IV.G.3 Low-Cost, High-Efficiency, High-Pressure Hydrogen Storage

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Objectives

This project is to improve the system weight and cost efficiency of Type IV hydrogen gas storage vessels through:

- Liner material and molding process development to reduce liner thickness by 90%, improve production efficiency from approximately 2-hour cycle time to 2 minutes, and reduce the amount of composite usage by roughly 3% in the current pressure vessel (named "129 Liter" used in this project).
- Hydrogen compatible materials study and metal fitting redesign to reduce metal fitting material cost by 80%.
- Liner-metal fitting interface study for proper seal against pressure up to 87.5 MPa.
- Composite manufacturing process evaluation to improve composite reinforcing efficiency and reduce composite usage by 25% in the current pressure vessel.

Technical Barriers

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

(A) System Weight and Volume

(B) System Cost

Technical Targets

This project is to develop blow molding for liner production and reduce liner thickness; reduce metal fitting material usage and change current material to cheaper hydrogen compatible metals; and optimize current filament winding process to reduce composite material usage. If successful, the project will help to improve the storage efficiency of our hydrogen storage systems towards meeting the DOE target, as listed in Table 1. Quantum has made a lot of such commercially available systems. In Table 1, Quantum's status is calculated based on a system, which includes a single 129 liter type IV H_2 tank (approximately 5 kg hydrogen capacity at 70 MPa service pressure) with a solenoid valve, a set of high-pressure and low-pressure regulators, a mid stage valve, a receptacle with filter, all tubing and fittings for this system, a frame, a wire harness, a pressure sensor and a balance of parts (consisting mainly of fasteners etc). The end-user cost efficiency is calculated based on an assumption of 500,000 units/year, as well as that 1 kg hydrogen is able to generate 33.3 kWh energy. Per the DOE request, we performed a cost analysis for 10,000, 100,000 and 500,000 units/year. The cost efficiency is approximately $54.1/kWh and $48.1/kWh for the first two cases respectively, with the last case shown below in Table 1.

TABLE 1. Progress towards Meeting Technical Targets for On-Board Hydrogen Storage for Light-Duty Vehicles

Storage parameters	Units	2010	Quantum Status
System Gravimetric Capacity	kWh/kg	1.5	1.50
System Volumetric Capacity	kWh/l	0.9	0.83
System Cost	$/kWh	4	45.9

Accomplishments

- Through material study, we found the right candidate materials to use for the liner blow molding process, and evaluated blow molded liners.
- Finished literature review on hydrogen compatible metals, and selected the candidate material to use to replace current expensive materials in metal fittings.
- Improved the filament winding process and composite reinforcing efficiency through design, 90% finished.

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Introduction

The goal of this project is to lower the hydrogen storage system weight and cost of type IV pressure vessels through three different routes. The first is to develop a blow molding process of liner production for liner thickness reduction, more precise quality control and much shorter production cycle time. Quantum has located candidate materials with much better barrier performance than what is currently used, developed a blow molding process, evaluated the liners made through the blow molding process, and demonstrated the feasibility of the blow molding process. The second is to reduce metal fitting material usage by metal fitting design. Quantum has located a much cheaper material to replace the current expensive metal fitting material, and is working to reduce the current metal fitting volume and remove some components. We have made prototypes of the liner-metal fitting interface and proved the feasibility. The third is to improve the filament winding process and composite design to improve composite reinforcing efficiency in the pressure vessel structure. We have improved the translation efficiency (composite reinforcing efficiency) from 65% to 82%.

We plan to continue to work on these three areas and further improve the system cost and weight efficiency.

Approach

Type IV pressure vessels consist of a polymer liner material as the gas barrier, metal fitting for connection to the valve systems, and a fiber reinforced polymer composite to support the load. In the pressure vessel, composite weight is about 90%; composite material cost is about 65% and the metal fitting is about 34% of the vessel. Therefore in order to improve the vessel cost and weight efficiency, we need to work mainly on both composite and metal fittings.

Currently the liner made through rotational molding using high density polyethylene (HDPE) material has a thickness about 5 mm. We are developing a blow molding process to reduce the liner thickness, so that composite usage can be reduced; to improve liner quality control; and to reduce the production cycle time to meet the DOE goal of 500,000 units per year. We are working on a metal fitting design to lower the metal fitting cost by removing component usage, reducing part volume, and changing to cheaper hydrogen compatible materials. We are also working on composite optimization to save composite material usage by improving the filament winding process and composite design efficiency.

Results

Since the project started in July 2008, through thorough material literature study and characterizations, we have successfully located liner candidate materials which have much better barrier performance than the HDPE liners we currently use. We developed a blow molding process for these materials, and evaluated some blow molded liners. The blow molded polyethylene teraphthalate (PET) liners with only 1 mm averaged thickness have a barrier performance about 5 times better than our current 5 mm thick HDPE liners. And the PET liners have passed the ambient pressure cycle fatigue test according to European Integrated Hydrogen Project (EIHP) standards. We also demonstrated the excellent toughness of the liner. Once we can prove the liner-metal fitting seal design, we will demonstrate the feasibility of the blow molding process for liner production. We will evaluate polyethylene naphthalate (PEN) blow-molded liners. We plan to continue to work on this area if we can continue to get funding support. If successful in achieving what we described in the Objectives, the estimated improvement will be from $45.9/kWh to $44.9/kWh for the system we discussed before. And the system weight efficiency will be improved approximately from 1.50 kWh/kg to 1.54 kWh/kg. In addition, the success of the blow molding application in liner production will reduce the liner production cycle time from approximately 2 hours to 2 minutes, and help to meet the DOE mass production goal of 500,000 units per year.

We did a thorough literature review and found a few hydrogen compatible metals much cheaper than the material we currently use for the metal fittings. We plan to use these materials to replace the expensive material in the metal fitting. The metal fittings used in the vessel consist of polar boss and adapter. We plan to remove the adapter so that the valve is directly sealed against the polar boss. We also plan to reduce the size of the current polar boss and make it much smaller. We have made prototyped metal fittings according to the new design, and demonstrated the validity of the liner-metal fitting interface seal. We will make new metal fittings using an aluminum alloy and evaluate them according to EIHP tests. If successful in achieving what we have in the Objectives, we will improve the hydrogen storage cost efficiency from $45.9/kWh to $44.9/kWh. With continuous funding, we will evaluate the metal fittings using other metal materials to further improve the cost efficiency. The drawing of the metal fitting components are shown in Figures 1 and 2, with Figure 1 showing the current design which includes the polar boss, adapter and valve; and Figure 2 showing the future design which only contains the polar boss and valve and which has a much smaller polar boss opening and therefore volume.

Since the project started, we have improved the filament winding process in terms of:

1. The balance between fiber tow tension and surface curvature.
2. The balance between fiber tow tension and liner pressure.

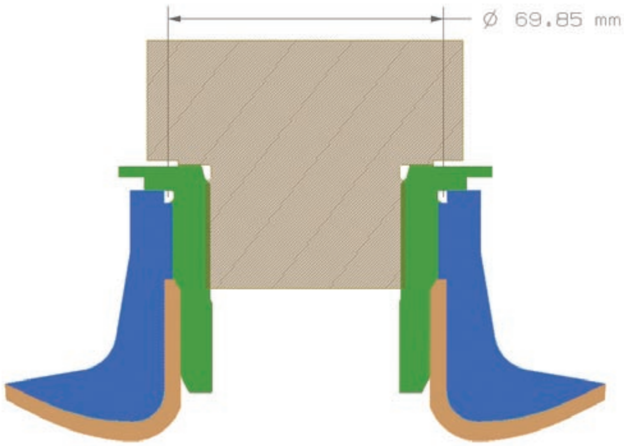

FIGURE 1. Current Metal Fitting-Liner Interface Design

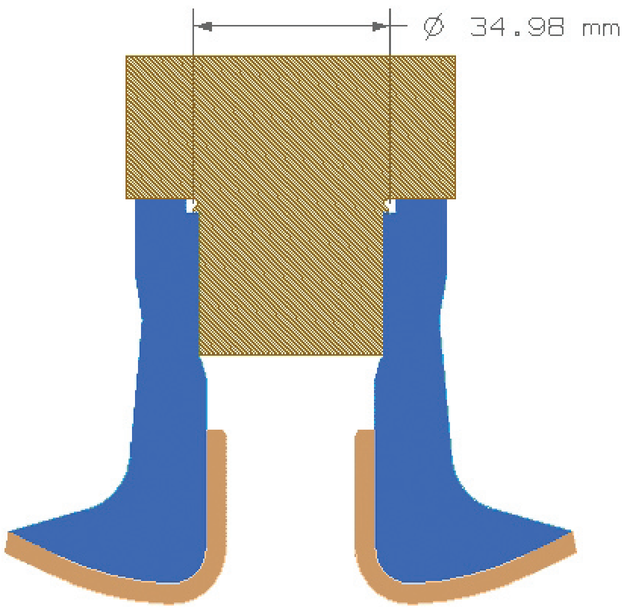

FIGURE 2. Future Metal Fitting-Liner Interface Design

3. The accuracy of fiber tow tension control.
4. The control of resin bath temperature and cure profile.

With these improvements, we increased the fiber translation efficiency (composite reinforcing efficiency) in the vessel structure from 65% to 82%. Although still lower than our target (85%), we are almost finished. With such achievement, we improved the system cost efficiency approximately from $50.7/kWh when the project started to the current value of $45.9/kWh, and weight efficiency approximately from 1.18 kWh/kg to 1.50 kWh/kg. If successful in achieving the target, the storage system cost efficiency will be further improved to $45.6/kWh, and weight efficiency to 1.54 kWh/kg.

In addition to the work in the scope of this project, we propose to work on a few different tasks. Study of S-glass fiber performance in the vessel structure is one of them. The cost of S-glass fiber is about $5.0 per pound, roughly 1/3 that of the carbon fiber we use. The replacement of carbon fiber with S-glass fiber will reduce the system cost significantly. Our study will focus on the translation efficiency we can gain from using S-glass fiber in the vessel structure, and on the safety factor we should follow on S-glass fiber. Currently the safety factor to use for S-glass fiber in the vessel structure is 3.5, determined according to the environmental and stress crack of E-glass fiber, which is much weaker and much less environmentally durable than S-glass. We believe that the safety factor for S-glass should be close to 2.25, the one people use for carbon fiber in the U.S. The estimated improvement on cost efficiency will be reported later once we have more confirmative results.

We also propose to work on components used in the storage system. Quantum has been developing more cost-efficient fuel control components. Continuous improvement will lead to a system with less components, and higher cost and weight efficiency. We have made detailed plans to reduce material usage and pursue alternative and cheaper hydrogen compatible materials, which will approximately improve the system cost efficiency from $45.9/kWh to $30.4/kWh. This cost cutting is contributed by the optimization of all components.

Conclusions and Future Directions

- We have very positive results in demonstrating the feasibility of a blow molding process in liner preparation, and further evaluation is on-going. Success will result in the estimated improvement of system cost efficiency from $45.9/kWh to $44.9/kWh.
- Material study for metal fittings is finished, and design is on-going; prototypes of new metal fitting design were made and evaluation is on-going. Success will result in the estimated improvement of system cost efficiency from $45.9/kWh to $44.9/kWh.
- Composite optimization through filament winding process improvement and design are 90% finished and the rest of the work is on-going. The finished work resulted in improvement of system cost efficiency from $50.7/kWh when the project started to a current value of $45.9/kWh.
- Propose to work on S-glass performance study in the vessel structure.
- Propose to work on component study in the storage system. Success will result in the estimated improvement of system cost efficiency from $45.9/kWh to $30.4/kWh.

FY 2009 Publications/Presentations

1. Low-Cost High-Efficiency High-Pressure H2 Storage, Annual Merit Review, Department of Energy, May 18–22, 2009, Arlington, VA.

2. H2 Tank Manufacturing Optimization, Annual Merit Review, Department of Energy, June 9–13, 2008, Arlington, VA.