Joshua Schmitt (Southwest Research Institute)

DEVELOPMENT OF AN ADVANCED HYDROGEN ENERGY STORAGE SYSTEM USING AEROGEL IN A CRYOGENIC FLUX CAPACITOR (CFC)
Acknowledgement and Disclaimer

Acknowledgment: "This material is based upon work supported by the Department of Energy Award Number DE-FE0032003."

Disclaimer: "This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof."
Overview

- Project Team
- Objectives
- Background on the Technology
- Project Update
- Future Technology Development
Project Team

Principal Investigator
Southwest Research Institute

Development of Test and Validation of Test Setup
Air Liquide

Performance of Test and Data Analysis

Commercialization and Development Pathway
TTS

IAA with DOE

Development of Test, Validation of Test Setup, and Data Analysis
NASA
Project Objectives

- **Project Goals**
  - Validate CFC hydrogen performance at a smaller scale
  - Develop and commission test-scale lab to support planned test plan
  - Perform test campaign on pure hydrogen from gas bottles and an electrolyzer
  - Analyze data and feed into techno-economic analysis (TEA)
  - Pair the CFC with an electrolyzer to demonstrate system dynamics

- **Test Goals**
  - Physisorption performance will be demonstrated between 80K and 120K
  - Estimated storage size is 100 kWh(t) of hydrogen, which is approximately 3 kg
  - Current estimated size of the electrolyzer is 5 kW or 1,000 normal l/hr
  - Charge and store at atmospheric pressure and discharge between atmospheric and 20 bar
Background – Past Work

• Pursued by NASA for high density storage of fluids such as oxygen, hydrogen, natural gas, and nitrogen
• Storage demonstrated that has the dynamic capabilities of a gas bottle, but with much higher storage density
• Explored aerogel, a nanoporous, composite material
• Tests developed to demonstrate physisorption of various fluids into aerogel
• Physisorption: the individual fluid molecules are physically bonded within the pores of a meso- or nano-porous storage media
Background – Technology Readiness

• NASA development of various aerogel packaging for containment in a pressure vessel

• Improved storage at a range of temperatures: 200K, 100K, 77K

• Demonstrated storage performance for nitrogen, air, oxygen, and argon

• Mass uptake measurements to demonstrate CFC aerogel material performance
Project Status

SMALL SCALE RIG
Small Rig for Hydrogen Adsorption

• Small scale rig experimental results will improve final design for CFC demo scale hydrogen storage apparatus
  – Aerogel cooling rates from LN$_2$ as cooling fluid
  – Rate of adsorption for Nitrogen and Hydrogen
  – Provide validation data for numerical models

• With scale of rig, a large experimental parameter space can be explored with low risk and cost
Experimental Mini Vessel Rig
Experimental Mini Vessel Rig Overview

- Feedthrough for 10 T-type thermocouples
- Pressure transducer, 0-30 PSIA
- Pressure vessel submerged in LN2 in a glass Dewar flask
- Vacuum and gas feed ports
- Manually operated ball valves

N₂ feeds through an 800 SCCM mass flow controller from a high-pressure gas cylinder regulated to 50 PSI
Thermocouple Instrumentation

- 10 thermocouples total
- 3 locations axially
- 3 thermocouples radially per axial location
- 1 internal wall temperature thermocouple

![Diagram showing thermocouple locations](image)
Small Scale Testing Methodology

• Purging cycles (air displacement cycles, 3 cycles total)
• Initial precooling (110K average internal temperature before charging starts)
• Pressurizing cycle (12-14 PSIA internal pressure)
• Adsorption cycle (internal pressure drop rate <0.01 PSI/min)
• Repetition of adsorption and pressurization cycles until pressure drop between pressurizing and adsorption cycles is less than 0.1 PSI
Charging Cycles After Purging

Decreased charging cycle times, decreased pressure drop per adsorption cycle

Charging cycles

Adsorption cycles

Absolute Pressure, Flow VS Time

- Pressure
- Flow SCCM
- AVG Temp inside

Time, Seconds

2000 5600 9200 12800 16400 20000

Absolute Pressure, PSIA

0 2 4 6 8 10 12 14

0 200 400 600 800 1000
Initial Small Scale Results

• Total flow in 45.7L (Overall volume of the rig is 1.51L)
• Total mass in 57g
• Density inside of the rig 37.7 kg/m^3
• For reference: Density of N₂ at rig P&T conditions inside of the rig with no adsorption would only be 3.38 kg/m^3
• Density increased 11.15 times
Challenges

- Feeding ambient temperature N\textsubscript{2} into cooled aerogel, increases internal temperature and charging time.
Small Scale Precooler

- To help mitigate the effect of feed temperature, a precooler will be used
- 12 ft of 1/8 in coiled copper tubing submerged in LN₂
Next Steps

• Install a thermocouple for N\textsubscript{2} feed line after the HX (inlet of the rig)
• Full LabView control over the rig (purging, charging, discharging cycles, PID control of feeding rates)
• Solenoid valves instead of manually operated ball valves
• Further testing and optimization of the rig with N\textsubscript{2}
• Repositioning of the rig to a rolling cart (transportable standalone unit for future Hydrogen tests)
• Transferring the rig to a different lab with H\textsubscript{2} access
• Determining adsorption rates of H\textsubscript{2} per aerogel volume
Testing with Hydrogen

• Utilize the same testing technique as used with N₂ experiments
• Determine the adsorption rates of H₂ per volume of aerogel
• Determine the optimal charging technique for H₂ (constant Pressure vs constant mass flow charging cycles)
• Determine the H₂ flow rate needed for the CFC
Project Status

TEST SCALE RIG
CFC Design Cross-section

- Internal Cooling System
- Aerogel
- Cryolite
**CFC Test Setup**

**Operation mode**

A. Vacuum + Purge
B. LN$_2$ cooling $\rightarrow$ temp. target $\rightarrow$ maintain temp. $\rightarrow$ until C stop $\rightarrow$ D
C. Electrolyze + charging $\rightarrow$ until ($\dot{m} = 0$ & $P_{H2}$ steady) $\rightarrow$ Stop
D. Maintain LN$_2$ flow to accommodate ortho/para equilibrium
E. Maintain LN$_2$ for storage only (@equilibrium para/ortho)
F. Elevate temper. For discharging
ANALYTICAL MODELING

Project Status
Analytical Model and Numerical Simulation

• ANSYS Fluent is the chosen analytical tool
• Due to complex nature of adsorption physics, User-Defined Functions are implemented which account for adsorption kinetics and energy
• Small scale experimental data is used to validate the numerical method, and provide parametric data for model constant calibration if needed
• Fully validated/calibrated numerical model will be used for design exploration of cooling schemes for the test scale CFC
Experimental Data Validation

• Current models use a simplified 2D axisymmetric model for the tank simulation
• Adsorption of $\text{H}_2$ in silica aerogel contained in a vessel submerged in a bath of LN$_2$
• The grey area is a bed of silica aerogel (adsorbent) and cryogenic hydrogen (adsorbate).
• Recreating the adsorption in the simulation, three parameters must be adjusted
  – Mass and energy conservation equations are modified
  – The Mass Flux User Defined Function (UDF) is hooked to the inlet to regulate the filling and discharge
Future Technology Development

• Commercialization Potential
  – Aerogels are currently commercially available, so there is no barrier to production
  – Scalability of materials is not an issue like lithium ion battery
  – CFC is high density and could support monthly cycling, which corresponds to 10 to 100 hours of storage duration

• Future Integration with Target Fossil Application
  – Primary target asset is ground-based gas turbines used for electricity generation
  – CFC is intended to be modular and mounted on racks, like cells in a battery
  – For a reference plant of 100 MW net power output with a 50% net thermal-to-electric efficiency,
    – 100 hours of duration would require 9,090 m³