after cycling, and they met the required burst pressure criterion.
- Prepared a preliminary procedure for insulated hydrogen pressure vessel certification and submitted it to Structural Composites Industries (SCI) and the SCAQMD (our industrial and state government project partners).
- Wrote a comprehensive summary of hydrogen storage technologies to be published in the "Encyclopedia of Energy."

Future Directions

- Conduct a demonstration project at SunLine Transit where the insulated pressure vessels will be installed in two trucks.
- Conduct a fundamental study of conformal cryogenic compatible pressure vessels and analyze desirable shapes as well as desirable pressure ratings.
- Build conformal cryogenic compatible pressure vessels with optimum characteristics as identified in the fundamental study.

Introduction

The goal of this project is to develop a hydrogen storage technology that can satisfy light-duty vehicle storage needs in a cost-effective way. This high pressure, low temperature vessel has the packaging advantages of liquid hydrogen tanks (low weight and volume), with much reduced evaporative losses, infrastructure flexibility, lower energy consumption, lower cost, enhanced user convenience, and safety.

For reduced cost and complexity it is desirable to use commercially available aluminum-fiber pressure vessels for insulated hydrogen pressure vessels. However, commercially available pressure vessels are not designed for operation at cryogenic temperature.

We plan to demonstrate insulated hydrogen pressure vessels that have packaging characteristics similar to liquid hydrogen (LH2) tanks and are superior to ambient temperature pressure vessels. Compared with liquid hydrogen tanks, insulated hydrogen pressure vessels give increased flexibility to the fueling infrastructure, since the vehicle can be fueled with liquid hydrogen for long trips, or with less-energy-intensive ambient temperature hydrogen for daily driving. The high-pressure capability of the pressure vessel and the thermodynamic properties of hydrogen result in virtually zero boil-off losses for insulated hydrogen pressure vessels. Finally, due to their high-pressure capability, insulated hydrogen pressure vessels never run out of hydrogen after a long period of parking. This may be a major issue for liquid hydrogen tanks that can lose all their hydrogen due to evaporation.

Approach

We are conducting experiments and analysis to verify that insulated hydrogen pressure vessels are a safe technology for vehicular storage of hydrogen. We have conducted a long list of Department of Transportation (DOT), International Standards Organization (ISO) and Society of Automotive Engineers (SAE) tests, and our pressure vessels have successfully met the passing criteria for all of them.

We are planning a demonstration to prove the feasibility of insulated hydrogen pressure vessels in vehicles. To accomplish this task, we have secured

$800,000 of complementary funding from the South Coast Air Quality Management District, SCI and SunLine Transit.

Results

During this year, we completed the two final certification tests for insulated hydrogen pressure vessels. These are the SAE cryogenic drop test (Figure 1) and the SAE cryogenic bonfire test (Figure 2). These tests were successfully conducted, and our vessels met the required passing criteria.

We are also working on demonstrating the safety and advantages of insulated hydrogen pressure vessels by installing two of these vessels in pickup trucks owned by SunLine Transit. As a part of our work for demonstrating the insulated hydrogen pressure vessels in the pickup trucks, we have designed a system for fueling the truck engine with hydrogen from the vessel. We have selected and purchased all required components (valves, regulators, connectors, and safety devices). These components will be mounted into the pickup trucks in the near future.

We have also designed a computerized control system that will operate our fueling system for the pickup trucks. This system uses a MatLab-based program that runs on a laptop computer that will be carried in the vehicle.

We have prepared a draft certification procedure for insulated hydrogen pressure vessels. This procedure is considered to be guidance to manufacturers who may want to commercialize this technology in the future. The certification procedure includes 28 tests that have been selected from existing standards for ambient temperature pressure vessels (DOT, ISO) and for cryogenic vessels (SAE, European Integrated Hydrogen Program).

We wrote a comprehensive summary of hydrogen storage technologies. This will be published in the "Encyclopedia of Energy." This paper offers a new perspective on the characteristics of hydrogen storage technologies, including weight, volume, cost, safety and energy required for fuel processing.

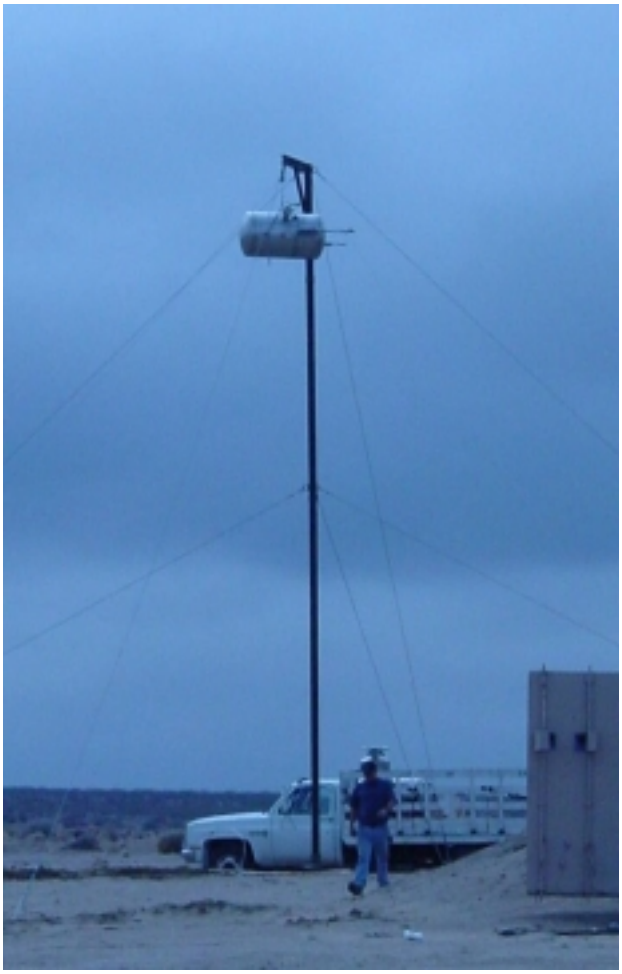

Figure 1. Insulated Hydrogen Pressure Vessel Being Subjected to the SAE Cryogenic Drop Test

Figure 2. Insulated Hydrogen Pressure Vessel Being Subjected to the SAE Cryogenic Bonfire Test

Conclusions

Insulated hydrogen pressure vessels are being developed as an alternative technology for storage of hydrogen in light-duty vehicles. Insulated hydrogen pressure vessels can be fueled with either liquid hydrogen or compressed hydrogen. This flexibility results in advantages compared to conventional hydrogen storage technologies. Insulated hydrogen pressure vessels are lighter than hydrides, more compact than ambient-temperature pressure vessels, and require less energy for liquefaction and have less evaporative losses than liquid hydrogen tanks.

A series of tests have been carried out to verify that commercially available pressure vessels can be operated at cryogenic temperature with no performance losses. All analysis and experiments to date indicate that no significant damage has resulted. Future activities include a demonstration project in which the insulated hydrogen pressure vessels will be installed and tested on two vehicles. Future work will address the possibility of optimum space utilization inside the vehicle through the use of cryogenic-compatible conformal pressure vessels.

FY 2002 Publications/Presentations

1. **Certification Testing and Demonstration of Insulated Pressure Vessels for Vehicular Hydrogen and Natural Gas Storage**, Salvador M. Aceves, Joel Martinez-Frias and Francisco Espinosa-Loza, Randy Schaffer, William Clapper, Proceedings of the 8th International Conference and Exhibition on Natural Gas Vehicles, Washington, DC, October 8-10, 2002.

2. **Hydrogen Storage and Transportation**, Gene Berry, Joel Martinez-Frias, Francisco Espinoza-Loza, Salvador Aceves. Invited article submitted to the Encyclopedia of Energy, 2003.

Special Recognitions & Awards/Patents Issued

Project will be featured in a 4-page article in "Science and Technology Review" magazine in June 2003.