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 perlitic 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
- Active pumping on the annulus during tank drain
- 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
- There is another known tank, currently in service, with a small air leak
- The current model employs a finite difference solver to determine temperatures and estimated sublimation rates
- Complete the molecular model and find absorption isotherms
- Transition hydrogen in the thermal model into a fluid model using FLUINT to allow for variations in liquid level
- SINDA/FLUINT was used to create a thermal model in order to determine the temperature profile throughout the perlitic 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
- Application of heat to the outer tank wall

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 abrupt change in slope experienced by T01, T02, and T03
- The completed model will also provide simulation results for comparison to experimental results

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 drain
  - 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
- Comparison 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