Optimizing the Heisenberg Vortex Tube for Hydrogen Cooling

Collaboration and Coordination

Washington State University (WSU)

Prime recipient, Laboratory testing and modeling

Plug Power

Sub-recipient, Manufacturing and field testing

Poster Design: Ian Wells (WSU)

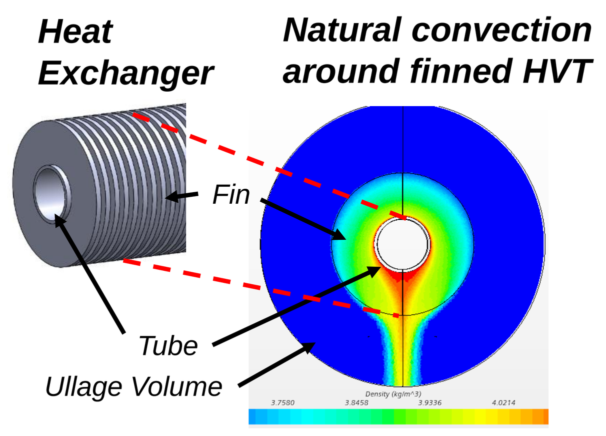
Project Goal

Establish, via experimentation, atomistic simulations, and Computational Fluid Dynamics (CFD), **that the Heisenberg Vortex Tube** (HVT) **can improve**:

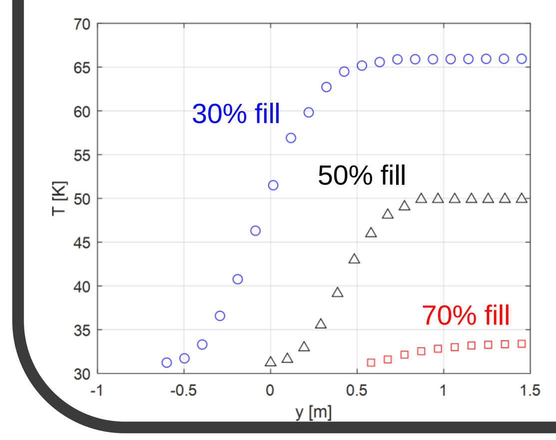
1. Liquid hydrogen pump volumetric efficiency by 20% through vapor separation and subcooling.
2. Liquid hydrogen storage tank boil-off losses by 20% through thermal vapor shielding (TVS).
3. Supercritical hydrogen expansion by increasing isentropic efficiency from 31% between 40-50 K to greater than 40%.

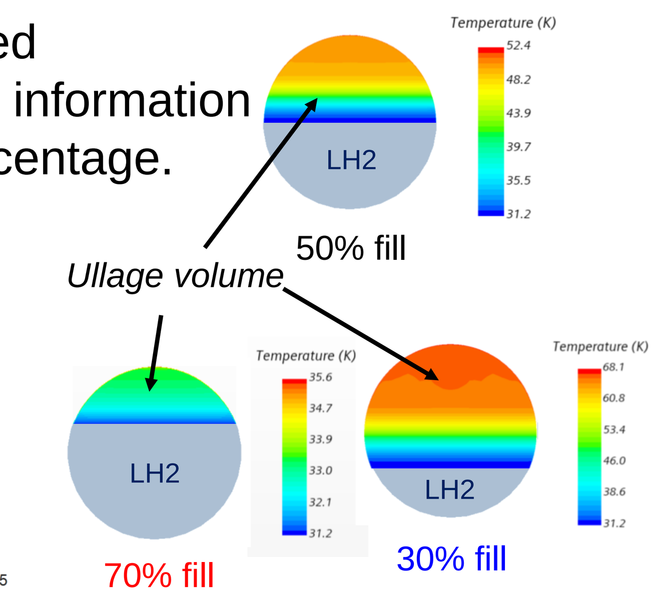
Approach

Testing enabled CFD analysis of a finned HVT, showing that para-orthohydrogen conversion to equilibrium within the vapor ullage (<77 K) of a storage tank increases the energy removed from the tank by the boil-off-gas compressor by up to 35%, reducing hydrogen vents with no additional input power required.



Analysis then provided temperature gradient information dependent on fill percentage.



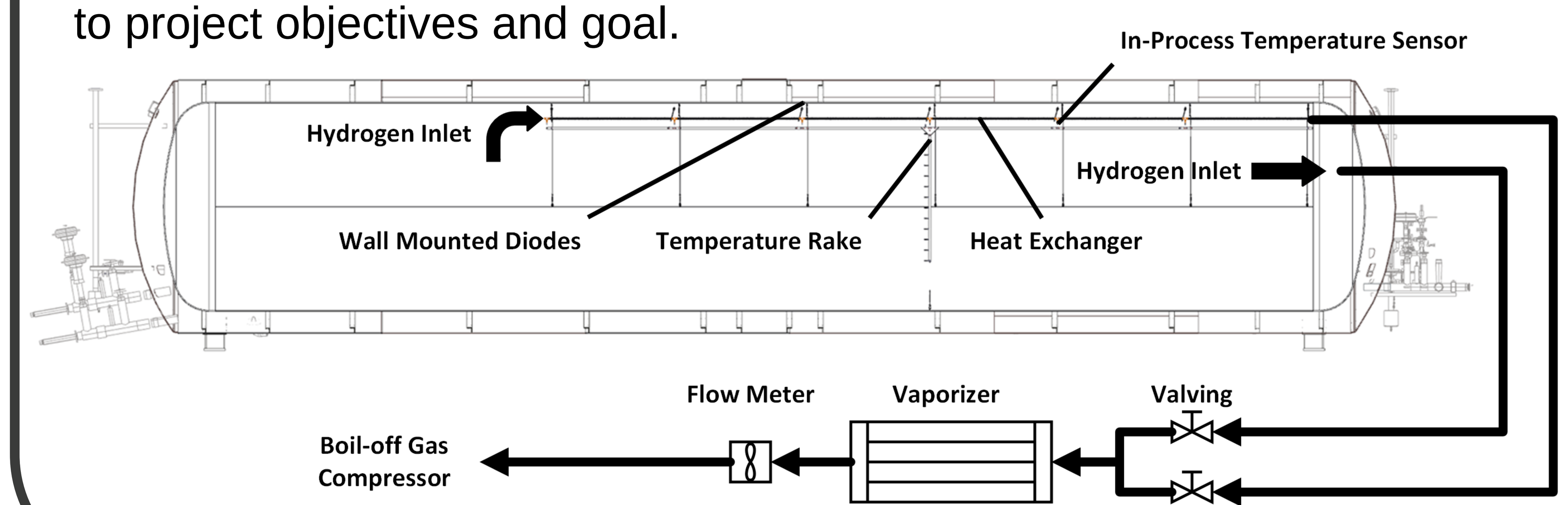


A method was developed to determine ortho-parahydrogen conversion probability using the Ru atom.

Modeling determined the conversion rate and was confirmed experimentally in laboratory.

Progress

Objective 3.3.1: Field based performance test results for comparison to project objectives and goal.



Validation of conversion is evaluated by a combination of several temperature sensors and a mass flow meter. An instrumented tank was designed to evaluate both the temperature of the liquid volume, ullage, tank wall, periodic distances on the heat exchanger and the mass flow of the vapor outlet.

Objective 3.3.2: Recommendations to Plug Power management on technical successes of project, and potential for cost savings if concept is implemented at other sites.

The ruthenium coating proved to be expensive, **yet still offers the benefit of paying for itself at greater than 50% of Plug Power sites in less than 3 years**. As most conversion of the molecule happens at the beginning of the tube, designing a heat exchanger for these conditions should be investigated.

Objective 3.3.3: Recommendations for future work.

1. Optimization of heat exchanger based on Ru cost
2. Complete field testing of tank to compare scaled results with laboratory results
3. Investigation of alternative catalysts and heat exchanger designs with lower cost prohibition.

Any proposed future work is subject to change based on funding levels

1. "Modeling of Liquid Hydrogen Tank Cooled with Para-Orthohydrogen Conversion," Accepted by Hydrogen.
2. "Numerical Simulations of cryogenic Hydrogen Cooling in Vortex Tubes with Smooth Transitions," Energies
3. "Parahydrogen-orthohydrogen conversion on catalyst loaded scrim for vapor cooled shielding of cryogenic storage vessels," Journal of Thermophysics and Heat Transfer
4. "Numerical investigation of vortex tubes with extended vortex chambers," Accepted for Publication, International Journal of Refrigeration
5. "Numerical study of hydrogen cooling in cryogenic vortex tubes with smooth transitions between vortex chamber and main tube," Presented at the Second Pacific Rim Thermal Engineering Conference
6. "Analytical and numerical performance models of a Heisenberg Vortex Tube," *Transactions of the Cryogenic Engineering Conference–CEC: Advances in Cryogenic Engineering,*
7. "Para-Orthohydrogen Conversion Using a Vortex Tube," *United States Patent US 10,425,294 B2*

2019

CFD simulation of flow along the length of an HVT

2023

Overview

DOE Project Award: #DE-EE0008429

AMR Project ID: in015

This presentation does not contain any proprietary, confidential, or otherwise restricted information.

Timeline:

Start: 1/23/2019

BY1 extended through 9/30/2020

BY3 extended through 9/30/2023

End: 9/30/2023

Budget: $2,382.6k

Federal Share: $1,897.8k

Cost Share: $484.8k

BY1 Expenditures: $1,005.8k

BY2 Expenditures: $442.2k

BY3 Expenditures: $411.3k

Total DOE Spent: $1,524.9k

Barriers Addressed:

1. Reliability & cost of liquid hydrogen (LH_2) pumping
2. High cost & low efficiency of liquefaction
3. Other fueling site/terminal operations

Partners:

Project Lead: Jacob Leachman (WSU)

Co-PIs: Konstantin Matveev and Jeffrey McMahon (WSU),

Tim Cortes, Gilbert Hegermiller, and Kellen Randall (Plug Power)

Partner Organizations: Washington State University, Plug Power

Relevance and Impact:

Plug Power, the largest single user of LH_2, needs to reduce boil-off and venting losses from LH_2 storage facilities. Cryocooler technology cannot yet mitigate boil-off in a cost-effective manner. The HVT enables flow separation into hot and cold streams without moving parts. The hot stream is exposed to catalyst, driving endothermic para-orthohydrogen conversion. This addresses the DOE HFTO barrier: Improving LH_2 utilization for other fueling site/terminal operations.

Summary

1. Verified HVT performance with para-orthohydrogen conversion in the lab.
2. Validated numerical models of HVT performance in lab and designed field test.
3. Field test article scheduled for completion in June 2023 with Plug Power.