IV.B.7 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 adsorbents
- Evaluate design, materials, or manufacturing process improvements necessary for containing adsorbents
- Demonstrate these improvements in prototype systems through fabrication, testing, and evaluation

Fiscal Year (FY) 2015 Objectives

- Manufacture prototype tanks and distribute to Hydrogen Storage Engineering Center of Excellence (HSECoE) partners for Phase 3 testing
- Demonstrate alternate tank designs with improved performance
- Demonstrate the use of liquid nitrogen to pre-cool the prototype tank and gather test data
- Design full-scale tanks based on testing of subscale designs

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 fundamental 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 adsorbent 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 2020 hydrogen storage targets:

- Gravimetric capacity: >5.5%
- Volumetric capacity: >0.040 kg H_2/L
- Storage system cost: <$10/kWh

FY 2015 Accomplishments

- The revised Phase 3 test vessel, of three-piece Type 1 construction, was designed as a right circular cylinder with flanged ends and end plates attached by bolts, having the same internal diameter as the Phase 2 vessel, but with simpler sealing mechanism and the ability to better compress the seals, so that there was no leakage at 100 bar and 80 K.
- Subscale Type 1, Type 3, and Type 4 tanks designed in the prior year have been manufactured and are being tested to evaluate further improvement possibilities in alternate designs.
- A Type 1 subscale tank was tested in a prototype liquid nitrogen cooling system, and data evaluation indicates the system can be used to fill a tank with the desired time.
- A Type 3 subscale tank was tested in the prototype liquid nitrogen cooling system. Full data evaluation has not been completed, but the data indicate the minimum temperature reached was higher than with the Type 1 tank, and there was an increased time to cool.
- Full-scale Type 1 and Type 4 tanks were designed based on testing conducted to date.

INTRODUCTION

Hexagon Lincoln is conducting research to meet DOE 2020 hydrogen storage system goals by identifying appropriate materials and design approaches for the hydrogen container. 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 adsorbent materials that operate at cryogenic temperatures to operate efficiently.

APPROACH

Hexagon Lincoln established a baseline design for full-scale and test tanks 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 was designed for safety and reusability, but problems developed with high-pressure sealing at cryogenic temperatures. A revised design was developed that addressed the sealing problem and allowed team partners to demonstrate their adsorbent systems. 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, 2-L 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 final test vessel was designed using 304 stainless steel (SS) and a three-piece construction (Figure 1). The three-piece construction allowed HSECoE partners to remove and replace components in the vessel between tests. This test vessel was intended to facilitate system testing by HSECoE partners and was not intended to be representative of production units. No leakage occurred after changing to this design.

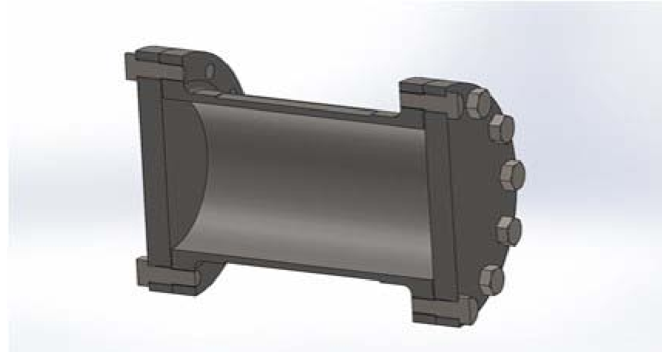

FIGURE 1. Phase 3 Type 1 test tank

FIGURE 2. Type 3 tank

A Type 1 prototype tank and Type 3 prototype liner were manufactured in accordance with designs prepared during the prior year. The Type 3 tank (Figure 2) was burst at 318 bar (4,615 psi), well above the required burst pressure. The Type 1 tank was tested to 276 bar (4,000 psi). It did not burst at this pressure, but significant yielding had occurred, and the outer diameter had grown by about 10 mm (0.4 in).

Type 4 tanks have also been fabricated but have not yet been burst tested. A resin layer was used as a liner in these Type 4 tanks so that the tanks would not be affected by cryogenic temperatures, as was the prior high-density polyethylene liner. The first unit had a pronounced leakage rate, while the second unit had a low leakage/permeation rate, 1.2 cm^3/s at 4 bar (60 psi). The third unit had a leakage/permeation rate of only 0.001 cm^3/min at 4 bar (60 psi) and is undergoing additional testing.

Cooling studies were conducted with the prototype 2-L Type 1 tank to determine fill characteristics. Figure 3 shows sample data of wall temperature at various locations as a function of time with bottom fill. Data evaluation indicates the system can be used to fill a tank with the desired time.

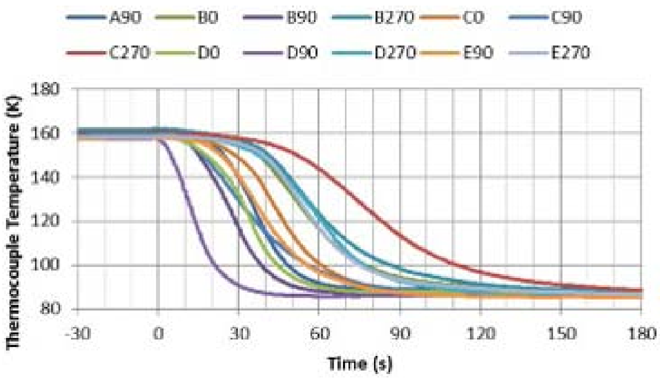

FIGURE 3. Wall temperature vs. time with bottom fill

Testing of a Type 3 tank, with carbon fiber reinforce, showed the minimum temperature reached was higher than with the Type 1 tank, and there was an increased time to cool, reflecting differences in thermal conductivity and heat capacity of the wall.

Full-scale Type 1 and Type 4 tanks were designed based on the prototype work done. The volume required to contain 5.6 kg usable hydrogen in MOF-5 (metal organic framework) adsorbent material, as reported during the 2015 DOE Annual Merit Review meeting, was about 300 L. Service pressure was 100 bar, and service temperatures were from 80 K to 160 K. Inner diameter was about 20 inches, and length about 65 inches. A Type 1 tank made of AA 6061-T6 would have a wall thickness of about 0.9 inch and would weigh about 390 pounds. This might decrease as elastic-plastic properties and cryogenic strength vs. room temperature properties and operating conditions are evaluated. A Type 4 tank made of carbon epoxy would be similar in size but would have a wall thickness of about 0.2 inch and weigh about 55 pounds. This might increase as damage tolerance is addressed.

CONCLUSIONS AND FUTURE DIRECTIONS

- A Type 1 tank met the pressure and temperature requirements for Phase 3 testing and component development and had the lowest program risk. A revised design would be required for production.
- Subscale one-piece Type 1, Type 3, and Type 4 tanks were fabricated to achieve higher performance than the three-piece Type 1 tank. Additional testing at room temperature and at 80 K is required to confirm suitability of the designs.
- A subscale tank was pre-cooled using prototype components. Data indicates desired filling rates could be met. Full-scale testing would also be desirable.
- Full-scale designs were completed based on testing of subscale components to date. These tanks are large compared with a passenger vehicle. Full-scale demonstration would be useful.
- Full-scale Type 1 and Type 4 designs were prepared. There is a need to improve volumetric efficiency of designs to be more usable on vehicles, and a need to optimize designs.

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 2015 PUBLICATIONS/PRESENTATIONS

1. 2015 DOE Hydrogen Program Annual Merit Review, June 10, 2015.