The safe removal of frozen air from the annulus of an LH2 storage tank

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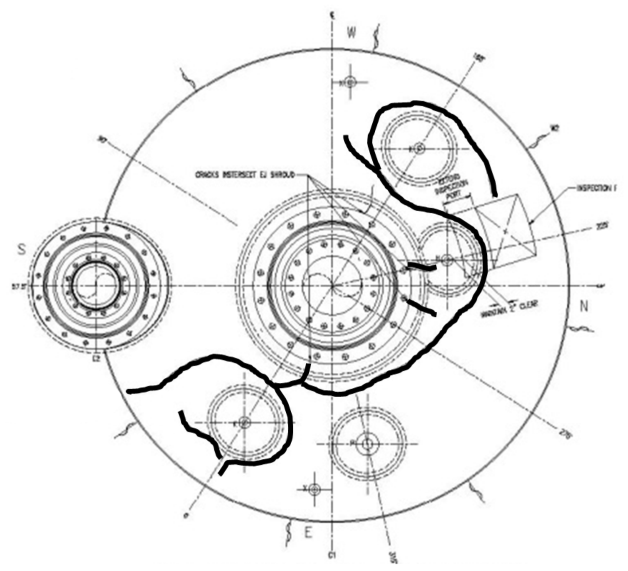
Introduction

- Large Liquid Hydrogen (LH2) storage tanks are vital infrastructure for NASA
- These tanks are double walled and can develop air leaks into the perlite filled annular region
- Opportunities to bring tanks out of service for repairs are extremely limited
- As leaks persist, large quantities of air can be ingested and frozen into the perlite's interstitial space
- Upon removal from service, liquefaction of the air can result in severe cracks on the outer jacket of the vessel
- An 850,000 gallon storage tank was used as the model for this work
- Two proposed methods of air removal will be evaluated

Historical Information

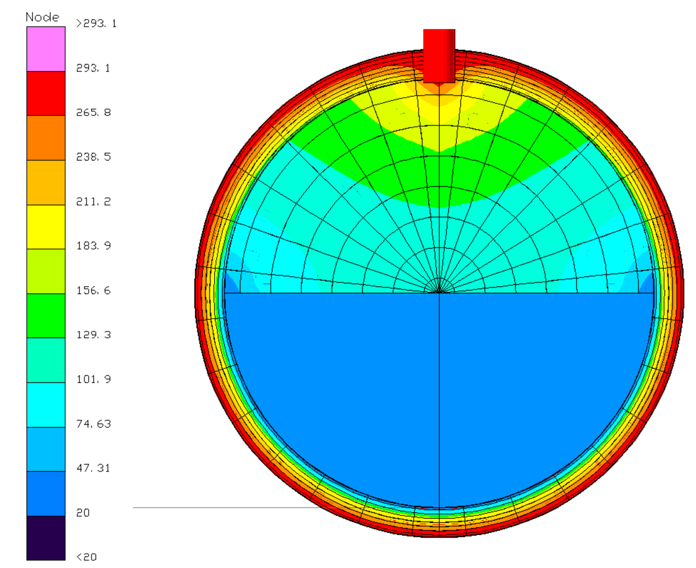
- Stennis Space Center's LH2 tank at their B-1 Test Facility developed a vacuum leak into the annulus in 2011
- Operational constraints resulted in short-term, continued use of the vessel
- Upon removal from service, the carbon steel outer jacket dropped to 77 – 90 K
- Large cracks occurred 18 days after tank drain



- There is another known tank, currently in service, with a small air leak
- Details cannot be released due to contract issues, but it is hoped that this work will be completed in time to prevent major damage of that vessel

Thermal/Molecular Model

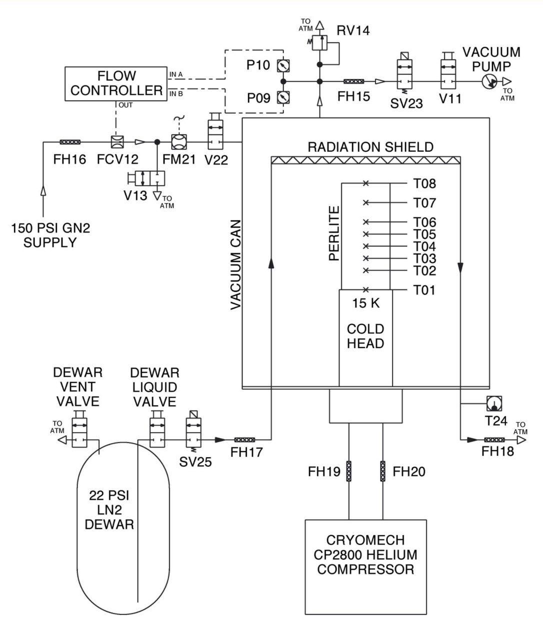
- SINDA/FLUINT was used to create a thermal model in order to determine the temperature profile throughout the perlite filled annular region
- The current model employs a finite difference solver to determine temperatures and does not account for pressure changes or convection
- Updates to the model are planned which will add fidelity to the liquid and gas sections and allow for liquid level changes
- Results from the current model show that at a 50% fill level in a 850,000 gallon tank, approximately 38.2 cubic meters (2.3% of the annular volume) is cold enough to freeze air

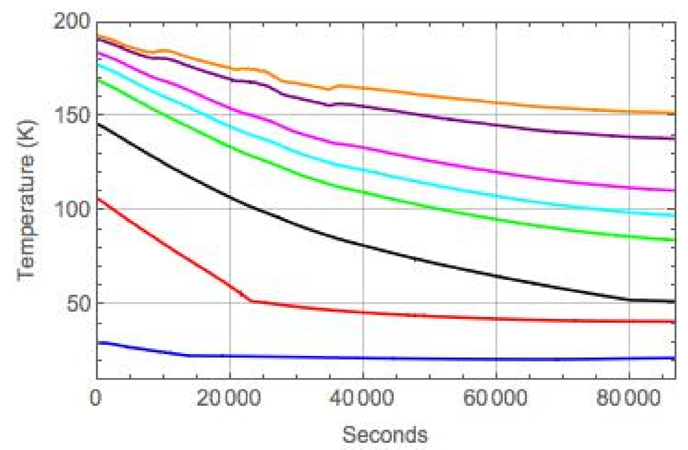


- A molecular simulation that predicts the absorption isotherms of gas molecules in perlite is also being developed
- Simulates a system of gas in a Grand Canonical ensemble and uses the Monte Carlo algorithm
- The completed model will also provide simulation results for comparison to experimental results

Experimental Work

- Testing to determine the thermal conductivity changes of perlite with nitrogen frozen into the interstitial space has been completed
- The test set-up involved a Cryomech AL230 cold head covered by 5 inches of perlite and a radiation shield flowing liquid nitrogen through it to minimize the total temperature gradient through the perlite sample
- A multi-layer insulation (MLI) lined vacuum can was installed over the entire set-up and pressure was controlled at a constant near 6500 millitorr
- Gaseous nitrogen flow into the chamber was measured with a mass flow meter
- Temperature sensors spaced throughout the perlite sample show the change in thermal properties as the air freezes by the abrubt change in slope experienced by T01, T02, and T03





Proposed Air Removal Methods

- Active pumping on the annulus during tank drain
  - Requires a fully functional internal pump down system
  - Annular pressure must remain below 1,000 microns as the tank warms to avoid liquefaction
  - Timing will be determined by comparing known evacuation rates to estimated sublimation rates
- Application of heat to the outer tank wall
  - Use total heat flow estimates to determine the amount of heating power required to keep the carbon steel within its ductility range (>244 K)
  - Power requirements must be met by commercial products and access must be present at the site of tank
  - Allows a more rapid air removal than active pumping
  - Requires consideration of Class 1 Division 2 electrical equipment limitations

Forward Work

- Transition hydrogen in the thermal model into a fluid model using FLUINT to allow for variations in liquid level
- Complete the molecular model and find absorption isotherms
- Compare molecular model results to known physical quantities and experimental results
- Complete analysis on data gathered during testing in order to determine the thermal conductivity of perlite/frozen nitrogen
- Determine the time scale for active pumping during tank drain
- Determine power requirements for heating option
- Determine feasibility of heating option based on safety limitations and power requirements
- Publish all data, results, and recommendations

Presented at the Cryogenic Engineering Conference , 2015 June 28 – July 2, Tucson, Arizona; CEC-02 Large-Scale Systems, Facilities, and Testing; C1PoB Intermediate Temperature Systems