IV.D.1j Microscale Enhancement of Heat and Mass Transfer for Hydrogen Energy Storage

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Objectives

Use microchannel technology to:

- Reduce the size and weight of storage.
- Improve charging and discharging rate of storage.
- Reduce size and weight and increase performance of thermal balance-of-plant components.

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 Research, Development and Demonstration Plan (Section 3.3.1):

(A) System Weight and Volume

(E) Charging and Discharging Rates

(H) Balance of Plant (BOP) Components

Technical Targets

Fundamentally, microchannel technology reduces barriers to heat and mass transfer by reducing characteristic diffusion lengths. Any diffusion-limited process can be improved by reducing the characteristic diffusion length associated with that process. As an example, consider a cool fluid flowing in a channel with hot walls. For a diffusion-limited process (laminar flow), the residence time necessary for the fluid to come to the temperature of the walls is a function of channel D^2 where D is the width of the channel. A similar effect is encountered in any other diffusion-limited process. The residence time can be reduced without increasing the pressure drop by adding more channels. If the total flow area is kept constant as the channel dimensions are reduced, moving to a larger number of smaller channels increases heat (or mass) transfer, which in turn allows the channels to be shorter. For laminar flow, the increase in pressure drop caused by reduced channel size is just offset by the impact of the shorter channel on pressure drop. A significant reduction in barriers to heat and mass transfer will improve the heat and mass transfer efficiency and reduce the size, weight, and cost of automotive hydrogen storage systems.

Examples of where OSU has applied microchannel technology to reduce heat and mass transfer barriers include: microscale combustion systems, high flux microscale heat exchangers and recuperators, microtechnology-based heat-actuated heat pumps, microchannel thermal management systems for fuel cells, microscale absorption and adsorption systems, microchannel catalytic reactors for hydrogen production, microchannel biodiesel reactors, microchannel hemodialysis systems, microscale separations systems, and microreactors for the production of nanoparticles. Applying microchannel heat and mass transfer enhancement to diffusion limited energy and chemical systems has often resulted in a reduction factor of 5 to 10 in the size of the device while attaining high thermal and mass transfer efficiency. Currently, four companies are commercializing microtechnology-based energy and chemical systems developed at OSU and the Pacific Northwest National Laboratory (PNNL).

Microscale enhancement of heat and mass transfer can be applied to two classes of problems related to hydrogen storage. First, the microscale enhancement can be used in the actual automotive hydrogen storage component to enhance heat and mass transfer allowing rapid charging of the storage system, rapid startup, and quick response to changing driving conditions. In addition, the overall efficiency of the hydrogen storage system will depend on how efficiently the system can use the available waste heat from the fuel cell. This is particularly true for hydrogen storage systems where material characteristics require temperatures above that available from the fuel cell, mandating the use of hydrogen combustion. The performance of the balance-of-plant components, needed for utilization of fuel cell waste heat or combustion of hydrogen, will to a great extent determine the round trip efficiency of the system. The use of microscale components for balance-of-plant applications has the potential to allow efficient use of fuel cell waste heat and efficient combustion of hydrogen for discharging storage. Microtechnology-based balance-of-plant components such as microscale heat exchangers, recuperators, and combustors have been demonstrated for similar applications. Based on OSU's experience in developing other microtechnology-based systems, when compared to conventional components we expect an increase in heat and mass transfer efficiency, and a significant reduction in size and weight.

In the case of metal hydride storage, heat removal during charging is the critical technical issue. Given that the rate limiting processes associated with charging metal hydride storage are typically limited by diffusion, this is a classic example of an application that should be amenable to miniaturization using microchannel architecture. It is currently intended to use waste heat from a high temperature fuel cell to provide heating during discharge. In this case, the role of microscale enhancement would be primarily in enhancing heat removal during charging. Balance-of-plant opportunities will include high performance miniaturized heat exchangers and recuperators. If insufficient waste heat is available from the fuel cell or if a higher discharge temperature is required in the metal hydride storage system, it is straightforward to develop a microtechnology-based integrated hydrogen combustion system with a microchannel combustor and a high effectiveness recuperator to maximize the thermal efficiency of the discharge process.

The first year of the project will identify several high priority applications of microchannel technology to hydrogen storage. At the end of the first year, quantified performance, weight, size and cost goals will be established for each high priority applications.

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Approach

The proposed work plan consists of three phases with Go/No-Go decision points at the end of each phase. Working with Savannah River National Laboratory, OSU will develop and supply microchannel-based heat transfer components for both the hydrogen storage component and any balance-of-plant components. In addition, OSU will be available to consult on microchannel-based mass transfer enhancement for the storage system. The goals and objectives are described below:

- **Phase 1: System Requirements & Novel Concepts** – Initially, OSU will focus on system-level simulation conducted by center members to identify and prioritize opportunities for applying microscale heat and mass transfer techniques. Working with other team members, OSU will identify the highest value applications and, where necessary, conduct experimental investigations and use modeling to collect data necessary to support the Go/No-Go decision to proceed to Phase 2. The identification of the specific OSU and PNNL scope of work relative to balance-of-plant components will be defined at the end of year one. Phase 1 will extend from April 1, 2009, to September 30, 2010.
- **Phase 2: Novel Concepts Modeling, Design, and Evaluation** – For each high-priority application, OSU will develop predictive models, design and evaluate components, fabricate proof-of-principle test articles, conduct proof-of-principle tests, and use the results to validate the predictive models. With other team members, OSU will select one or more high-priority components for prototype demonstration. Results will be used to support the Go/No-Go decision to proceed to Phase 3. Phase 2 will extend from October 1, 2010, to September 30, 2012.
- **Phase 3: Subsystem Prototype Construction, Testing, and Evaluation** – For each high-priority component, OSU will design, optimize, and fabricate the component and provide it to the hydrogen storage system integrator. Phase 3 will extend from October 1, 2012, to September 30, 2014.

Accomplishments

This is a new project, funding for this project was available on April 1, 2009, however, we have made significant progress in this limited time period. Key accomplishments are summarized below.

- Worked with other center members we have identified two applications that merit additional investigation. These include:
  - Microtechnology-based energy and chemical systems (MECS)-based structured bed metal-hydride storage where we optimized a unit cell for heat and mass transfer and then "number up" rather then "scale up" using microlamination to produce a full scale hydrogen storage system.
  - Microchannel-based integrated hydrogen combustor/heat exchanger/recuperator plus other balance-of-plant heat exchangers.
- Outlined fabrication strategy for MECS-based metal hydride storage concept.

- Initiated development of the optimization code that will be used to optimize the unit cell for the MECS-based metal hydride storage system.

Future Directions

As indicated above, we are focusing on the development of a MECS-based metal hydride storage concept and an integrated microchannel combustor/heat exchanger. Future research activities are summarized below:

- MECS Metal Hydride Storage Concept
  - Use simulation to optimize unit cell
  - Experimentally validate simulation
  - Outline fabrication approach and production cost
- Integrated Combustor/Heat Exchanger
  - Use simulation to optimize integrated system
  - Fabricate technology demonstration
  - Experimentally validate simulation
  - Demonstrate rapid start-up and transient performance
- Second Law Analysis
  - Use 2nd Law analysis tools to evaluate thermodynamic losses in hydrogen storage and identify design improvements

Special Recognitions & Awards/Patents Issued

1. One invention disclosure has been filed at OSU.

FY 2009 Publications/Presentations

1. Presentations have been made at the Hydrogen Storage Center of Excellence kick-off meeting and a poster was presented at the 2009 Hydrogen Program Merit Review Meeting.