IV.G.3 A Cassette Based System for Hydrogen Storage and Delivery*

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*Congressionally directed project

Objectives

Objectives	Status
Choose Software System for Modeling	Fluent, completed
Select Chemical Systems for Modeling	In progress, see discussion
Select Thermal Management Schemes	Completed, but refinement continues
Model Thermal Management Schemes	Completed, but refinement continues
Model Basic Cassette System	Completed (Excel model)
Foster Scientific Communications	In progress, see below
Build a Team to Meet Goals	Completed
Presentations, Communications	See list below
Lab Preparation and Equipment	In progress, see below
Research Documentation Control	Continuing
Project Cost Control	Continuing
Test Reliability of Alanate	In progress, apparatus constructed
Lifetime Testing	In progress, apparatus constructed

Goals and Objectives

In Phase I, we evaluated several heat transfer models using Fluent, Inc. software, built test equipment and model cassettes, and prepared hydrogen absorption materials.

Phase II is underway and involves testing various aspects of the cassette hydrogen storage and delivery system to evaluate the model predictions and to provide data for refinement of the model. Our efforts are focusing on designing a safe, modular, adaptable, rechargeable and transportable system for hydrogen storage and delivery.

Our testing includes refinement of materials and system components to optimize the "balance-of-plant" metrics. The total energy balance is being determined and partitioned among the various system elements so optimization can be efficiently achieved. The ultimate objective is to achieve the DOE weight percentage and hydrogen delivery goals.

Technical Barriers

This project addresses the following technical barriers from the Hydrogen 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
(C) Efficiency
(E) Charging/Discharging Rates
(H) Balance of Plant (BOP) Components
(J) Thermal Management
(K) System Life-Cycle Assessments
(R) Regeneration Processes
(S) By-Product/Spent Material Removal

Technical Targets

This project is currently evaluating liquid-based hydrogen storage systems utilizing a cassette for media storage that can meet the DOE 2007 targets as summarized in the table below.

Storage Parameter	Units	2007 Target	Status
Specific Energy	kWh/Kg	1.5	In progress, data are preliminary
Energy Density	kWh/L	1.2	In progress, data are peliminary

Accomplishments

- Selected parameters for a hypothetical metal hydride–used sodium alanate as a model. Applied this to several cassette system designs to meet end-user requirements.
- Modeled heat transfer concepts for the cassette model and compared results for selected approaches.
- Compared virtual cassette with other hydrogen storage methods.
- Evaluated heat transfer in selected systems.
- Designed and constructed demonstration cassette system hardware and software to illustrate features of a multiplexed cassette system.
- Modified materials and evaluated properties.
- Compared different hydrogen storage systems in cassette test system.
- Constructed and utilized automated dual Sievert's test system.
- Conducted preliminary testing of liquid-based systems.
- Conducted 1 kWh tests on liquid-based system.

Introduction

FST is developing a technologically feasible and commercially viable approach to solving the problems with hydrogen storage. FST's objective in this project will be to improve on methods that store hydrogen in a solid state and safely hold and release that hydrogen at lower temperatures and higher quantities, in smaller housings that deliver superior operating efficiencies. This objective will be discussed in the final study as it relates to previous optimization metrics and solutions.

Approach

The proposed optimization solution is the integration of an advanced metal hydride chemistry that that has the prospect of meeting the DOE goals with a specialized transportable container that takes best advantage of the chemistry, advances the flexibility and distribution for the use of the hydrogen, increases the safety of transportable hydrogen and reduces the infrastructure needs for a domestic hydrogen delivery system.

The goals of this work will be to discover and develop processes that conform to the Department of Energy's published goals for storage systems, particularly gravimetric capacity, volumetric capacity, and storage system cost. Computer models will assess heat transport for several basic designs. We will seek to identify and evaluate suitable materials in a cassette test system. The test system addresses such important and practical issues as interconnections, heating methods, heat transport and safety.

A prototype multiplexed cassette system was constructed that can demonstrate the advantage of parallel series operation of cassettes by increasing the dynamic range of hydrogen delivery. An automated material test system was also constructed and utilized for material and hardware evaluation. One problem we have faced is the lack of suitable materials for study. Materials that have the potential for meeting the DOE goals are not much better that sodium alanate at this time, and many face a number of problems yet to be solved. There are however, a number of systems that under hydrolysis conditions have the prospect of affording high gravimetric yields. They also face a number of problems, but the least of these appears to be their ability to release high percentages of hydrogen under relatively mild conditions. We have therefore developed a cassette system to test and evaluate several of these hydrolysis systems.

Results

Fluent and Excel models have been utilized to evaluate and compare our rectangular cassette with cylinder storage systems. Advantages of a flat rectangular design include better heat transport, easier handling, storing, stacking and transporting. The main disadvantage is reduced volume to surface area that increases the package weight. This is traded off for less internal structure required for heat distribution.

Hardware has been developed and refined for testing solid hydride materials that allow for heating, cooling, charging and discharging automatically for any number of cycles. This includes the ability to charge and discharge two systems simultaneously and has been applied to sodium alanate. The system can be set up and programmed to vary time and temperature for any given pressure of hydrogen, and is thus adaptable to a variety of systems. The cassettes utilize quick connects for interconnections that have proved to be relatively trouble free. Rapid heating of the material is achieved by utilizing a short thermal path.

We have explored modification of the hydride with carbon that renders the material electrically conductive. This allows for resistive heating of materials, however the carbon loading required to achieve suitable wattage is 30% or greater.

A constructed prototype system utilizing several parallel cassettes demonstrates some of the advantages of series parallel operation of cassettes that increase the dynamic range for hydrogen delivery, facilitates complete discharge of cassettes without loss of pressure or volume

of gas, and provides for instant automated backup when a cassette is expired or near expiration.

Experiments are underway with a new system designed for hydrolysis of metal hydrides. We will examine different chemistries, hardware, and reaction conditions. Some of the issues to be addressed include handling of the solid materials and waste products, use of solvents, mixed chemistries, and thermal conditions. A number of small scale tests have been run as well as several 1 kWh tests.

Conclusions and Future Directions

Computer models demonstrate excellent heat transfer with a flat cassette for metal hydride containment. Cost and gravimetric models show that the flat cassette model is competitive with cylinders that contain either high pressure compressed gas or metal hydrides. Laboratory tests with small cassettes afford good heat transfer and therefore good kinetics. We have evaluated a number of hardware questions such as interconnections and find that quick connects for example, give leak-free performance at 100 atmospheres of hydrogen after extended use.

Multiplexed parallel cassettes offer some advantages in hydrogen delivery systems by increasing throughput and enhancing flexibility, but at some cost in complexity.

Gravimetric and balance-of-plant metrics required to meet DOE targets present a difficult challenge that have not been met by any system. Hydrolysis reactions with certain metal hydrides may be able to meet the gravimetric and kinetic targets, but these require external multistep processes for regeneration with uncertain long term cost.

Our basic cassette system should be adaptable to future solid metal hydrides that reversibly bind hydrogen. We are now exploring hydrolysis systems that offer new and different challenges than posed with total solid state systems. Preliminary experiments have been conducted on a hydrolysis reaction on a 1 kWh scale.

Special Recognitions & Awards/Patents Issued

1. CleanStart Finalist.

FY 2006 Publications/Presentations

1. DOE Annual Review Poster Presentation, May 2006.
2. CalStart Presentation at Caltech, June 2006.