IV.B.9 Development of Improved Composite Pressure Vessels for Hydrogen Storage

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Overall Objectives

- Improve the performance characteristics, including weight, volumetric efficiency, and cost, of composite pressure vessels used to contain hydrogen in adsorbants.
- Evaluate design, materials, or manufacturing process improvements necessary for containing adsorbants.
- Demonstrate these improvements in prototype systems through fabrication, testing, and evaluation.

Fiscal Year (FY) 2014 Objectives

- Select the best tank size and design option to use for Phase 3 testing.
- Manufacture prototype tanks and distribute to Hydrogen Storage Engineering Center of Excellence (HSECoE) partners requesting them.
- Demonstrate alternate tank designs with improved performance.

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Storage section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan:

(A) System Weight and Volume

(B) System Cost

(G) Materials of Construction

Technical Targets

This project is conducting studies for the development of improved composite pressure vessels for hydrogen storage, and developing an optimized vessel for use by HSECoE partners in demonstrating a functioning vehicle storage system using adsorbant materials. The targets apply to the storage system, of which the vessel is a part. Insights gained from these studies will be applied toward the design and manufacturing of hydrogen storage vessels that meet the following DOE hydrogen storage targets:

TABLE 1. Project Technical Targets

	2017
Gravimetric capacity	>5.5%
Volumetric capacity	>0.040 kg H_2/L
Storage system cost	<$12/kWh

FY 2014 Accomplishments

- HSECoE partners confirmed operating requirements for the Phase 3 test vessel, including a confirmation of the 100-bar operating pressure, and an internal volume of 2 L.
- The Phase 3 test vessel, of 3-piece Type 1 construction, was designed to have the same internal contour as the Phase 2 vessel, but thinner walls to make it more cost and weight efficient.
- The Phase 3 test vessel was subjected to 200 pressure cycles and a burst test, achieving 292 bar at ambient temperature, and 380 bar at 77 K, which confirmed the design and safety for use. A Type 1 vessel is about 20% to 40% heavier than a Type 4 vessel, but about 30% to 50% lower in cost at 100 bar.
- Phase 3 test vessels were distributed to HSECoE partners as requested. An internal thermal insulation layer was also provided.
- Subscale Type 1, Type 3, and Type 4 tanks are being designed to evaluate further improvement possibilities in alternate designs.
- Toughened resin systems continue to be evaluated as a means to improve composite performance by improving response to impact loading.

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INTRODUCTION

Hexagon Lincoln is conducting research to meet DOE 2017 Hydrogen Storage goals for a storage system by identifying appropriate materials and design approaches for the hydrogen container. At the same time, the pressure vessels must continue to maintain durability, operability and safety characteristics that already meet current industry guidelines. There is a continuation of work with HSECoE partners to identify pressure vessel characteristics and opportunities for performance improvement. Hexagon Lincoln is working to develop high-pressure vessels as are required to enable tank design approaches to meet weight and volume goals and to allow adsorbant materials that operate at cryogenic temperatures to operate efficiently.

APPROACH

Hexagon Lincoln established a baseline design for full-scale and test tank using HSECoE team operating criteria as a means to compare and evaluate potential improvements in design, materials and process to achieve cylinder performance improvements for weight, volume and cost. Hexagon Lincoln selected the most promising engineering concepts to meet Go/No-Go requirements for moving forward. The emphasis was on demonstrated technology to ensure ability of HSECoE partners to test their system components.

In Phase 3, operating conditions have been confirmed, and a reduced weight laboratory test vessel was designed and tested. This three-piece Type 1 tank is designed for safety and re-usability. Studies are continuing to identify designs and materials that may result in lighter weight and/or less expensive tanks.

RESULTS

HSECoE partners confirmed operation at 100-bar service pressure, with an operating temperature range from 80 K to 160 K, and a non-operating limit of 373 K. A test vessel configuration with three-piece Type 1 construction, a 2-liter volume, and reduced wall thickness was also established to demonstrate component technology. Test vessels were designed, manufactured, tested, and distributed to HSECoE partners to facilitate Phase 3 testing of prototype components.

The Phase 3 Type 1 test vessel was designed using aluminum alloy 6061-T6 and a three-piece construction (Figure 1). The three-piece construction allowed HSECoE partners to remove and replace components in the vessel between tests. A Type 1 vessel is about 20% to 40% heavier than Type 4 construction, but about 30% to 50% lower in cost at 100 bar. The Phase 3 prototype, with reduced wall thickness compared with the Phase 2 prototype, was 15% lighter in weight. A burst test to 290 bar at ambient temperature confirmed safety. A test vessel was also subjected to 200 cycles to service pressure at 80 K, then burst at 380 bar (Figure 2). This test confirmed safety for use by HSECoE partners in laboratory testing.

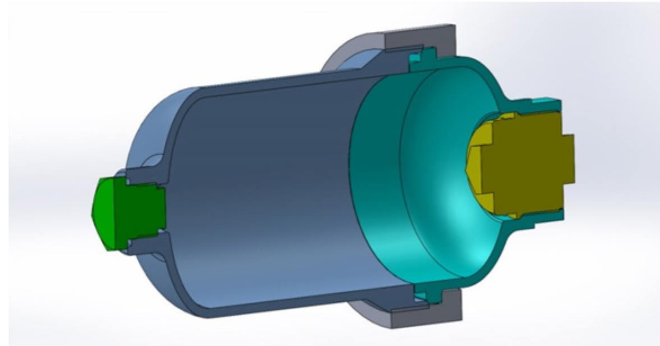

FIGURE 1. Phase 3 T1 Test Tank

FIGURE 2. Tank after Cryo Burst

A Teflon® liner was fabricated as internal thermal insulation for the subscale tank. The liner has a thickness of 1/8 inch. The liner allows the completed tank to be submerged in liquid nitrogen to cool the apparatus, and then adding heat to drive off the hydrogen in the adsorbant material, without the added heat being absorbed totally by the liquid nitrogen.

Designs were prepared for a single-piece Type 1 tank to be made of 6061-T6 aluminum, and a Type 3 tank using the same material as a liner, and using carbon/epoxy reinforcement. The inside of the two tanks would have approximately the same dimensions as the 3-piece Type 1 tank. A supplier for the tank and liner has been identified and an order placed for the components. Efforts are continuing to design a Type 4 tank that is compatible with the cold operating conditions that have been specified.

HSECoE partners have begun using the three-piece Type 1 tanks to demonstrate system components. A problem developed with leaking seals. It appears this problem will be resolved with the use of crushable metal washer type seals.

Additional cooling experiments were conducted to evaluate the external insulation system that will also be used for cooling the shell at time of fill. It was determined that a 3-mm gap between the outside of the tank and the inside of the insulating shell would be sufficient for use on the prototype system.

A task to evaluate toughened epoxy resin has been continued from Phase 2. Six different technologies have been selected for toughening the epoxy resin used in hydrogen pressure vessels. Table 2 shows results of initial screening. The glass transition temperature must remain above 105°C to maintain environmental stability in use, and the maximum viscosity for ease of manufacture is 2,500 cP.

TABLE 2. Results of Initial Screening

Material	Glass transition temperature (°C)	Room Temperature Viscosity (cP)
Baseline	118.3	916
ATBN	116.8	1,530
Core shell rubber	118.3	1,460
Nanosilica	118.2	1,070
Surface Modified Silica	117.3	960
Titanium Dioxide	118.4	930
Phase separating rubber	118.1	1,080

Neat resin coupons (Figure 3) were then fabricated and tested for tensile strength. The top four resin formulation showing the greatest increase in toughness will continue in the evaluation using composite rings and subscale tanks.

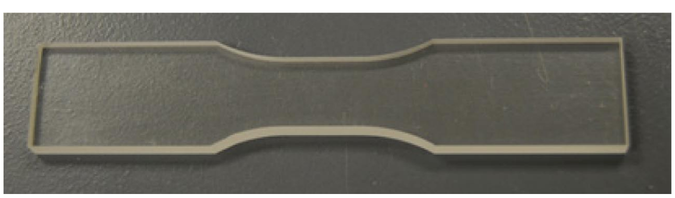

FIGURE 3. Resin Coupon

CONCLUSIONS AND FUTURE DIRECTIONS

- A Type 1 tank can meet the pressure and temperature requirements for Phase 3 testing and component development, and has the lowest program risk. A revised design of lighter weight was developed and tested.
- Subscale 1-piece Type 1, Type 3, and Type 4 tanks will be designed and fabricated to achieve higher performance than the three-piece Type 1 tank, and suitable for cryogenic service. The Type 1 tank and Type 3 tank liner have been ordered.
- The concept for insulating and pre-cooling the tank has been tested using prototype components. A full-scale component will be designed and modeled. A subscale unit will be manufactured and tested.
- Toughened resins that may further improve performance of Type 3 and Type 4 composite tanks are being developed and tested.

SPECIAL RECOGNITIONS & AWARDS/PATENTS ISSUED

1. A patent application was filed on the concept for a thermal insulation shell system that would also allow cooling of the tank prior to refilling.

FY 2014 PUBLICATIONS/PRESENTATIONS

1. 2014 DOE Hydrogen Program Annual Merit Review, June 18, 2014.